

**Evaluation of a fuzzy-expert system for fault diagnosis
in power systems; using an object-oriented hybrid
solution for real-time power alarm processing**

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Abstract

A major problem with alarm processing and fault diagnosis in power systems is the reliance on the circuit alarm status. If there is too much information available and the time of arrival of the information is random due to weather conditions etc., the alarm activity is not easily interpreted by system operators. In respect of these problems, this thesis sets out the work that has been carried out to design and evaluate a diagnostic tool which assists power system operators during a heavy period of alarm activity in condition monitoring. The aim of employing this diagnostic tool is to monitor and raise uncertain alarm information for the system operators, which serves a proposed solution for restoring such faults.

The diagnostic system uses elements of AI namely expert systems, and fuzzy logic that incorporate abductive reasoning. The objective of employing abductive reasoning is to optimise an interpretation of Supervisory Control and Data Acquisition (SCADA) based uncertain messages when the SCADA based messages are not satisfied with simple logic alone. The method consists of object-oriented programming, which demonstrates reusability, polymorphism, and readability. The principle behind employing object-oriented techniques is to provide better insights and solutions compared to conventional artificial intelligence (AI) programming languages.

The characteristics of this work involve the development and evaluation of a fuzzy-expert system which tries to optimise the uncertainty in the 16-lines 12-bus sample power system. The performance of employing this diagnostic tool is assessed based on consistent data acquisition, readability, adaptability, and maintainability on a PC. This diagnostic tool enables operators to control and present more appropriate interpretations effectively rather than a mathematical based precise fault identification when the mathematical modelling fails and the period of alarm activity is high.

This research contributes to the field of power system control, in particular Scottish Hydro-Electric PLC has shown interest and supplied all the necessary information and data. The AI based power system is presented as a sample application of Scottish Hydro-Electric and KEPCO (Korea Electric Power Corporation).

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List of Symbols

Kv	Kilo Volts
Kva	Kilo Volt-Amperes
MW	Mega Watts
AC	Alternating Current
DC	Direct Current
AI	Artificial Intelligence
ANNs	Artificial Neural Networks
FNNs	Fuzzy Neural Networks
ES	Expert Systems
GA	Genetic Algorithm
EHV	Extra High Voltage
SCADA	Supervisory Control and Data Acquisition
Sec	Second(s)
μ s	Micro-seconds
Msec	Millie-seconds
Hz	Hertz
KHz	Kilo Hertz
HE	Scottish Hydro Southern Energy group
NGC	National Grid Company
CBs	Circuit breakers
MNN	Mutilayer Neural Network
U	Universe of discourse
μ	Membership function
\cup	Union
\cap	Intersection
FLS	Fuzzy logic system
MB	Measure of Belief
ACSR	Aluminium conductor steel enforced
EMS	Energy Management Systems
KEPCO	Korea Electric Power Corporation
V_a, V_b, V_c	Three-phase voltages

Ia,Ib,Ic	Three-phase currents
$X_{(n)}$	Input variables
P	Percent distance to fault
MVA _r	Mega Volt Amperes
KBS	Knowledge Base system
GUI	Graphical User Interface
GIS	Geographical Information System
API	Application Programming interface
OODB	Object-Oriented Database
EI	Error Index
SCI	Single Confidence Index
ACI	Average Confidence index
OOP	Object-oriented programming

Related Publications

- Min Y Park, Martin Lefley, Bruce Ramsay, and Ian Moyes; An abductive fuzzy knowledge based system for fault diagnosis in a power system, The fourth Asian fuzzy systems symposium, AFSS2000, pp. 191-196, 31st May-3rd June 2000, Tsukuba Science City, Japan, 2000
- Min Y Park, Martin Lefley, Bruce Ramsay, and Ian Moyes; An abductive fuzzy knowledge based system for fault diagnosis in a power system, fourth international power conference on power system technology, pp.345-350, IEEE, 4th-7th December 2000, The University of Western Australia, Australia, 2000
- Min Y Park, Martin Lefley, Bruce Ramsay, and Ian Moyes; An alarm prioritisation knowledge based system in a power system, International Symposium on Computational Intelligence (CI'2000), pp.283-290, 12th-15th December 2000, the University of Wollongong, Australia, 2000

Chapter 1: General introduction to project and overview of thesis

1.1 Electrical power system

The operation of a power system involves a complex transfer of electrical energy from one station to another. Power systems are dynamic in that conditions are continuously changing and electric power delivery takes place instantaneously on demand by its users. These changes are controlled and monitored by a generic SCADA (Supervisory Control and Data Acquisition) computer. This chapter reviews several problems with power system operation in preparation for the subsequent design of an AI (Artificial Intelligence) based power system; electrical power system, power system protection, transmission line faults, and the current fault identification.

1.1.1 Generation system

Because of escalating fuel costs over the decade, various systems are considered for effects of fuel costs, as follows:

- ❖ Nuclear generation
- ❖ Geothermal generation
- ❖ Solar and wind generation
- ❖ Co-ordination of hydro and thermal generation

Nuclear generation presents a special advantage which the incremental production costs are quite low whereas fossil-fuelled plants are costly. The total energy can be produced by a nuclear reactor. This total energy is maximised if it is operated at a relatively constant load. Consequently, such units are designed to be base-loaded.

Geothermal generation has emerged in recent years that the development of such a source is increasing greatly. This source is used where natural steam or hot water is available. The place of the largest on going development is in the US, the Geysers geothermal development in Northern California with a total capacity of approximately 1000 MW.

Solar and wind generation is considered to develop without using fossil fuels. Efforts have been proceeded in the development of solar energy and wind power, which converts into economic sources.

Co-ordination of hydro and thermal generation considers overcoming an extension of the economic loading problem, and they are in use. The procedure of such a system is called hydrothermal co-ordination. The system consists of input-output curves for each hydro unit, and they are developed for an estimated power system operation. These curves are based on the incremental water rate in acre-feet per megawatt/hour plotted against the load in megawatts. An effective integration of hydro and thermal generation for minimum cost is quite complex and has been developed by a digital computer.

The nature of a generator in conjunction with these four types is dependent on the source of available energy. The generated voltage varies from the range of 11 to 25kV and the size of generation extends from the units of kVA to 500 MVA.

1.1.2 Transmissions and distribution

Plant to generate electricity is connected to the consumers' loads, i.e. by means of an interconnected system of transmission and distribution network. The transmission system requires a high-voltage in order to connect and deliver bulk generation to the distribution networks. These distribution systems then supply the electricity on a smaller scale to the customers.

The types of choosing a transmission voltage are controlled by physical factors, i.e. electrical losses and economic factors. This is based on the cost of line construction and maintenance. The use of high voltage minimises such losses when the necessary power transmits over long distances, e.g. reducing the current for a given amount of power. In the United Kingdom, power stations supply a transmission network which operates from 132kV and 400kV. On the contrary, current overseas countries employ transmission systems, which operates at 750kV.

1.1.3 Synchronous interconnections

There has been a great deal of synchronous interconnections to production and transfer of energy in power systems. These systems are based on large ac generators, which carries a magnetic field, as follows:

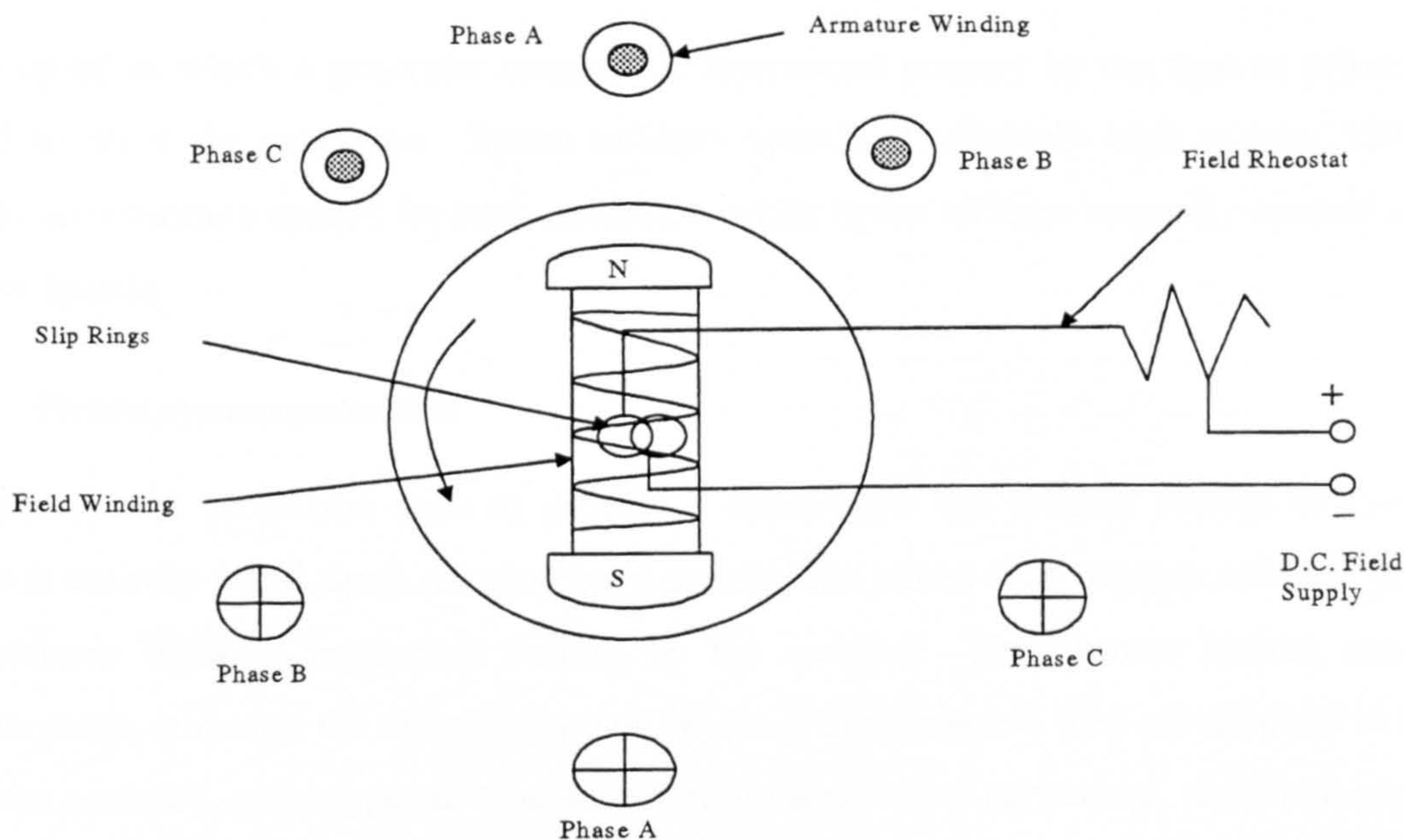


Figure 1 Diagrammatic representation of an ac generator

Figure 1 illustrates the relationship of field and armature windings. In large machines, the field is normally the rotating part as the field currents are much less than the armature currents. This can be supplied by means of sliding contacts or brushes on slip rings, permitting the armature connections to be made solid, and with conductors large enough to carry the full load currents.

As the field rotates, its magnetic poles induce voltages in the armature winding, and the consecutive movement of one pole and then the other under the armature winding will develop a full cycle (360 electrical degrees). These machines are called synchronous in conjunction with interconnections of power system elements. This is because the speed of rotation and the number of poles in the generators determine the generated frequency. For example, on a 50-cycle system, a machine with two poles will rotate at 3000 r/min and four-pole machine at 1500 r/min. The speed of the ac generator is, as follows:

$$S = 120f/p \text{ r/min} \dots\dots\dots 1$$

Where S= speed, r/min

f= frequency, Hz

P= number of poles

The speed at which a generator operates is determined primarily by the type of prime mover used to drive the generator. Steam turbines operate at relatively high speeds: 1500-3000 r/min are common speeds for such machines, while hydro turbines normally operate at much lower speeds.

1.2 Power system protection

Power system protection aims to provide a dependable and reliable service to customers. This is entirely relied upon the protection system that senses such outages and acts promptly to remove lines or equipment caused by the outages. Most power system events are momentary, and after the affected lines or device is disconnected, they are returned to service. On the contrary, some types of troubles are more serious and permanent, and these events are likely to damage lines and equipment.

To prevent these events, two elementary systems are employed, circuit breakers, and distance relays. These are a kind of pilot-wire system, and incorporate prevent alive tripping of circuit breakers for faults outside the line section protected, but provide high-speed operation for all faults inside the line section. The objective of power system protection is to detect these faults as quickly as possible. However, any power system is subject to weather conditions such as lightning storms, and damage to towers that can cause damage to system facilities and different types of interruptions of service to customers.

1.2.1 Correct operation of protective equipment

As electrical transmission system on the transmission lines and distribution is complex, many forms of interruption such as outages caused by permanent short circuit faults occur quite often. The consequence of these outages is likely to constrain the alarm management. The detected fault zone is normally isolated from the network and operated by the main protection relays. It is located at each end of the feeder. For protection, a back-up relay is operated when the main protection fails to clear the fault.

1.2.2 Incorrect operation of protective equipment

The back-up relay is not highly reliable in time delayed tripping of the circuit breaker in association with weather conditions and multiple faults, which should have been tripped by the specified protection scheme employing various relays. Identifying the fault is inevitable where it happened and whether the protection relays and circuit breakers operated according to the normal state. A solution for this problem has been relied on by operators' heuristic knowledge. This diagnostic tool developed for this problem will provide more effective solution, utilising their heuristic knowledge, in conjunction with a hybrid system.

1.3 Transmission line faults

Power systems are getting bulky due to an increased demand from customers, which causes the transmission line faults to occur quite often. Most faults are momentary and returned to service, by means of operating protective equipment. Such transmission voltage levels are usually considered to be 60kV or above.

In general, high-voltage (HV) lines are capable of transmitting more power over greater distances than lines of low voltages. Now, many lines operate with the extra high-voltage (EHV), which is above 300kV.

This thesis provides a sample system which is based on the transmission lines of Scottish Hydro-Electric PLC. The power company, privatised, serves two range of voltages such as 132kV (HV) and 275kV (HV), generating electricity by hydraulic system. Most plant sites are well maintained, but they are constrained by several problems, i.e. maintenance failure, and weather conditions. This brings on a permanent outage which requires a high level of intellectual work.

1.3.1 Accurate fault Identification for transmission lines

A major problem in the protection of a power system is the determination of the currents that can occur for different types of faults and voltages. These constrain the transmission lines because of a fault. Under normal condition, a three-phase system prevents further severe damages, e.g. the currents and voltages are balanced.

However, exceptional unbalances could occur, in conjunction with the network faults. The solution of such unbalanced transmission lines is quite difficult when conventional formulas are employed, i.e. Ohm's and Kirchoff's laws, claims [Miller 1993]. Although in 1918, C. L. Fortescue developed a mathematical-based method and greatly simplified the solutions of such problems, the mathematical based modelling fails quite often due to uncertainty of protective equipment operation. This means there is a demand for minimising damage by restoring the faulted line as soon as possible, in order to maintain system security and stability more effectively.

The degree of accuracy required in alarm processing and fault diagnosis is increasing and is much higher than these simple conventional techniques. An AI based system introduced in this thesis might mitigate such workloads as the knowledge of domain experts will solve faster and effectively when a heavy period of alarm activity is involved.

1.3.2 Fault behaviour during the selection of transmission line voltages

An important measure to power system security is that of the rapid disconnection of lines or equipment, which prevents any further trouble to the neighbouring systems. The equipment such as protective relay systems is designed to disconnect the unbalances in dispersive order when such trouble is not tripped in the primary relay. This trouble is alerted to the control centre, which SCADA computer collects and displays on operators' consoles. Almost all modern dispatch and operating centres of power systems are provided with at least some SCADA system equipment.

The fault behaviour of a transmission line occurs when a large block of generation or load is lost. In such cases, the transient stability of the system must be adequate to withstand the shock of the relatively large change that occurs. System disturbances are usually accompanied by rapid reductions in system voltage, and restoration of voltage to normal is important in maintaining stability.

1.4 Current fault identification methods

New fault identification systems have emerged for various purposes. In order to determine what systems are effective to the application of power systems, reviewing the characteristics of AI techniques are, as follows:

- Expert systems
- Artificial neural networks
- Genetic algorithms
- Fuzzy logic
- Fuzzy- neuro

These systems are popular to the applications of power systems. The techniques of such applications are based on their characteristic paradigms. Important integration issues in developing an AI based system in conjunction with SCADA computers are involving the variances of the power system model and the interface [Bann 1997].

Expert systems represent a heuristic knowledge and utilise knowledge base typically in sets of if-then-else rules. The heuristic knowledge proves quite robust solutions from a problem which processes through the rules in a chain which consists of two, forward chaining, and backward chaining. The forward chaining has maintained a measure where the problem is well defined is quite successful. On the other hand, the backward chaining has inferred a difficulty of maintaining a consistent and complete set of rules against uncertain data.

In Song & Dunn [Warwick 1997], they say, “artificial neural networks acquire knowledge through training. This has a major advantage: often the training set can be composed of actual observations of the physical world, rather than being formed of the human opinions used for fuzzy (or expert) systems”. In this respect, the technique of neural networks such as a back-propagation learning algorithm has been used to handle fuzzy information although it is quite difficult to determine the explanation of how an artificial neural network processed an incorrect decision. This is necessary so that a problem can be rectified.

Genetic algorithms consist of adaptive search techniques. For example, a genetic algorithm is a computational model and iterative procedure that has an initial population which is generated at random or heuristically. Genetic Algorithms are search procedures based on the mechanics of natural genetics and natural selection. They combine a Darwinian survival-of-the-fittest with recombination and other genetic operators to form a search mechanism with surprising breadth of application and efficiency.

Fuzzy logic is similar to expert systems that rely on a set of rules. However, a distinctive point to emphasise between expert systems and fuzzy logic is these rules allow the uncertain information to be fuzzy, which is based on the natural way that humans express knowledge in semantic terms. Therefore, fuzzy logic can represent the uncertainty of knowledge in which an expert system might have difficulty. Otherwise, this expert system needs a large set of rules.

Fuzzy-neuro is a fuzzy-centric hybrid system which carries out fuzzy inference with neural networks structure, and adjusts the parameters of the fuzziness, using neural networks learning. Fuzzy logic can capture the salient features of a given process, but rules and membership functions are quite difficult to obtain as designing such knowledge base requires a great effort. On the contrary, neural networks can be trained to extract the rules and learn membership functions from some domain data.

1.4.1 The application of artificial intelligence techniques

Since the early to mid 1980s much of the effort in power systems analysis has turned away from the methodology of formal mathematical modelling which came from the fields of operations research [Warwick 1997]. However, now, the main AI techniques applied in power system operation are evolving into the utilisation of the logic, knowledge representations of expert systems, fuzzy logic, artificial neural networks, genetic algorithms, and evolutionary computing. The details of these techniques are delineated in Chapter 3.

Over the last few years, existing computer based solutions are becoming inadequate while today's control requirements demand complex power system model, fast access and information sharing across the whole of the system. This problem has prompted a new methodology which is reusable, maintainable, and updateable in the condition monitoring such as object-oriented programming.

The central aim is to measure certain strength and weakness in the power system model when a hybrid system between an expert system with fuzzy rules is incorporated to optimise the analysis of uncertain data from the SCADA.

1.4.2 Objectives of the project

The objectives of developing this diagnostic tool are:

- To develop a system this improves the accuracy of fault location on the transmission and distribution network.
- To design a prioritised alarm processing system which may allow more effective knowledge base maintenance.
- To incorporate reusability which will simplify maintenance and development, without complex programming.
- To produce a knowledge acquisition system incorporating API design and OODB modelling to provide a more effective fault diagnosis in an alarm condition.

1.4.3 Scope of the thesis

Chapter 2: An overview of fault identification algorithms for alarm management

This chapter presents general overview of fault identification algorithms for alarm management. The techniques reviewed fall into the following parts:

- Routine alarm management
- Faulted equipment alarm management

These two areas provide an important alarm prioritisation which is to assess what alarms to look at and based on the availability of data acquisition.

Chapter 3: Artificial intelligent techniques

The applications of AI in power systems are reviewed. Research into expert systems, fuzzy logic, genetic algorithms, and neural networks is covered with emphasis on practical consideration of a fuzzy logic expert system is used to adapt an optimum knowledge.

Chapter 4: The simulation of power system & applicable systems

This chapter explains the use of a simulation of a power system when faults occur. Realistic fault arrangement for data acquisition design is achieved through the employment of a systematic approach on a power system model. The simulation study is based on 132kv of 12buses-16lines sample power system, in conjunction with Scottish Hydro-Electric PLC.

Practical considerations such as proposed message prioritisation, fault type classification, and process of multiple simultaneous events are taken into account in association with the SCADA based uncertainty.

Chapter 5: Object-oriented expert system based alarm processing and fault diagnosis

An effective fault identification technique using object-oriented expert system is developed in this chapter. The expertise-based scheme is discussed with object-orientation for real-time interpretation, to assess how the architecture of object-oriented power system model will respond to a change of power systems. The method is based on utilising the derived data from the SCADA that processes prioritised alarms and the uncertain data through the object-oriented architecture and produces a solution for operators.

Chapter 6: The integration of fuzzy logic to the expert system

A hybrid approach incorporating the expert system and fuzzy logic is developed in this chapter. This is called “A fuzzy logic expert system”, which is based on separating the uncertain SCADA data into two groups.

First, the tool employs an abductive expert knowledge based system to observe which system produces observed disorders, a plausible explanation, an observed explanation, and configuration value of fault detectors' operation. The composition method between the observed explanation and the configuration value of fault detectors is based on MB(Measure of Belief) by MYCIN theme [Shortliffe 1976].

Second, on the basis of these inference methods, the designed fuzzy expert system carries out an object-oriented fuzzy set operation employing configuration value of fault detectors, in

order to achieve a better explanation. The explanation comprises the expert system and fuzzy logic for an adaptable knowledge base system and further improvement in relation to approximately locating faults on the sample power system. The common technique adopted in the tool is abductive inference that provides the fundamental adaptability in this work.

Chapter 7: Performance evaluation of the fault diagnosis techniques

Analysis of the results is presented in this chapter and the evaluation of the proposed system for fault identification is discussed. The test results for fault identification based on FE is presented and compared with the previous fault identification solely on the expert system architectures.

Chapter 8: Conclusions and recommendations

Conclusions are discussed to draw attention to what is the significance of this work involved and employing synergetic systems in an AI based power system suggests future work that will be considered in conjunction with Geographic Information System (GIS).

Chapter 2: An overview of fault identification algorithms for alarm management

2.1 Introduction

This chapter delineates a brief overview of current fault identification algorithms for alarm processing. Several knowledge engineering techniques were studied and employed for alarm management systems. These identify the relationships between chains of rules, estimation of the worst case processing time of rule-based systems, and the equivalence class method for validation and verification of rule-based systems in energy management systems. These three algorithms provide the possible applications to an object-oriented AI based power system when an event occurs within the sample power system.

2.2 Algorithms employing alarm prioritisation from SCADA

SCADA (Supervisor Control and Data Acquisition) message processor receives a message of power system changes at the control centre. The priority level is determined by configuring the SCADA system, with colour, flashing text, and audible signals. In respect of the priority level, prioritising an event is the most complex task to determine, which falls into two reasoning categories:

- 1) Shallow reasoning;
- 2) Deeper reasoning;

Shallow reasoning employs the minimum amount of input information, for example, what relays have been operated, caused their zones of operation, etc. When the model can not locate the fault using such information it determines an area suspected of containing the fault. This area is considered as faults suspect area. The model is simulated by operators and based on the intertripping scenario model and the certainty of a given relay operation being correct [Crossley 1996].

The feeder of suspected area is scored the highest certainty, which is considered the faulted feeder. When the certainty, e.g. more than one feeder is high, then each of these feeders is considered as a fault candidate. This model uses shallow reasoning based on:

- Faults are usually detected by their main protection relays
- The item of plant is normally isolated by its own breakers
- The operation of a backup relay implies a high probability of a main protection failure
- Any feeder where the main protection relays have operated at both ends is judged to be the faulted feeder

Deeper reasoning provides accurate interpretation to fault location when the input information is insufficient. This requires designing a fault identification technique which consists of fault types for the fault assessment. These fault types are; Routine Alarms, Known Fault Alarms, Emergency Alarms, Alarm Equipment Failure Alarms, Repeated Alarms, Sympathetic Alarms, and Network Circuit Breaker (CB) Alarms. With these alarms, this diagnostic tool considers a prioritisation of the alarm management system that is designed and determined to help operators during a heavy alarm period.

2.2.1 Urgent alarms

Urgent alarms are divided into different fault categories in Transmission lines before presenting the information to a PC based system. In order to model such fault categories, simulating a sample power system is carried out, in conjunction with Scottish Hydro Electric PLC.

The criteria of urgent alarms consist of a communication from real-time systems, which conveys that automatic action has taken place and automatic protection equipment on the main system has operated. Such categories fall into the following table 1. Table 1 shows that various alarm messages are categorised in conjunction with the relevant protection feeders.

Scottish Hydro operators have shown an interest what if these categorical messages are informed in an AI based condition monitoring. This is so that they can control alarms more effectively. To the extent, these urgent alarms will be designed to the existing SCADA system employing SCADA message prioritisation system.

Types of the events	Types of the urgent alarms
Busbar fault	Accelerated trip
Busbar protection zone trip	Aided trip
Sensitive earth fault trip (self trip)	Auto trip
Circuit breaker fail	Backup protection operated
Circuit breaker protection operated	Buchholz alarm
Circuit breaker lockout or L.O.	Busbar protection defective
Circuit breaker trip or trip	Busbar protection operated
Fault thrower operated	Circuit breaker air pressure low lockout
Feeder switch trip	Distance protection switch on to fault
Trip on fault	Distance protection Z2 Z3 trip
	Fault (transformer)
	Feeder lockout alarm
	First main protection operated
	Group trip
	Isolator operation incomplete
	Low frequency trip
	Main protection operated (or trip)
	Main protection unstabilised
	Main protection VT supply fail
	Overcurrent protection operated
	Primary protection trip (or operated)
	Reactor protection operated
	Restricted earth fault (REF)
	Second main protection operated
	SF6 GAS pressure low lockout/m
	Tap change incomplete
	Temperature trip
	Underfrequency trip
	Winding temp trip

Table 1 Urgent alarms

2.2.2 Minor alarms

Minor alarms cause other communications from real-time systems which convey that an abnormal condition exists whereby the main system will become affected. In Scottish Hydro Electric PLC, they consider these instances, as below:

Minor alarms	
110 volt battery alarm	Metering alarm
110 volt battery earth fault	PAX equip faulty
50 volt battery alarm	Plant group alarm
50 volt battery earth fault	Remote control off
Acceleration on standby	Salome battery alarm
Acceleration on test	Spring discharged
Acceleration "....." route defective	Tap change control at site
Battery charger fail	Telemetry equip defective
Battery earth fault	Tripping battery alarm
Carrier on cable equip defective	Under-frequency trip
Cooling supply fail	Zone 2 timer over-ridden
DAR in progress	PLC equipment fail
DAR sequence complete	"....."Reflex test fail
DAR trip counter limit	
Disturbance recorder operated	
DRYCOL breather supply fail	
Fault recorder operated	
Intruder alarm	
LVAC on standby	
"....."Control at site	
"....."CO2 locked off	

Table 2 Minor alarms

These alarms are filtered by an algorithm which presents the categorical systems, Minor alarms. In respect of these, the algorithm developed in the work reads the current power system from the SCADA computer, by designing an effective knowledge base. An AI based power systems has a potential capability in the first instance to reduce the burden caused by such problems.

Likewise, the implementation of developing minor alarms is demonstrated using the OOP toolkit, Kappa-PC and the benefits of employing this prioritisation for minor alarms will be delineated in the proceeding chapter 4.

2.2.3 Fault identification techniques for the fault patterns

In the early 1960s, researchers in applied logic assumed that theorem provers were powerful and general enough to solve practical, real-life problems [Lucas 1990]. A complicated real-life situation is that of the facts and experience for solving practical problems. In power systems, this applies to the location and classification of faults on the basis of observed plant data, which consist of two types of fault identification techniques, known fault types, and unknown fault types.

The former requires the correlation of observed parameters in order to locate and classify a fault, i.e. heuristic based qualitative methods. The latter falls into a popular method of uncertainty which refers to quantitative methods. An investigation of these literature studies was carried out corresponding power protection systems, as follows:

Modelling types		Protection types			
		Protection type A[Lines]	Protection type B[CBs]	Protection type C [Distance relays]	Protection type D[Buses]
Quantitative methods	Certainty factors	Preferred	Preferred	Fairly	Fairly
	Baysian nets	Preferred	Fairly	Good	Good
	Semantic nets/Linguistic variables	Preferred	Preferred	Good	Preferred
Qualitative methods	Non-monotonic logics	Preferred	Fairly	Good	Preferred
	Temporal logics	Good	Good	Good	Good
	Autoepistemic logics	Not feasible	Not feasible	Fairly	Fairly
	Causality	Preferred	Preferred	Preferred	Preferred
	Semi-autonomous support	Good	Good	Preferred	Fairly
	Relevance	Good	Fairly	Good	Good

Table 3 Review of fault identification techniques in power systems

Table 3 illustrates that two modelling types are used, quantitative, and qualitative methods. These two methods were observed on the basis of ten published papers in AI based power

systems [Bann 1997;Warwick 1997;Hsu 1994;McDonald 1997]. Referring to this survey, the methodology presented in this thesis is the combination of certainty factor and linguistic variables utilising an object-oriented technique, which will be adopted to test an inference technique. This inference technique will be discussed in the proceeding chapter 3.

2.2.4 AI based fault identification for the full range of system conditions

As a survey done by M. A. Laughton [Warwick 1997] suggests, the range of system conditions employing AI based fault identification is various, i.e. planning, operation, and analysis, as follows:

Power system subject	Categories	ES	FL	ANN	EC	Totals
Planning	Generation	6	4	0	5	15
	Transmission	5	0	0	2	7
	Distribution	3	2	0	9	14
	Reactive power	4	0	1	7	12
	Reliability	0	2	0	0	2
Operation	Generation scheduling	8	0	0	1	9
	Economic despatch	3	1	1	21	26
	Unit commitment	0	0	0	19	19
	Reactive power despatch	1	0	1	6	8
	Voltage control	4	3	4	1	12
	Dynamic security assessment	1	0	6	1	8
	Static security assessment	5	5	7	2	19
	Maintenance scheduling	6	3	3	3	15
	Contract management	1	0	0	0	1
	Equipment monitoring	14	3	4	0	21
	Load forecasting	4	2	12	4	22
	Load management	13	0	0	2	15
	Alarm processing & fault diagnosis	32	4	13	11	60
	Service restoration	26	1	0	7	34
	Network switching	23	1	0	3	27
	Contingency analysis	3	0	1	0	4
	Facts	0	0	0	3	3
State estimation	1	0	4	3	8	
Analysis	Power flow	1	0	4	7	12
	Harmonics	0	0	0	5	5
	Transient stability	1	0	5	0	6
	Dynamic stability of control design	2	15	13	7	37
	Simulation for operators	5	0	0	0	5
	Protection	12	0	7	0	19
Totals		184	46	86	129	445

Table 4 The full range of AI based fault identification in power systems

Table 4 illustrates the distribution of interest in fault identification of power systems with the AI techniques which are divided into four; expert systems (ES), fuzzy logic (FL), artificial neural networks (ANN), and evolutionary computing (EC). These four techniques available in 1990s have been tailored to certain requirements of domain expertise, and based on the following advantages:

- Expert systems: provide a practical and human based inference where alarm handling, safety critical applications, and sub-station switching are determined by operators' logical and heuristic knowledge.
- Fuzzy logic: allows a set of rules to be modified according to operators' experience, e.g. the system can be tuned for an adaptive system.
- Artificial neural networks: deploy adaptive rapid alarm processing using supervised training, in association with daily load forecasting.
- Genetic algorithms: cover an effective economic despatch and unit commitment as their completeness of problem representation is recognised.

Early applications of AI based fault identification in power systems were focused on the analysis of power systems that has turned away from the methodology of mathematical model in mid 1980s. This is because the rigorous mathematical theory constrained quite often the AI based fault identification and that the less rigorous techniques of artificial intelligence have been preferred.

Especially, in the highlighted row of the table, "alarm processing & fault diagnosis" has received much attention as the workload of coping with alarms for operators has increased due to weather conditions etc. The survey presented above indicates clearly that the alarm processing and fault diagnosis is most popular area using these techniques as mentioned earlier.

2.3 Summary

Interviewing with experienced operators provides empirical evidence in which the nature of alarm analysis is different between alarms on faulted equipment and routine alarm traffic. In particular circumstance, the alarms on faulted equipment cause potential damages over the transmission networks. In order to maintain effective alarm analysis, developing alarm

prioritisation is considered, in conjunction with the network circuit alarm status. In this respect, how these fault identification algorithms can be applied and tested are discussed in the proceeding chapter 5 and 6.

Chapter 3: Artificial intelligence techniques

3.1 Introduction

This chapter is concerned with current research, in association with alternative identification techniques based on artificial intelligence (AI). It is the study of reviewing intelligent systems using computational models in computers and is defined to different ways of developing tools, in order to solve problems intelligently. There are a number of AI techniques discussed; expert systems, fuzzy logic, artificial neural networks, and genetic algorithms in conjunction with various AI applications in power system problems.

3.2 AI in power system operation

Computers have been used to solve practical problems in complex systems, and the one, electrical power engineering is a field in which such computers are extensively used. The field includes both hardware and software achievements. As some work discussed by [McDonald 1997], “the first Intelligent Knowledge Base System (IKBS), AI, was applied to power engineering and implemented in a nuclear power plant at the end of the 1970s. Following this, in the beginning of the 1980s, AI researchers in power systems began to understand the feasibility of the first applications of AI to power systems. Since then, a number of papers devoted to AI techniques for power system applications have grown rapidly”.

He insists that AI techniques and computer developments are relevantly close together and in parallel. These links are evident in the definition of AI. According to [Mayers 1986], AI is the study of ideas that enables computers to be intelligent and has two goals:

- To make computers useful
- To understand the principles that make intelligence possible

In respect of these two requirements, the first electronic digital computer, ENIAC has been known that “an electrical brain can impair the most solid base of our hitherto existing valuation logic-intellect”, is prescribed by [MacDonald 1997]. This caused not only enthusiasm but also unrealistic expectations in the intellectual community between 1940s and 1960s. Its opinion has fallen into several aspects of developments.

First, modern artificial intelligence and digital processing in Supervisory Control and Data Acquisition (SCADA) provide potential for deriving essential information in respect of the state of power system changes. This is because the employment of IT (Information Technology) and advanced microprocessor-based hardware within the field of substation control has helped improving operational and economic efficiency of these tasks since early 1990s.

Second, the biggest concern of any operator is that of being unable to comprehend the overall status of the power system [Russell 1996]. This is because data overload or an inability to detect a developing problem is likely to occur during a heavy alarm period. Reliance would continue to be placed on the highly trained specialist operator to decide what data to select in order to assess the overall status of the transmission network. In the mean time, employing an AI based power system tool has solved such problems, e.g. reducing the burden of operators' tasks, as deriving the relevant information from the SCADA systems is available, provided that the SCADA systems are of the highest quality and reliability.

Third, the term "artificial intelligence"(AI) was coined at a conference in the 1950s. When the term "AI" was introduced, few concepts were known about the complexities involved in making machines appear to think [Mallach 1994]. A simple definition is concerned with devising computer programs make computers smarter; computers make decisions in the way humans do, with reasoning analysis.

Fourth, during the early to mid 1980s, much of the effort in power systems analysis has turned away from the methodology of formal mathematical modelling and such an enthusiastic attention has widened AI researchers' insight. Recently, the interest of AI in power systems has grown rapidly over the last decade. The one possible reason why AI techniques in power systems have proven effective is that computers are more powerful to cope with heuristic approach and etc.

Investigating the tendency over three decades shows that employing AI techniques in power system applications are changing from single systems to synergetic systems such as an integration of utilising the logic and knowledge representation of expert systems, fuzzy logic, artificial neural networks (ANN) and genetic algorithms.

3.3 Expert system

One of the most well known AI based systems is MYCIN that was classified as an expert system [Shortliffe 1976]. The system uses certain heuristic based rules and numbers for medical diagnosis and prescribed therapy for a patient in association with infections, which the system believed, was more likely. If the patient has several symptoms such as fevers, headache, and runny nose, etc., the diagnosis is complex for prescribing antibiotics. To overcome this, a heuristic based prescription technique is developed that employs certainty factors; its degree of belief in data, inference rules, and conclusions.

3.3.1 Structure of an expert system

Building expert systems have been proven substantial improvements in various areas and there are considerable advantages. First, it seems clear that employing the inference engine and knowledge base is quite reliable for solving uncertainty while other AI techniques evolve into mathematical based modelling [Lucas 1990]. They are based on the heuristic knowledge representation. Second, explanations as to why such problems occur serve a consolidated solution. The ability to explain the basis of results provides learnable algorithms for training a novice system engineer. A basic structure of expert systems is, as follows:

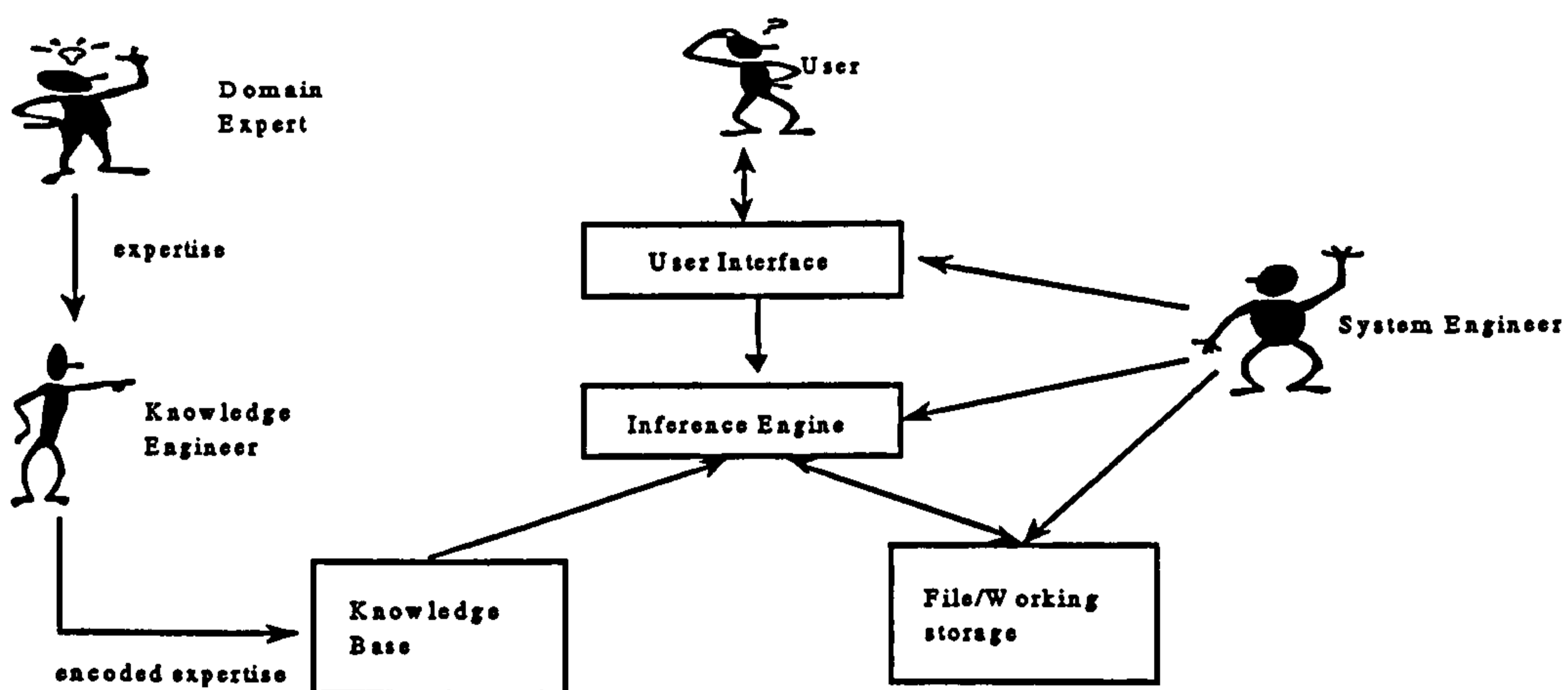


Figure 2 Expert system components and human interfaces

Figure 2 illustrates two factors, expert system components, and human interfaces. First, the expert system components require a programming language which falls into various algorithms, i.e. FORTRAN, ALGOL, and Pascal. These programming languages have

improved the functional expert system by the early 1980s. Second, the human interfaces against encoded machine have received much attention and such a human based system design is taken into account in conjunction with the expert system components.

This technique reviewed is to present a feasibility of hybrid systems in conjunction with fuzzy logic, which will be demonstrated in the proceeding chapter5 and 6.

3.3.2 Characteristics of expert systems

Successful expert system applications require investigating advantages and disadvantages before deciding to apply expert technology/ knowledge engineering to a problem. There are four considerable characteristics to review.

First, advantages of expert systems include speed, consistency, ease of replicating them as often as necessary, not costing the money when not in use, freeing humans for other tasks, training ability, and ability to integrate the knowledge of multiple experts.

Second, drawbacks of expert systems are of narrowness of expertise, lack of common sense, development cost, and requiring expert's services while they are developed. This means that a good expert system has to satisfy technical, economic, and operational feasibility, which relates to the task itself and to the experts who would develop it.

Third, expert systems collaborate with different type of people; the user themselves, knowledge engineers, and domain experts. Expert system developers need to consult the requirements to all these groups.

Fourth, knowledge engineer interface facilities include an editor to create the knowledge base, the ability to map the knowledge base, and the ability to trace the rules in a run. In other word, an expert system should provide a way for a knowledge engineer that solves problems in conjunction with the knowledge engineer' requirements.

3.4 Fuzzy logic

Fuzzy logic is to model incomplete, imprecise or uncertain information. This fuzzy set-based representation of the available information induces possibility and necessity measures for assessing the uncertainty. This is based on the vagueness of human reasoning, which reflects a variable's value through the assignment of a set of values to the variables. As discussed by G. Vachtsevanos [Patyra 1996], "The fever of the fuzzy logic control controversy stems, of course, from a historical paradox: a flurry of applications has proceeded any substantial theoretical developments. The question, therefore, is posed as follows: is there a systematic way design and assess the performance of FLCs?"

This query has been proved by the early successes and failure of fuzzy logic control (FLC) point towards a new look at the design, analysis and performance evaluation of controllers in which they employ fuzzy set theory. Thus, previous shortcomings have improved the paradoxical theory such as appropriately combining tools from fuzzy set theory, non-linear dynamics and artificial intelligence. In the mean time, the concepts of fuzzy logic and other AI techniques have evolved into a hybrid methodology. For example, one of the most successful areas of AI techniques has been the integration of neural networks and fuzzy logic that is an emerging area of AI techniques called Neuro-fuzzy system or fuzzy neural system. However, this approach is restrictive in that explanation of why facility against the uncertainty is not fully recognised.

On the other hand, a hybrid system based on the integration of an expert system and fuzzy logic is considerable and potential application to provide more effective AI algorithm, against uncertainty. Expert systems and fuzzy logic expert system are discussed in conjunction with an improved explanation, readability, etc in chapter 5.

3.4.1 Characteristics of fuzzy logic

[Zadeh 1965] has contributed the theory of fuzzy sets and its applications to artificial intelligence. The key concepts are:

- A linguistic variable, whose values are words rather than numbers;
- A fuzzy if-then rule and rule qualification, in particular probability qualification and possibility qualification;

- Interpolative reasoning;
- A fuzzy graph

With these concepts, fuzzy logic makes it possible to exploit tolerance for imprecision and uncertainty. In doing so, fuzzy logic has proved to be successful where traditional approaches such as rigorous mathematical modelling have failed or produced inferior results. For example, there is an ageing process illustrated, as follows:

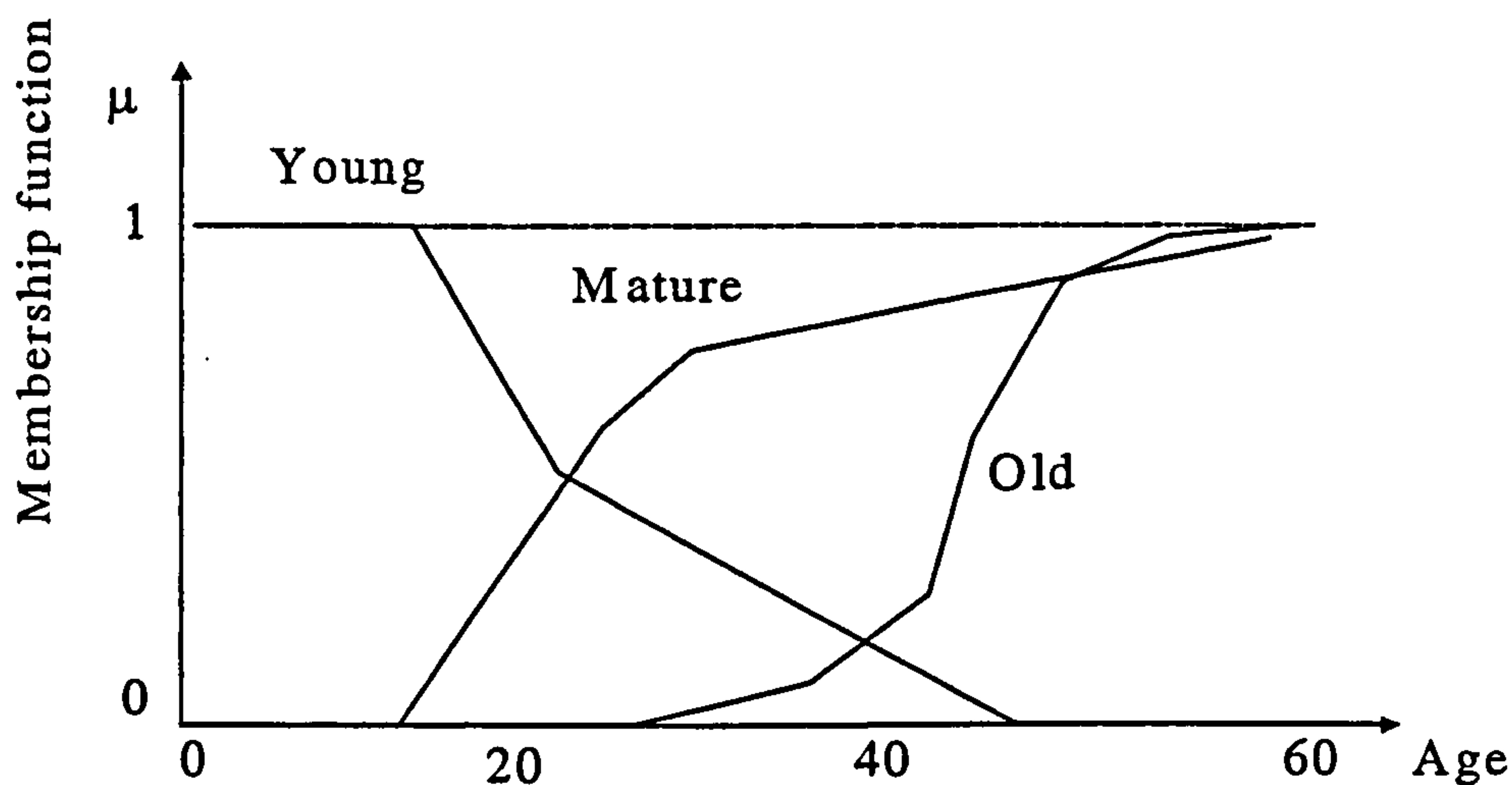


Figure 3 An ageing process presented in a fuzzy graph

Figure 3 describes an age but not a person as young, mature, and old. In this particular case, someone might consider one twenty-year old to be very mature and another to quite immature. This means that maturity depends on more than age, which causes great difficulty to process the representation in rigorous mathematical forms.

This representation is backed up and discussed by [Bender 1998], he insists that traditional methods start with a mathematical model of the system; technical and often difficult step that usually requires considerable understanding of the system. Since fuzzy method has emerged, much less technical skill and much less analysis is needed to design a fuzzy controller. To the extent, currently, fuzzy logic employs four methods; fuzzy methods, belief theory, Bayesian nets, and certainty factors.

3.4.2 The current application in power systems

As electrical transmission networks are subject to many forms of interruptions, i.e. outages caused by permanent short circuit, employing an AI based power system to reduce the disturbance has received much attention. The trends of intelligent system techniques have evolved into hybrid systems. The principle behind the synergetic AI techniques is to integrate the use of two or more techniques in order to combine their different strengths and overcome each other's weakness that generates hybrid solutions. These hybrid solutions are based on the following concepts:

- ❖ Fuzzy expert system hybrids
- ❖ Neural expert system hybrids
- ❖ Fuzzy neural network hybrids

Fuzzy expert system hybrids in power systems have begun to tackle the problem of imprecision from expert systems. The evolution considers more effective human based reasoning, and decision processes within an uncertain environment. These two factors are emulated and manipulated through the tools and techniques.

Neural expert system hybrids are characterised that falls into three functional modules, ANN module, ES module, and Operation Interface (OI). This system was implemented in C++ language and the tool, CLIPS, and called "Connectionist Expert System" (CES). The sample system chosen for fault diagnosis is the distribution system located in the Taipei West District Office of Taiwan Power Company in 1994.

The ANN module, which runs in real-time status, receives diagnostic messages from a trouble ticket and classifies the failure status and components status. The ES module receives the component status, performs the expert analysis function and provides recommended actions to system operators. The OI module, which is built in a window-based environment, provides the system operator with a user-friendly interface to the developed system.

As the approach of using ES or ANN by themselves alone has exposed some limitations in each domain, the integration of ANNs and ESs for distribution system fault diagnosis has

shown considerable results in terms of accuracy rate. The following evaluation illustrates a performance analysis;

System		Proposed CES	Fuzzy expert system	Discrete-event simulation
Running Time(SEC)		8	16	145
Accuracy Rate(%)	Search range	1	94	83
		3	96	91
		5	100	95
		10	100	98

*Search range i means that the first i suggested solutions are discussed.

Table 5 Performance analysis against alarm messages

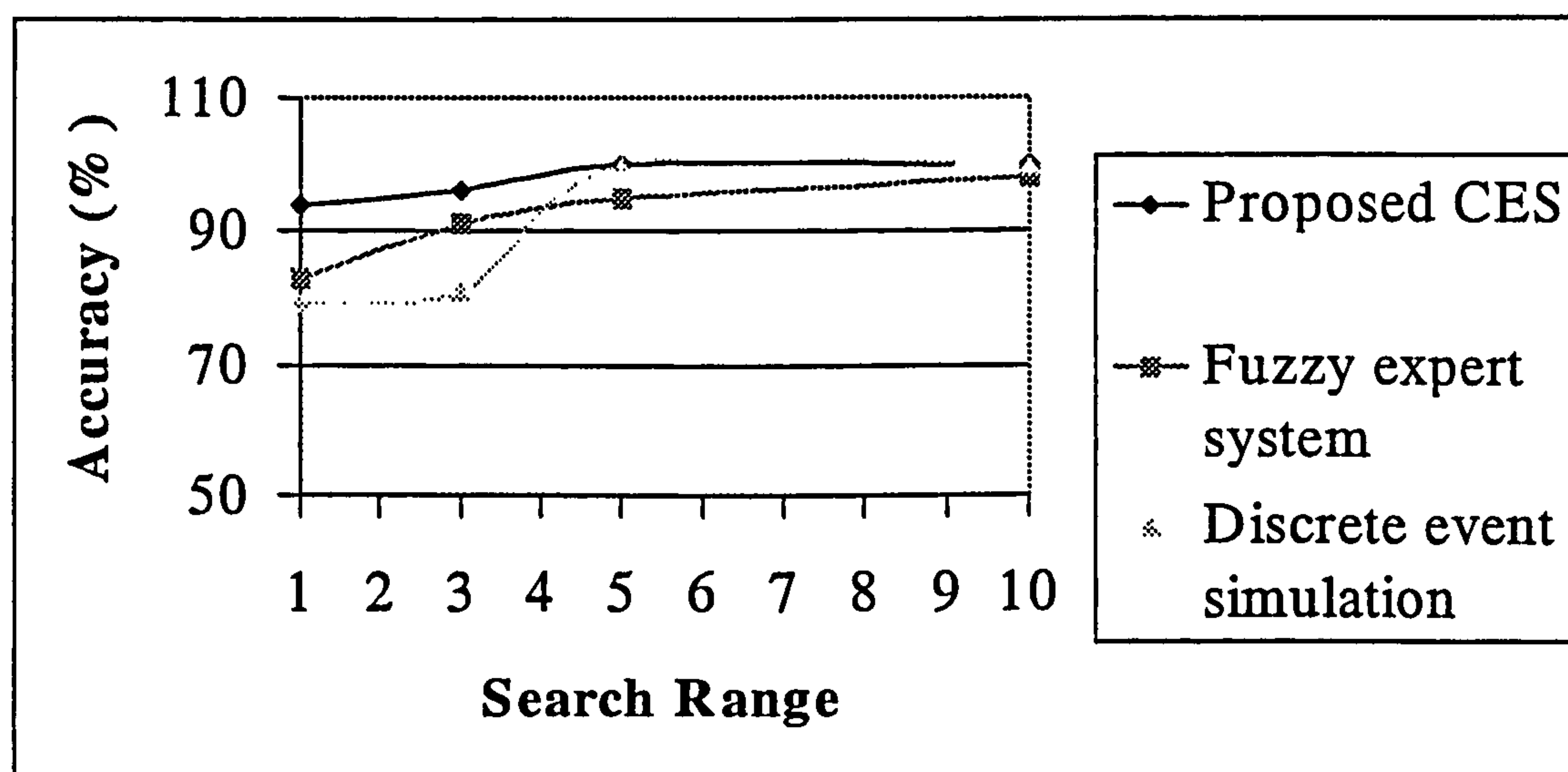


Figure 4 Performance analysis in the accuracy rate of alarm interpretation

This comparative performance evaluation study is conducted against the other two, i.e. fuzzy expert system and discrete event simulation. Although many factors are not evaluated for their usability such as knowledge maintainability and update, the performance of the CES shows superior when compared to the other two methods, in terms of accuracy and running time. The results of this comparison study suggest that hybrid systems are referred to an optimum solution in a power system.

3.5 Genetic algorithms

A genetic algorithm is a computational model that emulates biological evolutionary theories to solve optimisation problems. The GA comprises a set of individual elements and a set of biologically inspired operators defined over the population itself. As some work discussed

by Y. H. Song & R. W. Dunn[Warwick 1997], the features of genetic algorithms are different from other search techniques in several aspects, as follows:

- 1) GAs optimising the trade-off between exploring new points in the search space and exploiting the information discovered far.
- 2) GAs has the property of implicit parallelism. Implicit parallelism means that the GA's effect is equivalent to an extensive search of hyperplanes of the given space, without directly testing all hyper plane values.
- 3) GAs are randomised algorithms, in that they use operators whose results are governed by probability. The results for such operations are based on the value of a random number.
- 4) GAs operates on several solutions simultaneously, gathering information from current search points to direct subsequent search. Their ability to maintain multiple solutions concurrently makes GAs less susceptible to the problem local maxima and noise.

These GAs constitute a general optimisation method, are used to automate a wide variety of design procedures, and require quite little problem specific information to undertake optimisation. A performance analysis for these features in power systems is described in the proceeding section.

3.5.1 Application of genetic algorithms in power systems

This section reviews a scheduling maintenance of electrical power transmission networks using genetic programming implemented by (W. B. Landon & P. C. Treleaven); [Warwick 1997], and the model network is based on the National Grid Company plc, Chester, the UK. They cover England and Wales. Particularly, the South Wales region of the UK electricity network is discussed, which carries power at 275kV and 400 kV between electricity generators and regional electricity distribution companies and major industrial consumers. The sample tests reviewed are based on the following requirements:

- All lines must be maintained during the 53 week plan (1995 had 53 weeks rather than 52). Typically about a third of the lines are maintained in any one-year.
- All maintenance takes four weeks. Typically scheduled outage of a line is between a week and 1.5 months
- All conductor ratings were reduced by 50%

The region covers the major cities of Swansea, Cardiff, Newport and Bristol, as follows:

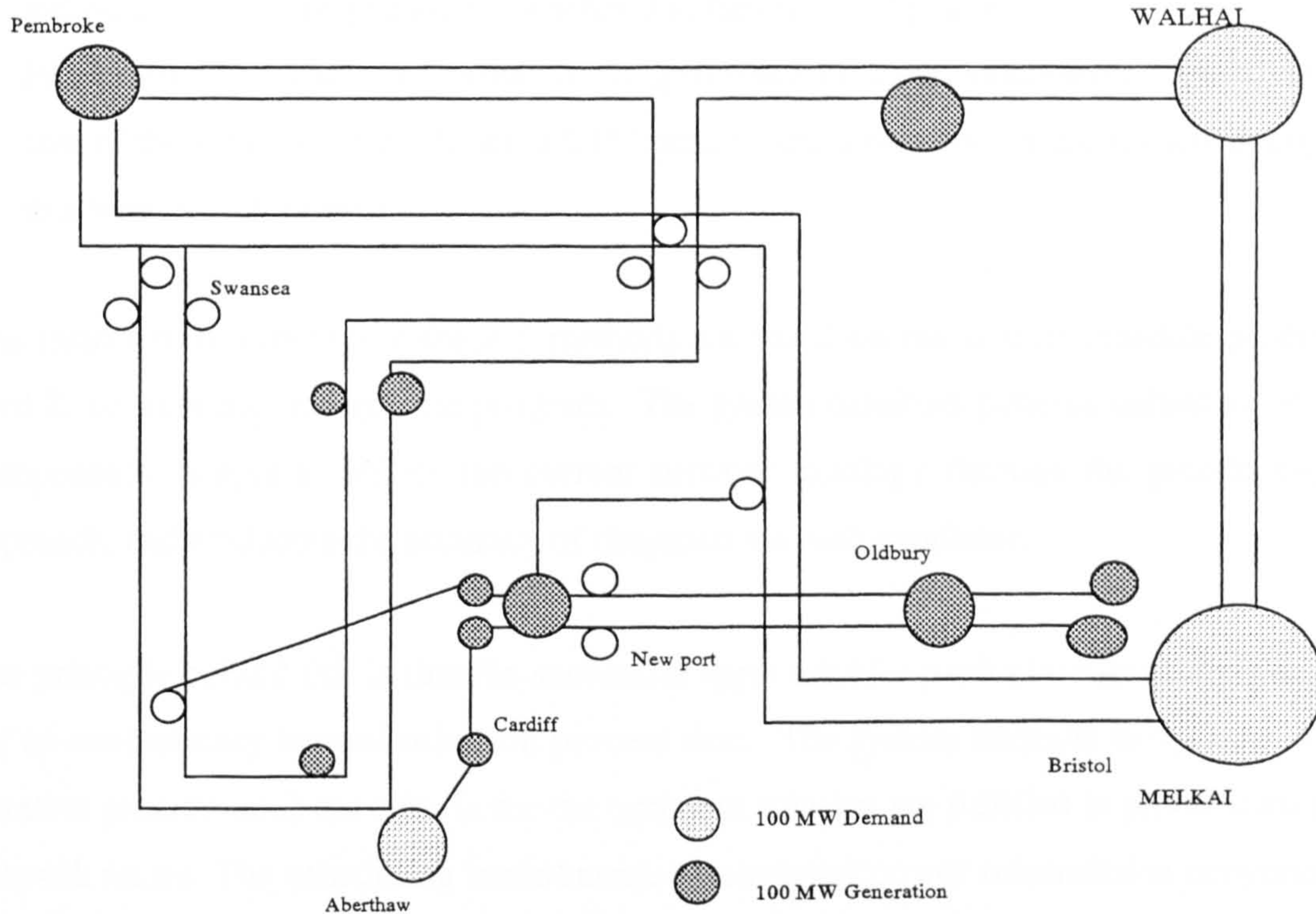


Figure 5 South Wales region high voltage network

The representation of the electricity network used in figure 5 is firmly based on the engineering data available for the physical network. The experiments suggest 5 fundamental methods:

- 1) Architecture- this program is called once for each line that is to be maintained, and its return value is converted from a floating point to an integer which is treated as the first week in which to schedule maintenance of that line. If this is outside the legal range 1.... 50 then that line is not maintained.
- 2) Choice of primitives- these network primitives return information about the network as it was just before the test program was called. Each time a change to the maintenance schedule is made, power flows and other affected data are recalculated before the GP tree is executed again to schedule maintenance of the next line. They are checked to see if they are within the legal range. If not the primitive normally evaluates to 0.0.
- 3) Mutation- there are two forms of mutation used with equal likelihood, sub tree mutation, a randomly selected function.

- 4) Constructing the initial population-these are the GA heuristics but written as GP individuals using the primitives described in the choice of primitives.
- 5) Fitness function-each individual is comprised of three independent components, the cost of the schedule it produces, a CPU penalty and a novelty reward for scheduling a line in a week which unusual.

The results from employing these 5 methods are based on the cost of schedule produced by seed 2, i.e. running one genetic program. The system monitors patterns indicative of faulted components, adapts to reflect the current network topology through the genetic algorithm approach, and evaluates the accuracy of diagnosis via fault simulator.

The principle behind this is that the successful approach of a particular algorithm is employed for an evolutionary natural selection process akin. The system attempts to optimise over the iterative process until the criteria for the optimum solution are fulfilled in power transmission network faults. The scheduling maintenance of electrical power transmission networks using genetic programming indicates that electrical elements such as lines and various conductors can be used an AI based power system. However, this genetic algorithm investigated in power transmission networks only shows a different aspect of successful approach, and is not leading to the proposed alarm processing and fault diagnosis.

3.6 Artificial neural networks

As the initiative of artificial neural networks was contributed by W. S. McCulloch and W H Pitt' (1943)/ [McDonald 1997], their neural-net model, called an M-P unit, was synchronous, e.g. using simple logical switches, but quite unlike real neurones. By 1970, brain simulation by neural networks was losing favour, while the symbolic representations for building formal structures capable of being solved by computers had more control of AI research funds.

In terms of practical applications, contemporary artificial neural networks provide the learning capabilities of neural networks where a problem requires estimation, prediction, or classification. It is notable that they do not store knowledge explicitly, but implicitly characterise behaviour through a learning process. To overcome this limit, developing a hybrid system is desirable, as a human based system should provide learnable explicit knowledge for operators.

3.6.1 Multi-layer feed-forward networks

Most ANN-architectures are loosely grouped by the term multi-layer feed-forward ANNs, and are constructed, as follows:

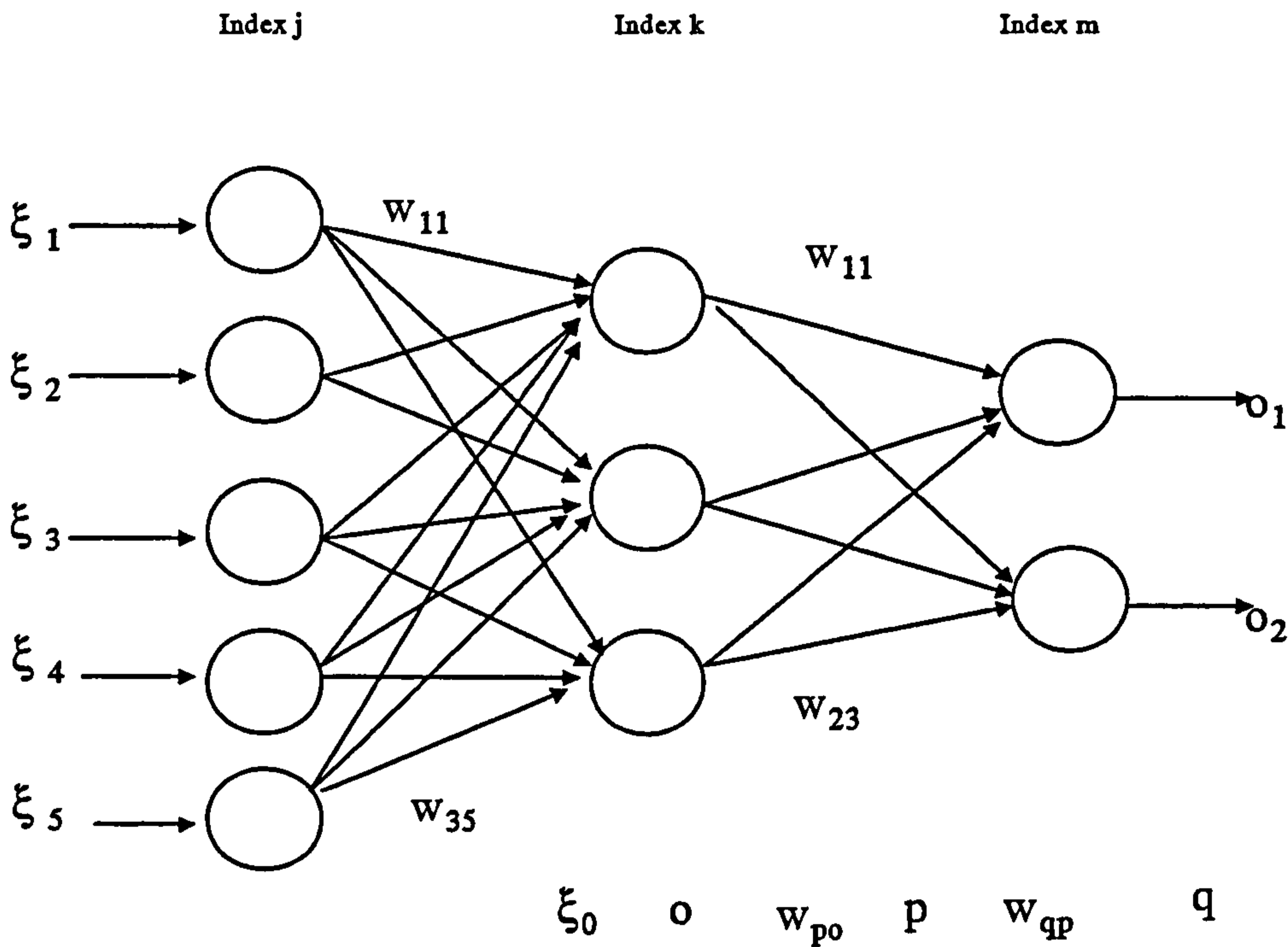


Figure 6 An example multi-layer ANN

The first layer is fed directly with the input, and each cell in one layer is fully connected to all other cells in the following layer. The output of the last layer is the output of the network. All layers between the input and output layers are called *hidden layers*.

Each cell carries out a very simple calculation, e.g. it sums all its inputs multiplied by their respective weights, as below:

$$\begin{aligned}
 o_q &= g(I_q) \dots\dots\dots 2 \\
 &= g(\sum \omega_{qk} o_k) \\
 &= g(\sum \omega_{qk} g(I_k))
 \end{aligned}$$

Where ω_{qk} is the weight of the connection between a cell k in layers l en cell q in layer l+1, and $o_k = g(I_k)$ is the output of cell k. The following figure illustrates a cell in conjunction with the weight of the connection:

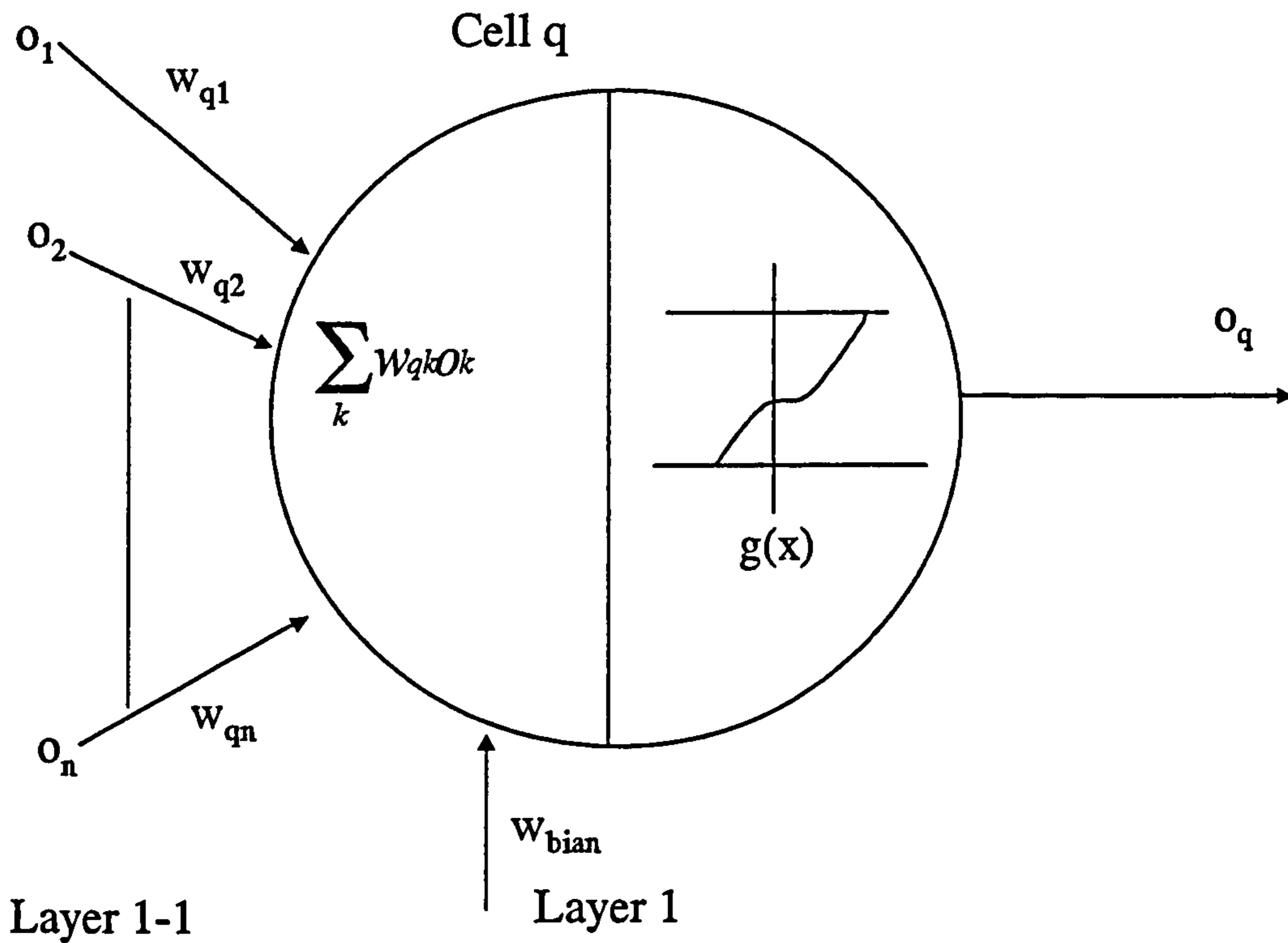


Figure 7 A cell

The squashing function is called activation function, is an important factor in the non-linear behaviour of neural networks in the following formula:

$$g_s(x) = \frac{1}{1 + e^{-x}} \dots\dots\dots 3$$

$$g'_s(x) = g_s(x)(1 - g_s(x)) \dots\dots\dots 4$$

$$g_d(x) = \frac{2}{1 + e^{-x}}, \dots\dots\dots 5$$

$$g'_d(x) = 2g_s(x)(1 - g_s(x)) \dots\dots\dots 6$$

With these formulae, the input propagates through the network, resulting in a value at the output-cells. The training of such an ANN consists of an iterative process to change the weights of all the connections.

In most architectures, a bias is incorporated. This is implemented as an incoming link connected to a constant value of 1. The weight of the connection is trained like all other weights. The effect is that besides squashing, a horizontal transaction is applied to the input; a factor is added to, or subtracted from the input of a cell.

3.6.2 The back-propagation learning algorithms

One of the most prominent and widely used training algorithms is the back-propagation method discovered independently by [Werbos 1974;Rumelhart 1986]. It is based on the gradient decent minimisation method. This method falls into four:

- ◆ Weight-space
- ◆ The formulae
- ◆ Stochastic back-propagation
- ◆ Adaptations

Weight-space is that of a search which is dependent on the space spanned by all weights in ANN. The goal of the search is finding a point in weight-space, which maximises a certain error criterion. Training of an ANN is equivalent to performing a minimisation procedure in weight-space with respect to the error criterion.

The formulae for the back-propagation method as aforementioned in section 3.6.1 will be worked out for an ANN with one hidden layers.

Stochastic back-propagation is based on the order in which the patterns are presented to the ANN is random. The path through weight-space is thus stochastic. The formula deduced in figure 7 are based on; The system shows all patterns once to the ANN, then update the weights and repeat until acceptable convergence.

Adaptations concern the learning rate after the discovery of the back-propagation method. Especially, parameters can be adjusted during the training process.

In respect of these four, one of the most widely used ideas is simulated annealing, in which a parameter is slowly decreased during the training process. As aforementioned, the well-

known method proposed by [Rumelhart 1986] incorporates a momentum to provide more stable convergence; it tends to avoid the oscillations. The momentum is incorporated in the weight adjustment function as follows:

$$\Delta w_{new} = -\eta \frac{\delta E}{\delta w_{previous}} + \alpha \Delta w_{previous} \dots\dots\dots 7$$

Notes: with $\alpha \in [0,1]$, usually around 0.9.

This accelerates convergence in ‘steady downhill’ direction, while having a stabilising effect in regions where the sign of the gradient oscillates. This approach raises a problem where the parameters η and α are hard to choose. However, they can be adapted during the training process.

Reviewing the back-propagation method for the training of multi-layer ANNs falls into two insights. One has several important advantages, as follows:

- ❖ The training is in essence done locally, so parallel implementations are possible, i.e. locality in space;
- ❖ The method is computationally not very complex; only type of error has to be passed backwards;

However, there are some drawbacks to note as below:

- The speed of convergence is relatively low;
- The method can get stuck in local minima;
- The possibility of network paralysis: if the weights get too large, the change in the weights become minimal, e.g. since aiming for large weights, the derivative of sigmoid is very small;

To overcome these problems, several adaptations for the back propagation algorithm have been receiving much attention among AI researchers.

3.7 Practical consideration of a fuzzy-expert system; designing an effective solution

A fuzzy-expert system is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic, which is to infer data. These rules in the fuzzy-expert system are based on the following example:

- If x is low and y is high then z is medium

Where x and y are input variables such as names for known data values, z is an output variable (a name for a data value to be computed), low is a membership function/fuzzy subset defined on x, high is a membership function defined on z.

The antecedent such as the rule's premise describes to what degree the rule applies, while the conclusion / the rule's consequence assigns a membership function to each of one or more output variables. The general inference process proceeds in four steps, as follows:

- 1) Fuzzification : the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise;
- 2) Inference: the truth-value for the premise of each rule is computed and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variables for each rule. The generally used inference rules are; MIN or PRODUCT. The MIN inferencing, output membership function, is clipped off at a height corresponding to the rule premise's computed degree of truth (fuzzy logic AND). The PRODUCT inferencing, the output membership function is scaled by the rule premise's computed degree of truth;
- 3) Composition: all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Usually, MAX or SUM is used. The MAX composition, the combined output fuzzy subset, is constructed by taking the pointwise maximum over all of the fuzzy subsets assigned to variable by the inference rule (fuzzy logic OR). The SUM composition, the combined output fuzzy subset is constructed by taking the pointwise sum over all of the fuzzy subsets assigned to the output variable by the inference rule;
- 4) Defuzzification: this is used when it is useful to convert the fuzzy output set to a crisp number. There are at least 30 defuzzification methods, but more common techniques

used are the CENTROID and MAXIMUM methods. The CENTROID method, the crisp value of the output variable is computed by finding the variable value of the centre of gravity of the membership function for the fuzzy value. The MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth-value is chosen as the value for the output variable.

To date, these four steps are considerable improvements from the conventional rule based system. Fuzzy expert systems are the most common use of fuzzy logic. They are used in several wide-rang fields, as follows:

- Linear and non-linear control
- Pattern recognition
- Financial systems
- Operation research
- Data analysis

These fields have attempted to improve their usability and maintainability in terms of intellectual evolution and financial effectiveness [Patyra 1996; Yen 1999]. The principle behind this hybrid system is that of considering the brittle systems between an expert system and fuzzy logic.

For instance, these problems have to be answered in two ways; First, how does the expert system cope with a problem which bends the rules, they are unable to cope with. These rules fail because they are not grounded in case. They are unable to fall back on the details of their experience, find a similar case, and apply it.

Second, how does fuzzy theory differ from conventional probability theory that based on mathematical modelling? At the mathematical level, fuzzy values are commonly misunderstood to be probabilities, or fuzzy logic is interpreted as some new way of handling probabilities. However, this is not the case in which a minimum requirement of probabilities is ADDITIVITY. They must add together to one, or the integral of their density curves must be one. Semantically, the distinction between fuzzy logic and probability theory has to do with the difference between the notions of probabilities and a degree of membership. Probability statements are based on the likelihood of outcomes: an event either occurred or

does not, and the domain experts can bet on it. By contrast, with fuzziness, one can not say unequivocally whether an event occurred or not, and instead these experts are trying to model the interpolative to which an event occurred.

These two problems are subject to incorporating fuzzy theory in the design and development of expert systems and are one of the most challenging problems in the area of artificial intelligence. As a practical consideration of reviewing these problems, this thesis presents an evaluation of a fuzzy knowledge based system to solve complex problems in a power system.

3.7.1 Adaptive process

Adaptation is known two types of learning, algorithmic tuning, and parameter tuning. The former is that of playing real data through the system which will highlight shortcomings and conceptual bugs in the underlining algorithms that must be fixed. This type of learning is best done by the human developers with the aid of tools on the machine. The latter uses a large number of parameters whose settings greatly influence the system's performance. Choosing best values for these parameters is generally difficult for a human for a numbers of reasons [Davis 1996] , as below:

- interactions between parameters;
- the difficulty humans have mentally juggling large amount of data to make statistically based decisions;
- the long time required to evaluate a single set of parameters;
- the difficulty of changing the parameters to meet new system specifications;

These requirements are well adapted to an application of neural networks, which suggests that the application is able to react automatically to random external influences. However, with neural networks, experience in the past has shown that various applications have different requirements in respect of efficiency and constrained the capability of its explanation as to why the adaptive process has concluded against these parameters.

To overcome this problem, the diagnostic system developed in this thesis employs a theme of fuzzy-expert system.

3.7.1.1 Determining the best explanation

Determining the best explanation is a pattern of reasoning which is to tract one best explanation. In this respect, abduction and induction have been recognised as important forms of reasoning with incomplete information that are appropriate for many problems in Artificial Intelligence.

Abduction is generally understood as reasoning from effects to causes or explanations, and induction as inferring general rules from specific data. In Artificial Intelligence, a typical application of abduction is diagnosis, and a typical application of induction is learning from examples.

The specific difference between induction and abduction is here that abduction is part of discovery process while induction is part of the process of testing discoveries. This is supported by [Peng 1990], by induction, a given general will only be confirmed or falsified by future experiments.

As some work discussed by [Josephson 1996], AI researchers have discovered one restricted class of abduction problems which it is tractable to find the best explanation. Major studies of an abductive approach to knowledge-base refinement are reviewed, as follows:

- Task analysis of explanatory hypothesis formation
- Tractable abduction
- Parsimonious covering theory
- Parallel processing in abduction

Task analysis of explanatory hypothesis formation is a composite explanation for a given body which can be achieved by way of two main subtasks; generating elementary hypotheses, and forming a composite hypothesis using the elementary ones. The following figure shows the task analysis of abductive hypothesis formation.

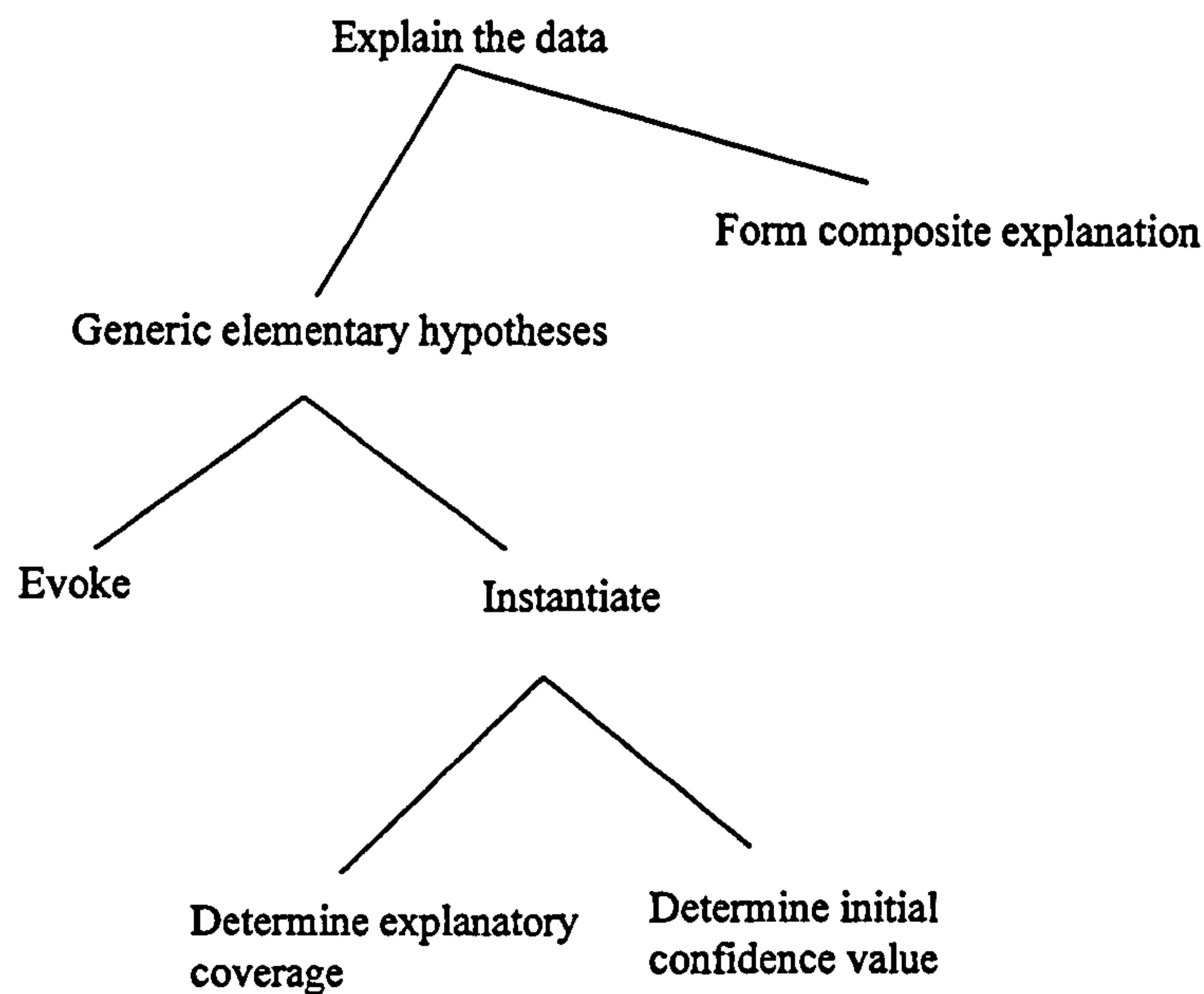


Figure 8 Task analysis of abductive hypothesis formation

Figure 8 illustrates only one family of ways to accomplish the task. It may be especially appropriate, but it is not necessary unique. Generating an elementary hypothesis can usefully be considered to consist of two subtasks: evocation and instantiation [Josephson 1996]. The evocation falls into three methods.

- i. First method is to search systematically for applicable concepts in a top-down fashion through a concept hierarchy organised by generality. Refinements of inappropriate general concepts are not considered. It is notable that there are usually no dependencies in judging the applicability of the refinements of a concept, so these judgements can be done in hierarchical-classification problem solving.
- ii. Second method is to stimulate consideration by cueing, that is, by taking knowledge stored in the form of associations between particular concepts, which are likely to be relevant, e.g. eating too much salt. One advantage to evocation by cueing is that it is very computationally efficient, but one disadvantage is that it is not exhaustive, so applicable concepts may be missed and it is difficult to be sure that they have not. Thus, it is notable that cueing can be done in parallel.
- iii. Third method is to use an explicit casual representation to work backward from effect to possible causes. This is based on casual hypothesis adapted from the previous episode

and then serves prima facie plausible. This is because it is already known that such things have happened.

Tractable abduction considers the best explanation, which includes the generation, criticism, and possible acceptance of explanatory hypotheses. It has been known that one explanatory hypothesis is better than another are such considerations as explanatory power, for example, plausibility, parsimony, and internal consistency. Currently, the tractability of the task under the new description in power systems is demonstrated by giving an efficient strategy for accomplishing it.

Parsimonious covering theory is to simplify several aspects of abduction. For example, composite hypotheses are defined as simple combinations of individual hypotheses as follows:

$$H_{\text{all}} = \{h_1, h_2, h_3, h_4, h_5\}$$

$$D_{\text{all}} = \{d_1, d_2, d_3, d_4\}$$

$$e(h_1) = \{d_1\} \quad pl(h_1) = \text{superior}$$

$$e(h_2) = \{d_1, d_2\} \quad pl(h_2) = \text{excellent}$$

$$e(h_3) = \{d_2, d_3\} \quad pl(h_3) = \text{good}$$

$$e(h_4) = \{d_2, d_4\} \quad pl(h_4) = \text{fair}$$

$$e(h_5) = \{d_3, d_4\} \quad pl(h_5) = \text{poor}$$

Key notes	
e	a map from subsets of $h(n)$ to subsets of $d(n)$
pl	a map from subsets of $h(n)$ to partially ordered set h has plausibility $pl(h)$
$d(n)$	a finite set of all the data to be explained
$h(n)$	a finite set of all the individual hypotheses

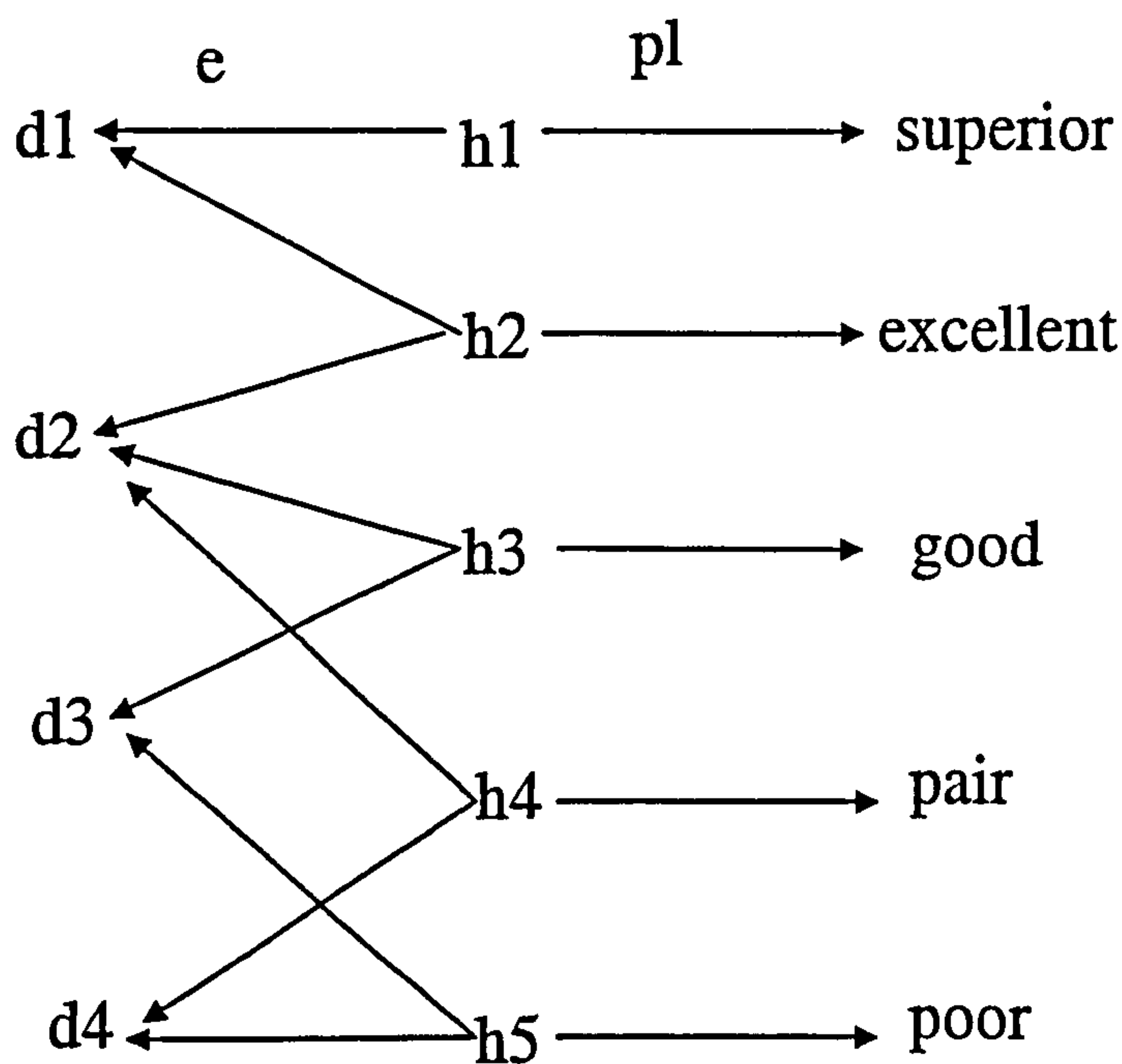


Figure 9 Example of an abduction problem

Figure 9 illustrates that this research has encountered the virtue of employing such an abductive reasoning, in conjunction with a fuzzy knowledge based system when a faulted feeder is persistent or permanent.

Parallel processing in abduction is a concurrency which communicates with each other either through a shared data structure (Goel, Josephson, & Sadayappan, 1987) or by passing messages. Two important perspectives are relevant during the formation of a composite explanation.

First, in respect of the perspective of each datum to be explained, a typical question might be; which available hypothesis can best explain me? This question could be asked for each datum in parallel with the others.

Second, each available hypothesis, and a typical question might be; which portion of the data can I be used to explain? This question could be asked for each hypothesis in parallel with the others.

3.7.1.2 Capability of sample training

Most knowledge-based systems can not learn from their mistakes. To correct a knowledge base, a system should identify what caused error and then suggests repairs to implement the correction ('knowledge reformulation'). This is because most systems for knowledge-base refinement rely heavily on the domain expert to identify mistakes and to provide corrections [Josephson 1996].

The problem of corrective-learning task is that of how to generate explanations as to why new explanation obtained is more preferred than old explanation. A sample system, CREAM, is a system that uses an abductive method to assign credit in a knowledge base. This begins by reviewing a trace of the KBS's execution of the case to propose a set of error candidates (hypotheses). The system consists of two parts, as below:

- 1) Identifying candidate errors
- 2) Using the functional description to generate error candidates

First, identifying candidate error requires a key which generates possible error candidates for a system's mistake. This key considers the tasks and methods that the system uses. The following functions demonstrate how the hypothesis is useful for describing the decomposition of tasks:

$$fg(O)=D_{all} \dots \dots \dots 8$$

Where O is the set of observations for a case, fg is the finding generator, and D_{all} is the data to be explained.

This hypothesis generator can be described as:

$$hg(d)=H \dots \dots \dots 9$$

Where $d \in D_{all}$ is a datum to be explained and $H \subseteq H_{all}$ is a set of fault hypotheses. This hypothesis is applicable as:

$$hr(h)=r \dots\dots\dots 10$$

Where $h \in H_{all}$ is a fault hypothesis and $r \in R$ is a confidence rating. Finally, the coverage generator can be defined as:

$$cg(H)=D \dots\dots\dots 11$$

Where $H \subseteq H_{all}$ is a set of fault hypotheses, and $D \subseteq D_{all}$ is a subset of the data to be explained; The range of function cg is the explanatory coverage of the hypothesis. More importantly, hypothesis assembly is a function from the observations to the set of the most plausible fault hypotheses satisfying the constraints of completeness, i.e. explaining all the data, and parsimony. A function mapping observations to fault hypotheses can be described, as follows:

$$ha(O)=H \dots\dots\dots 12$$

Where H contains the most plausible fault hypotheses to satisfy the following requirements:

$$cg(H)=fg(O) \text{ and } \forall H' \subseteq H, H' \neq H (cg(H') \subseteq cg(H) \text{ and } cg(H') \neq cg(H)) \dots\dots\dots 13$$

These functional descriptions are to determine their candidate errors while their explanations are tractable. This approach is applicable to generic tasks. Each generic task is characterised by a method for performing a class of tasks.

Second, using the functional description to generic error candidates is to determine the reason for difference between a fault hypothesis and its explanation. This is prescribed by [Josephson 1996]. He insists that “the problem of generating error candidates requires an analysis of each task and method used within a problem solving system to define the types of errors that each task and method can make and the conditions under which each type can occur”.

This effective method is applied to a diagnostic KBS's answer. For instance, let A_s denote the KBS's answer and A_e denote the expert's answer. The possible differences between the two answers are the following:

- 1) The KBS's answer is a proper subset of the correct answer, i.e., $A_s \subset A_e$. The KBS is not complete.
- 2) The correct answer is a proper subset of the KBS's answer, i.e., $A_e \subset A_s$. The KBS does not provide an economical solution and mistakenly identified some finding as requiring further explanation.
- 3) The KBS has chosen a different answer than the expert's to explain a particular finding: namely, $A_e \neq A_s$ but $A_s \not\subset A_e$ and $A_e \not\subset A_s$. Some subtask of hypothesis assembly is in error.

These three theoretical methods show that the methods used in the KBS is an analytic strategy and based on generic-task theory, but the success of this part is dependent on an explicit description of the tasks and methods used in the system.

The main intention of this theoretical sampling study is to test the way in which choice of fault hypotheses affects the fuzzy inference' ability to form an adaptable system from such disorders.

3.7.1.3 A synergetic approach

A synergetic approach is to provide intelligent systems that have been developed over the last decade. These hybrid systems are developed in a variety of ways, as below:

- 1) Combination;
- 2) Integration;
- 3) Fusion;
- 4) Association;

First, combination is concerned with certain brain activities in a complementary way which results in combining intelligent techniques. A typical architecture is the sequential combination of neural networks and expert or fuzzy systems.

Second, integration is to select the most appropriate elements to achieve a specific goal and then merges the selected elements' response. The integration of other intelligent elements helps to determine the total system behaviour.

Third, fusion is a distinctive feature of neural networks' technology which provides its capability of learning and adaptation. This feature increases their learning efficiency when compared with other techniques. This type of architecture is a fusion of intelligent techniques.

Fourth, association provides a distributed architecture which develops a wide variety of intelligent agents for different situations where each element works autonomously and cooperatively. This architecture will be useful with these different situations.

The system presented in this thesis employs these features when necessary.

3.7.1.4 Scaling of input features

Scaling of input features is reviewed utilising fuzzy logic. A graded classification system is used to infer these input features as a nature of interpolative reasoning, prescribed by [Zadeh 1994]. Most fuzzy logic applications involve the use of what might be called the calculus of fuzzy logic rules. The use of fuzzy rules determines to reduce the number of rules in conjunction with interpolative reasoning. These rules determine to improve imprecise dependencies and to make these input features easier for humans to articulate them.

In most control applications, a subset of the calculus of fuzzy rules is deployed as the calculus of fuzzy graphs. With this calculus, a function $f:U \rightarrow V$ is approximated by a fuzzy graph f^* , a disjunction of Cartesian products, as follows:

$$f^* = \sum_i A_i \times B_i \dots\dots\dots 14$$

Where, A_i and B_i , $i=1,\dots,n$ are values of linguistic variables, and \sum_i represents the disjunction (union) of Cartesian products, i.e. $A_i \times B_i$.

For instance, a fuzzy graph for scaling uncertain data may be expressed in the following coarse way:

$$f^* = \text{small} \times \text{small} + \text{medium} \times \text{large} + \text{large} \times \text{small} \dots \dots \dots 15$$

This formula is equivalent to the set of rules to the following representation:

If X is small then Y is small.

If X is medium then Y is large.

If X is large then Y is small.

The use of fuzzy graphs in conjunction with these scalable input has resulted in the data compression by means of scaling the input. This is one of the key, but not widely recognised as advantages of using fuzzy rules. This thesis assesses a performance of employing this theme.

3.8 Summary

AI researchers have been conducting research in various subjects, i.e. *Natural language, Learning, Automatic programming, Planning, Speech recognition, Understanding, and Neural modelling*, but one of the most difficult is that of adaptive systems. These systems require weightings in conjunction with an effective algorithm and should be modified according to experience for an optimum solution. This solution is obtained by tuning the synergetic systems which are based on the integration of heuristic knowledge and fuzzy knowledge based system. A major goal of designing this AI based system is to test whether any variance affects interpretation of outages on the power system, i.e. monotonic reasoning and non-monotonic reasoning. To the extent, this diagnostic system developed attempts to move in that direction employing these synergetic systems, which will explain as to why such outages occur.

Chapter 4: The simulation of power system & applicable systems

4.1 Introduction

The aim of a power system operation is to satisfy customers' demands in which electricity is provided in sufficient amounts, with satisfactory quality and reliability. The system consists of three subsystems, generation, transmission, and distribution. They are connected to substations whose basic roles are voltage transformation and switching. Thus, this power system contains thousands of these elements across countries. Since storing energy in the form of electricity is expensive in economic terms, the whole power system has to be operated simultaneously, and energy has to be generated to the moments of consumption. During the system operation, many events occur due to weather conditions etc. This requires a sophisticated and effective control for operators.

In order to employ applicable systems to an AI based power system, various methods are investigated and reviewed. Two methods are chosen in order for the design of the AI based power system. First, fault arrangement design is corresponded with real-time protection systems that how to form an effective part of the AI based power system in the proceeding chapters. Second, alternative fault detectors are studied so that these configuration values can be applied into the proceeding chapter 5 and 6.

4.2 Power system requirements

The operation of a power system always involves the transfer of electrical energy from one location to another in power system requirements. They are comprised of the following elements:

- Generators
- Transformers
- Overhead lines
- Capacitors
- Inductors
- Sectionalisers
- Buses

- Breakers
- Arrestors

These elements form the part of transmission lines in order to transmit EHV or HV across countries. The simulation study is based on plain protection equipment of High Voltage (HV) transmission lines in Scottish Hydro-Electric PLC, which is transported over long distances via grid systems.

The requirements of the power system are to use the best technological solutions in constructing the plant items, ensure continuous operation, and protect expensive devices. This research is proposed to protect the expensive devices in which failures of protective devices can cause damages to the insulation, etc., i.e. from overcurrent and overvoltage.

4.3 Source configuration

In a practical EHV (Extra High Voltage) system, sources with a three-phase delta connection with associated voltage and current have a return path, either the ground or a neutral conductor. The line-to-line voltage is equal to $\sqrt{3}E_p$ V, as follows:

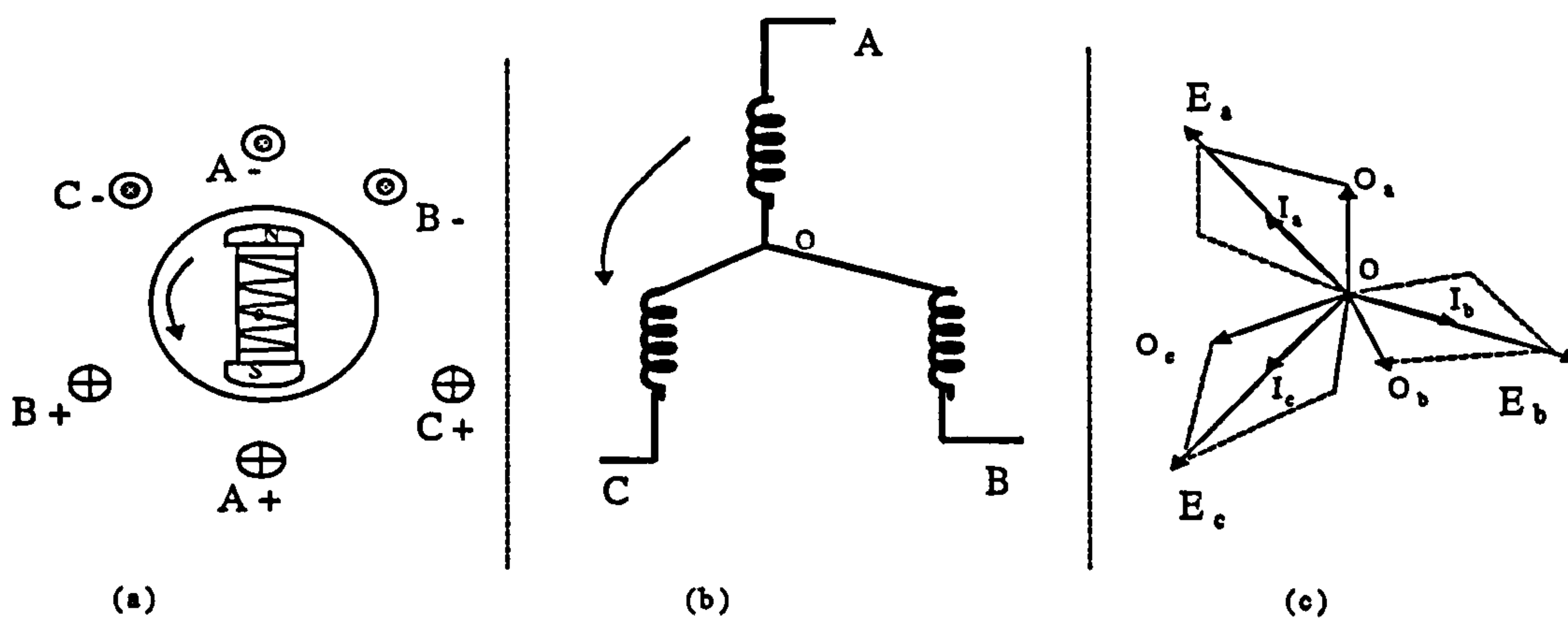


Figure 10 Diagram of a three-phase Wye (star) connection with associated voltage and current vectors

Where E_L = line voltage

I_L = line current

E_p = phase voltage

The product of current and voltage is greater than these quantities multiplied by a power factor which can not exceed 1 when the current is not in phase with the voltage. This assumes a balanced system, that is a system in which the currents and voltages are equal in all the phases. Unbalanced phase currents and voltages present a more complicated problem although power systems are well balanced. To some extent in the protective system, such unbalanced systems are discussed in this section.

A fault diagnosis system should be activated whenever the SCADA system detects a relay operation in the network. To the extent, contributions to this list of hypotheses fall into three sources (Daniel S Kirschen 1990)/ [Dillon 1990]:

- A topological algorithm uses the breaker status information to determine the blacked-out area.
- Any pieces of equipment included in this area are a possible candidate.
- If two or more separate blacked out areas are detected, a multiple fault is postulated and the hypotheses list is built accordingly.

These are augmented by all the equipment located in the zones covered by the primary relays which have been active. If any secondary or backup relay has reacted to the fault, the elements of its zone coverage list are merged into the list of hypotheses. The three sources are based the following two examples:

- Configuration used for the first fault diagnosis system examples
- Configuration used for the second FDS example

First, configuration used for the first fault diagnosis system example illustrates the principle and detect faults as below:

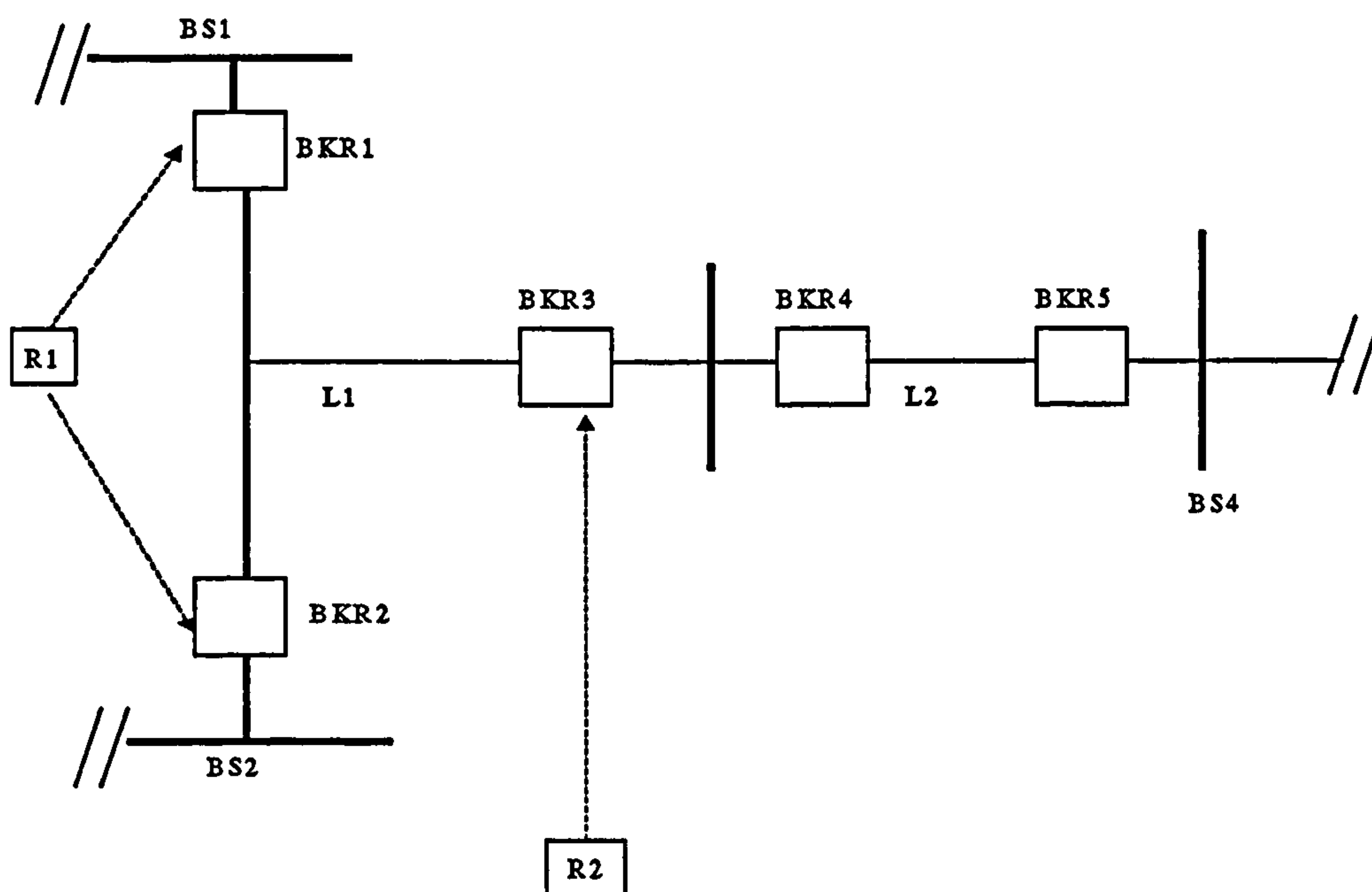


Figure 11 Configuration used for the first FDS example

Figure 11 illustrates the small portion of a power system which receives the following information:

- Breakers BKR1, BKR2 and BKR3 have tripped
- Relays R1 and R2 have operated as primary protection

The topological analysis determines that the only deenergised element is the L1. The plausibility of this hypothesis is checked and found quite high as it explains both of the relay operations and does not imply any device malfunction.

Second, configuration used for the second FDS example is based on the actual power system configuration and protection scheme shown on figure 12:

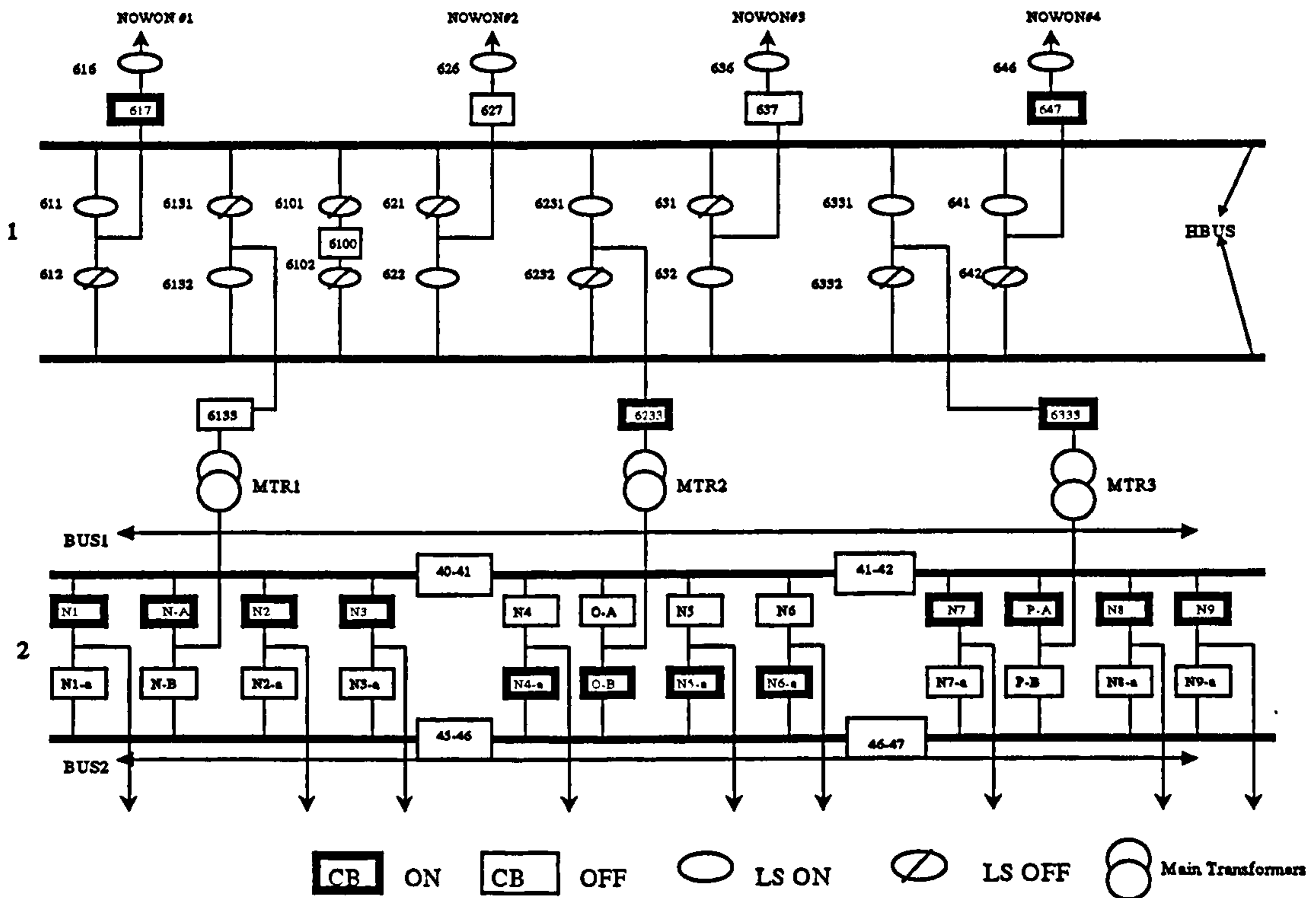


Figure 12 Configuration used for the second FDS example

Figure 12 shows the actual information available for alarm interpretation, supplied by KEPCO, which shows power system changes, by means of protection systems, i.e. circuit breakers' on/off trip, lines' on/off status, and transformers' symmetrical operation. This important information relies on the following sources:

- Alarm data from the SCADA system
- Power system topology from the SCADA system
- Interpretation knowledge obtained from the control centre operating staff
- Detailed alarm information from alarm design notes and schematics

Alarm data from the SCADA system essentially consists of digital information that flags unusual events or conditions in the power system. Also, it consists of information from protection system and out of range checks.

Power system topology from the SCADA system includes information on the status of breakers and transmission lines as well as measurements of power flows and voltages. This allows one to get a picture of the operational topology at a particular instant in time. This

information is transformed by the rules provided by control room staff, become alarm messages.

When a message obtained by the SCADA is presented, operating staff searches for the remedial action to be taken. The most important remedial action is taken by circuit breakers, isolating faulted plant or transmission lines. Some faults occur in protective equipment that is not isolated in this equipment and the control centre operating staff is responsible for providing remedial action. This remedial action does not involve repairing any faulty equipment rather it is aimed at minimising the impact of the fault on the system.

Detailed alarm information from alarm design notes and schematics relates to the follow up advice. Once remedial action has been taken, the detailed assessment of plant faults and the planning of action to repair faulted equipment must be undertaken. Therefore, the decision to despatch the relevant staff is the responsibility of the control room staff and the information required for the assessment of suitable staff is laid down in various operations handbooks and instructions.

In respect of these four, gathering information for alarm interpretation requires a systematic approach which is to design an AI based alarm processing and fault diagnosis. Having reviewed these empirical studies, this research considers *the power system topology from the SCADA system* as the electrical components and protective information are available for the real-time AI based power system. A topological alarm message format was attempted on the transmission lines whether any knowledge acquisition on the AI based power system is compatible and obtainable in corresponding to the actual transmission lines.

4.3.1 Specifying quantitative source

A quantitative source is concerned with mathematical theory such as use of fault calculation. The source is given in terms of transmission bus impedances. The source impedance is predominantly derived from the system analyser. If three lines converge at a single bus, the impedance is a certain value, provided that all lines are closed. The following figure 13 demonstrates how to determine these impedance figures from the available data of fault detectors.

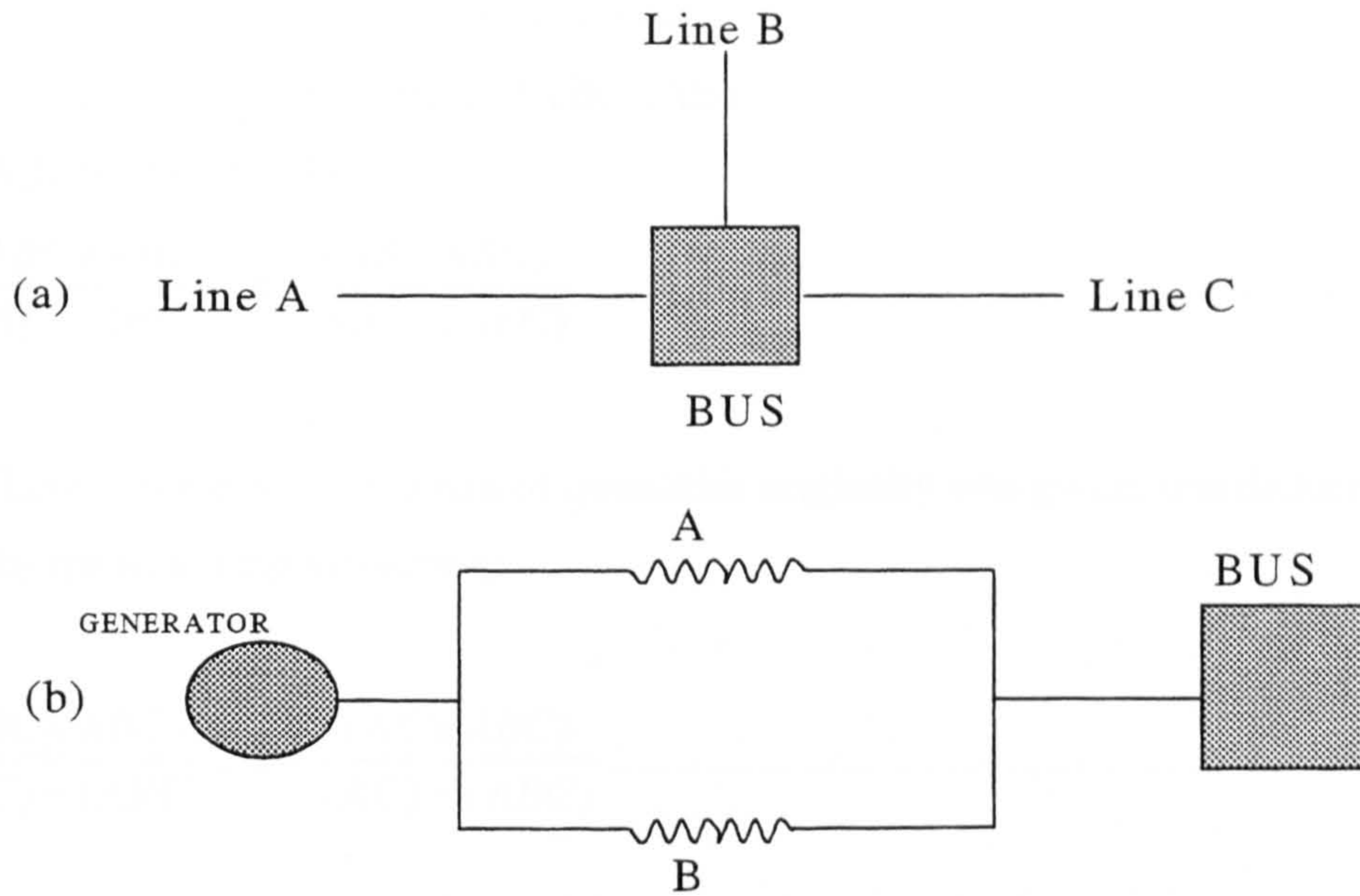


Figure 13 (a) single bus based transmission impedances, (b) the paralleling two impedances at the single based bus.

This picture (a) shows that Line A is the impedance of source A, Line B is the impedance of source B, and Line C is the impedance of source C. To the extent, Line AB is the impedance of source A and source B in parallel where Line C is open. This is assumed that Line A, B, and C find their way back to a common source so that Line AB can be shown in the picture (b). In order to identify the faulty equipment, a transmission network formula is simulated, as follows:

$$\text{If Line C is open, } (AB) = \frac{AB}{A+B} \dots\dots\dots 16$$

$$\text{If Line A is open, } (BC) = \frac{BC}{B+C} \dots\dots\dots 17$$

$$\text{If Line B is open, } (AC) = \frac{AC}{A+C} \dots\dots\dots 18$$

$$(ABC) = \frac{C(AB)}{C+(AB)} = \frac{A(CB)}{A+(CB)} = \frac{B(AC)}{B+(AC)} \dots\dots\dots 19$$

This solves for C, as below:

$$C(AB)=(ABC)(C+AB)=(ABC)C+(ABC)(AB)$$

$$C(AB)-C(ABC)(C+AB)=(ABC)C+(ABC)(AB)$$

$$C(AB-ABC)=(ABC)(AB)$$

$$C=\frac{(ABC)(AB)}{(AB)-(ABC)} \text{ Or } \frac{(AB)(ABC)}{(AB)-(ABC)} \dots\dots\dots 20$$

As this Line C impedance in terms of quantities originally was given, this deduces Line A and Line B by the following inspection:

$$A=\frac{(BC)(ABC)}{(BC)-(ABC)}, B=\frac{(AC)(ABC)}{(AC)-(ABC)} \dots\dots\dots 21$$

From these three impedances, it is possible to determine the strongest, middle, and weakest source. These themes are an important source for the application of the abductive fuzzy knowledge based system in the chapter 6.

4.4 Configuration and parameters in transmission lines

Electrical power is the product of voltage and current. Since large currents are expensive in requiring large conductors and switchgears, it is attractive in the case of transmission lines to increase the voltage to increase the transmitted power rather than increasing the current.

On the HE network, these lines range in voltage from 132 kV to 275 kV. A voltage level of 765kV is very common in other countries and in fact there are lines operating at over 1000kV. HE operates over 32,000km of transmission lines and over 110km of submarine cable had been laid to connect the more accessible islands.

In respect of these transmission lines, some of the significant design considerations are reviewed before designing the aspects of an AI based power system. Several important factors affecting the choice of line configuration and conductor spacing are, as follows:

- ❑ Transmission line voltage
- ❑ Conductor type and size
- ❑ Insulator type

- System protection
- Grounding
- Weather conditions
- Mechanical design ; Span length, Conductor sag, Conductor spacing, and hardware selection

These factors are the essential consideration of selecting the best line configuration to meet the system. This study employs these factors as a heuristic knowledge which consists of generating rules in association with a fault location rather than quantifying the sources.

An experiment was carried out whether any faulty locations can be identified in the transmission networks, and applies to the following knowledge acquisition process:

◆ Topological knowledge acquisition component

Topological knowledge acquisition components play an important role for an AI based power system, which specifies quantitative source in the power system.

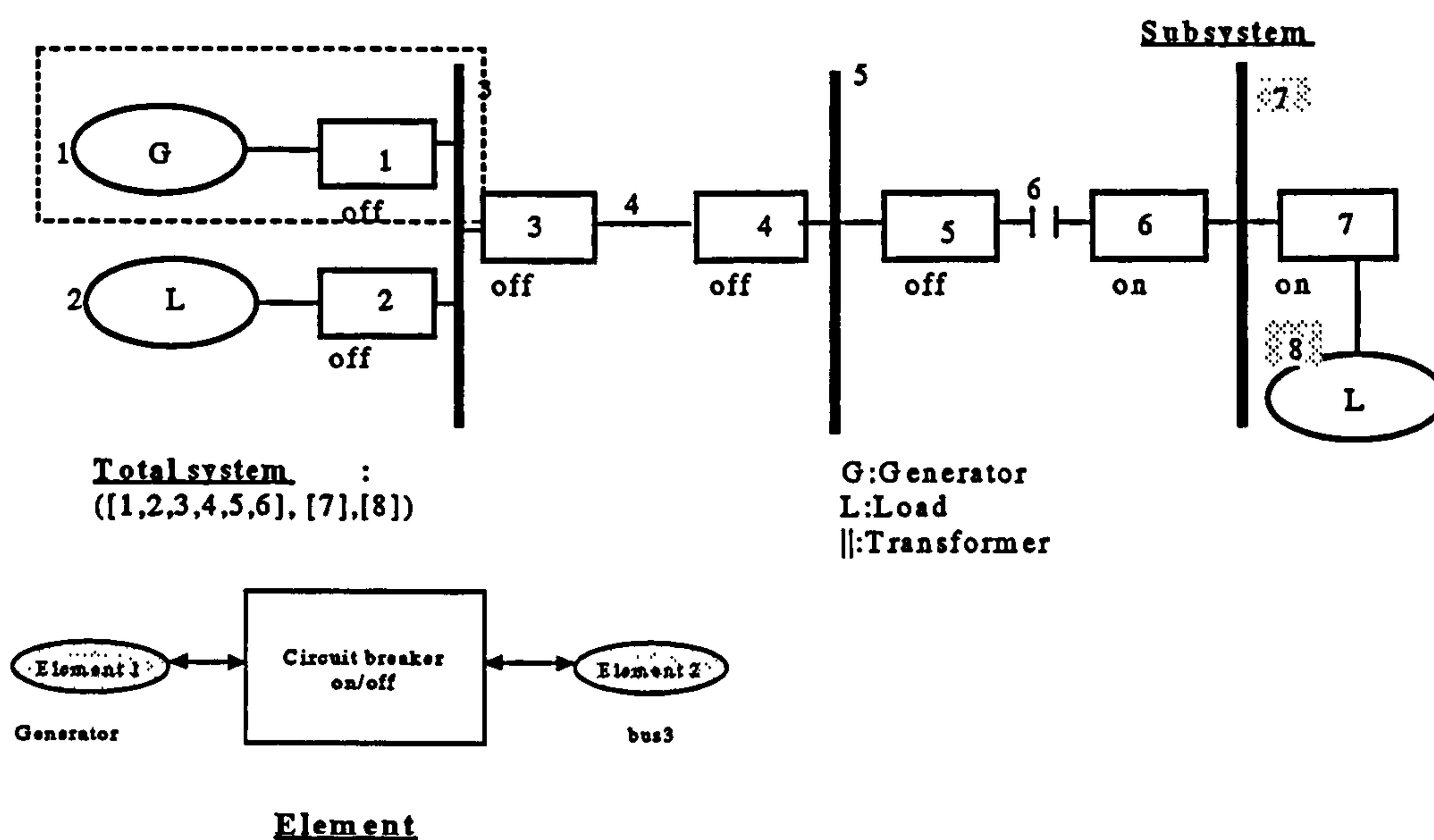


Figure 14 Topological knowledge acquisition components

The above figure illustrates three components, Element, Subsystem, and Total_system. First, the element represents when all the CBs are tripped, provided that the LINEs, BUSs, GENERATORs, LOADs, and TRANSFORMERs are electrically connected units, as follows:

Element (1, gen, [1])

Element (2, load, [2])

Element (3, bus, [1, 2, 3])

Element (4, line, [3,4])

Element (5, bus, [4, 5])

Element (6, transformer, [5,6])

Element (7, bus, [6,7])

Element (8, load, [7])

Second, the subsystem collects on-off status of CB in a given time, and electrically connects to a group of the element, as below:

CB (1, 1, 3, off)

CB (2, 2,3, off)

CB (3,3,4, off)

CB (4,4,5, off)

CB (5, 5,6, off)

CB (6, 6, 7, off)

CB (7, 7, 8, off)

The total system represents the element as the group of the subsystem, such as Total system = ([1,2,3,4,5,6], [7], [8])

At the same time, relays are used to protect electrical device against overload and fault conditions. For instance, if an abnormal condition occurs, the relay causes a circuit breaker to open and thus disconnect the faulty apparatus from the power supply and from other associated equipment. This can be represented as an element in the network, as follows:

- Relay (CB-index, Type, El-list, Sort, Phase)

1) The '*CB-index*' is a list of number in conjunction with '*EL_LIST*' from the Relay.

- 2) The '*Type*' is a form of the associated equipment.
- 3) The '*El-list*' is a hybrid element consisting of three elements; bus protective relay, line protective relay, and primary protective relay <In this case, it represents the protective relay's list of element, and monitors the list of CB's number from CB failure relay. >
- 4) The '*Sort*' represents information of the protective relay for a fault diagnosis.
- 5) The '*Phase*' indicates where the transformer is responded to a fault.

4.4.1 Transmission line design

An overhead transmission line falls into restrictive and reactive parameters, which are distributed along the length of the line. An equivalent circuit represents them with lumped components as T or π network, which is equivalent to the exact representation of a transmission line. In that the parameters of the lines are distributed along the whole length of the line. Likewise, the three-phase system is influenced by its two neighbours as well as reflection in earth planes and lines.

4.4.2 Electrical elements

Electrical elements are concerned with the type, size, and number of bundle conductors per phase. These conductors are selected to facilitate sufficient thermal capacity to meet continuous emergency overload and short-circuit ratings. A capacitance exists between conductors of a line and between the conductors and the capacitance involved is greater than those in lines with single conductors, resulting in increased capacitive charging currents.

Furthermore, as line voltage is increased, the capacitive charging kvar of a line increases. For instance, on a 500-kv line with two bundled conductors, approximately 2000 kvar/mi of capacitive reactive supply is required.

In respect of these elements, there are two different ranges. First, if a long line is lightly loaded, its receiving-end voltage will rise above that of the sending end. If it is heavily loaded, the receiving-end voltage will drop considerably below the sending-end voltage. When the voltage rise at light loads is excessive, insulation may be overstressed or voltage-regulating equipment at the receiving-end station may go out of range, i.e. resulting in undesirable customer voltage conditions. Second, when a long line is heavily loaded and its

receiving-end voltage drops excessively, voltage-regulating equipment may go out of range and cause customer voltage to be reduced.

4.4.3 Mechanical elements

Mechanical elements consist of three components, as follows:

- Network
- Static plant
- Rotating plant

Network covers transmission, distribution, and supply. The failure of network or partial network is caused by the failure of static plant or rotating plant associated with the network, which affects failure mechanisms in static and rotating plants. This is because primary causes of disruptions in energy management systems (EMS).

Static plant falls into two categories, electromechanical and mechanical elements. These elements are often fallible. In practice, most failures in operating plant are due to some mechanical root cause.

Rotating plant such as motors and generators performs a continuous energy supply which is converted into a form of electrical energy from mechanical movement. This consists of photoelectric, thermoelectric, and chemical.

4.4.4 Economic elements

Economic elements depend on the state of the system, which necessitates proper methods of forecasting and planning on the line. The total installed cost of line losses over the operating life of the line has to be kept at the lowest overall level. Power utilities use modern digital computer programs and consider physical experience to achieve optimum line design planning.

4.4.5 Transmission line transposition

The overhead transmission line used in this work is based on 132kv circuit breakers, busbars, transformers, etc. on the UK Scottish Hydro Electric PLC system, where a,b, and c represents three phase conductors in the overhead lines. The interchanging of positions of conductors along a transmission line is to reduce inductive influences and power loss. A sample system is illustrated between National Grid and HE grid system, as follows:

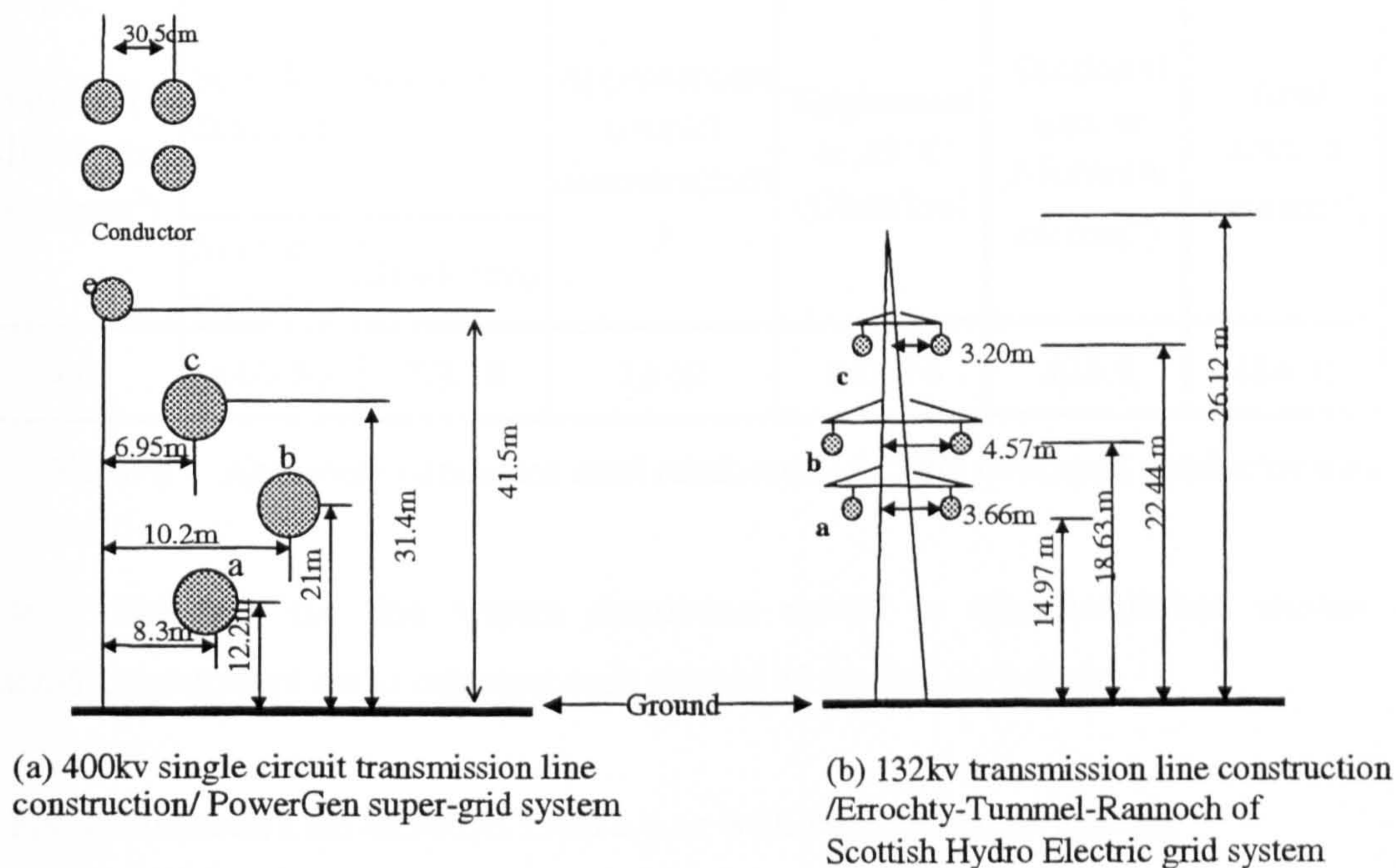


Figure 15 Balanced transposition of lines

Figure 15 illustrates three-phase conductors are designed for single circuits. The parameter for such surge impedance of a 132kV, three-phase transmission line is 440 ohms. By employing a fault detector on the line, the surge impedance loading of the line is, as follows:

- $(132)^2/440\text{MW}$

This surge impedance can be used a configuration value when a fault occurs on transmission lines. The work carried out in this research employs the configuration value, but is not intended to develop methodologies of the configuration value.

4.4.6 Phase conductors

Each phase conductor is composed of an aluminium tubular and steel reinforced core. This conductor is referred to the GEC protection relay application guide (1987), as follows:

Nominal Aluminum area (mm ²)	Stranding and wire diameter		Approximate overall diameter(mm)	Registance at 20 °C (Ohm/km)	Sectional area of Aluminium(mm ²)	Total section area(mm ²)
	Aluminium(mm)	Steel(mm)				
400	54/3.53	7/3.18	28.62	0.0674	428.9	484.55

Table 6 Aluminum conductor steel reinforced (ACSR) overhead conductor data

Table 6 illustrates the line system simulation model as aforementioned section 4.4.5. Generally, parameters are to calculate each section of the line, as below:

- Phase conductors are 4x54/7/0.33cm a.c.s.r with 30.5cm bundle spacing
- Earth wire is 54/7/0.33cm a.c.s.r.
- Earth resistivity is 100 Ωm
- Conductor resistance is $0.06740/4=0.0168$ Ω/km
- Earth wire resistance is 0.06740 Ω/km
- Conductor overall diameter=28.62 mm

Employing these parameters of the line is essential to diagnosis what conductor data fulfil the above criteria when a fault constrains the line. This study suggests that applying these parametric rules on an AI based power system is desirable.

4.5 Fault analysis

An unknown fault might occur on a transmission system for a number of reasons, which includes the following ones:

- Lighting, high winds, snow, ice and frost
- Switching
- Scattered fragments
- Broken conductors
- Maintenance

These factors are well known that causes transient fault, persistent, and permanent fault on the transmission system. Protective equipment is used to guard and control abnormal information. They can be included in the developed knowledge base system.

4.6 Fault simulation

Carrying out fault simulation requires different system and fault condition on transmission lines. Some factors affecting power system constraint were simulated, as follows;

- Fault position
- The fault type
- The line configuration
- The relay operation
- The circuit breaker operation

Fault position varies dependent on the transit time between the fault and source discontinuities. An apparent frequency of the superimposed travelling wave components decreases when the fault position makes more distant from the point of observation. According to this simulation study, the fault position was varied from 0 to 100% of the line length, as below:

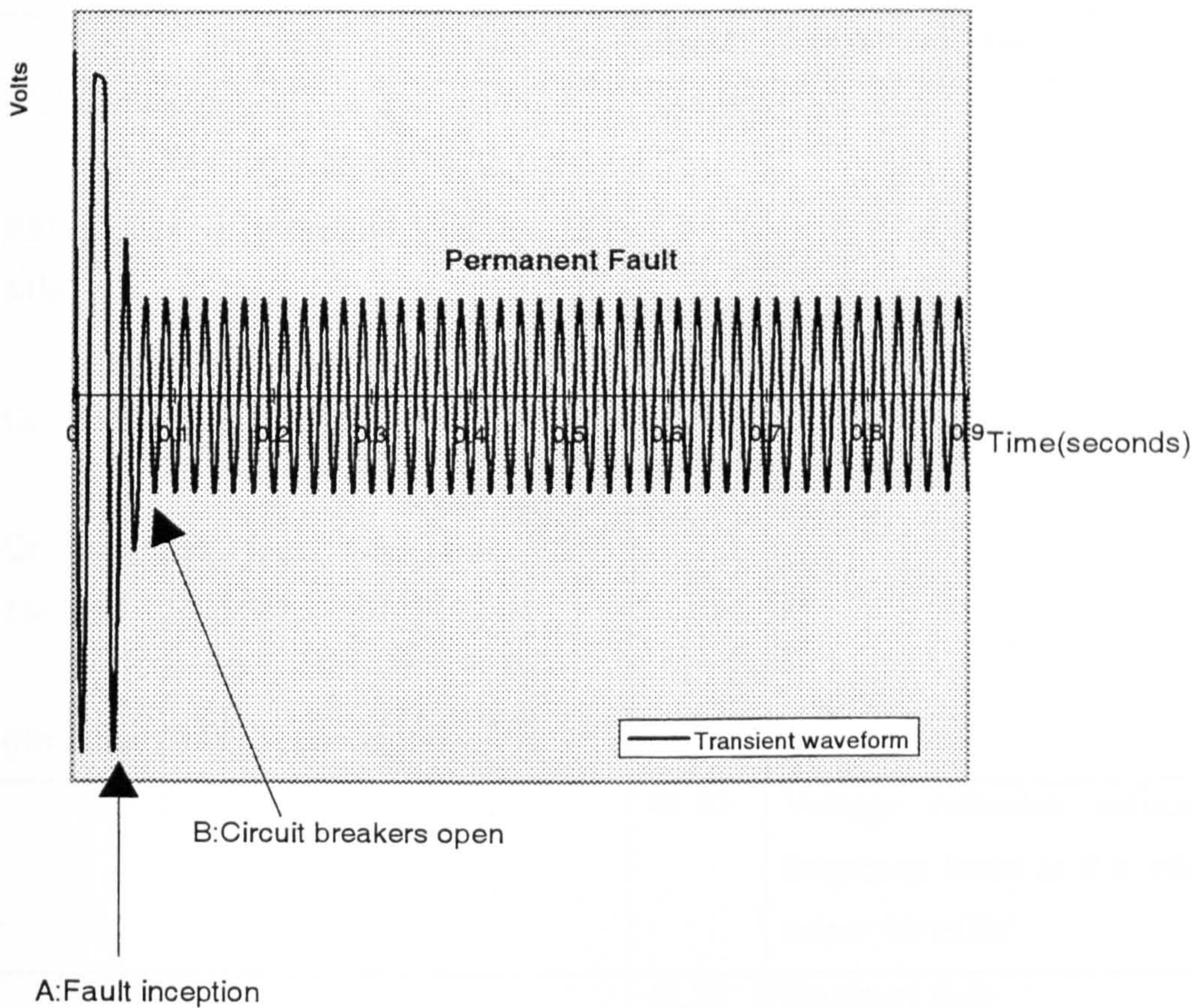


Figure 16 Voltage waveform for receiving permanent fault

Figure 16 illustrates two fundamental elements of the permanent fault, A: Fault inception, and B: Circuit breakers open. A peak value is reached at A when a fault occurs in the network. The second element is triggered at B when the CB is open in response to a certain frequency range before the permanent fault. These two fundamental elements are an accepted fact within power engineering industry that uncertainties inherent often cause major damage to the electrical apparatus elements and operators may not be able to analyse the event satisfactorily [Ozveren 1996; Brunner 1993]. To an extent, detection of low frequency by frequency tripping relays will be determined and circuit breakers attached to the distance relays will isolate where any load reductions or increase is necessary by manual. Figure 16 was associated with the following table:

Load reduction under Emergency conditions	FREQ. Hz	Load reduction under controlled conditions
	49.80	Operational limit
FOYERS: -Sequence scheme operates Either reduces pumping load by 150 MW Or initiates Spin Gen mode to 120 MW Or increases Gen load from 120-150MW (for either or both generators)	49.75	
	49.50	Voltage reduction initiated if frequency looks as if it will fall below 49.25Hz
	49.25	Statutory limit
	49.00	Load reduction by disconnection if frequency falls below this value
Low frequency Auto trip-stage 1 #	48.50	
Low frequency Auto trip-stage 2 #	48.30	
Low frequency Auto trip-stage 3 #	48.00	
Low frequency Auto trip-stage 4 # #: System control and/or Inverness Control will effect these load reductions manually if the automatic relay operation fails.	47.60	
FOYERS:both machines auto shut down	47.00	

Table 7 Frequency operational table for emergency conditions

Table 7 illustrates emergency conditions associated with the frequency deviation [Ringrose 1995]. It was necessary to establish what happened in the network because the fault was consistent. However, the nature of finding a fault was complex, involving measuring the changes of voltages, currents, and monitoring circuit breakers and relays so that the restoration time was delayed over an hour.

This survey carried out suggests that determining load reduction from the permanent fault for operators' view is concerned with the level of their knowledge represented by linguistic variables. For example, an operator attempts the problem of load reduction; "reduce the load as low as possible when the frequency deviation starts modulating". The respondents in this survey were recruited from the control centre operators that the main priority in association with the fault position is as follows:

- Operators need a human-factor-oriented system which will help them for controlling the load reduction.

This requirement is taken into account in conjunction with the implementation of the diagnostic tool. A methodology of implementing the frequency deviation was designed, as follows:

- Task 1. Was the value of frequency deviation applicable employing a fault detector/low frequency tripping relays for a PC based system?
- Task 2. Was the peak load of frequency from the substations calculable for total load?

These two tasks were attempted to obtain a configuration value when the automatic low frequency tripping had been observed. To evaluate this system model, interviews were conducted with a number of operators. The perspective of this investigation was qualitative, which would generalise the availability of such configuration values, in order to apply this theme in the proceeding AI based power system.

The procedure was begun at investigating HE' System Operation Memorandums. Access to Pitlochry Control Centre was permitted to do the work in June 1995 and Nov 1997. The participants in the tasks were Ian Moyes, Mathew Kelly, John Point, Walter Campbell, and Jim Murdoch. The tasks were focused on operation of automatic low frequency tripping.

The methods to collect such data were based on observations of Inverness area control, Scotland, from the post SCADA data and interviews. Specially, the interviews conducted in the tasks fall into the following discussions:

Agenda: Standing Instruction to low frequency control

- Discussion 1. Automatic load shedding will be carried out in planned stages of 48.5Hz, 48.3Hz, 48.00Hz, and 47.6Hz by the operation of low frequency relays.
- Discussion 2. Inverness Area Control will shed load in blocks at 48.5Hz, 48.3Hz, 48.00Hz, and 47.6Hz to control the system frequency unless automatic relay disconnection has not already taken place at the prescribed frequencies. This action will be carried out independently and without reference to system control.
- Discussion 3. Inverness Area Control will arrange attendance at all or as many bulk supply points as possible.

In respect of these three discussions, the collected data from the post SCADA data were examined, as follows:

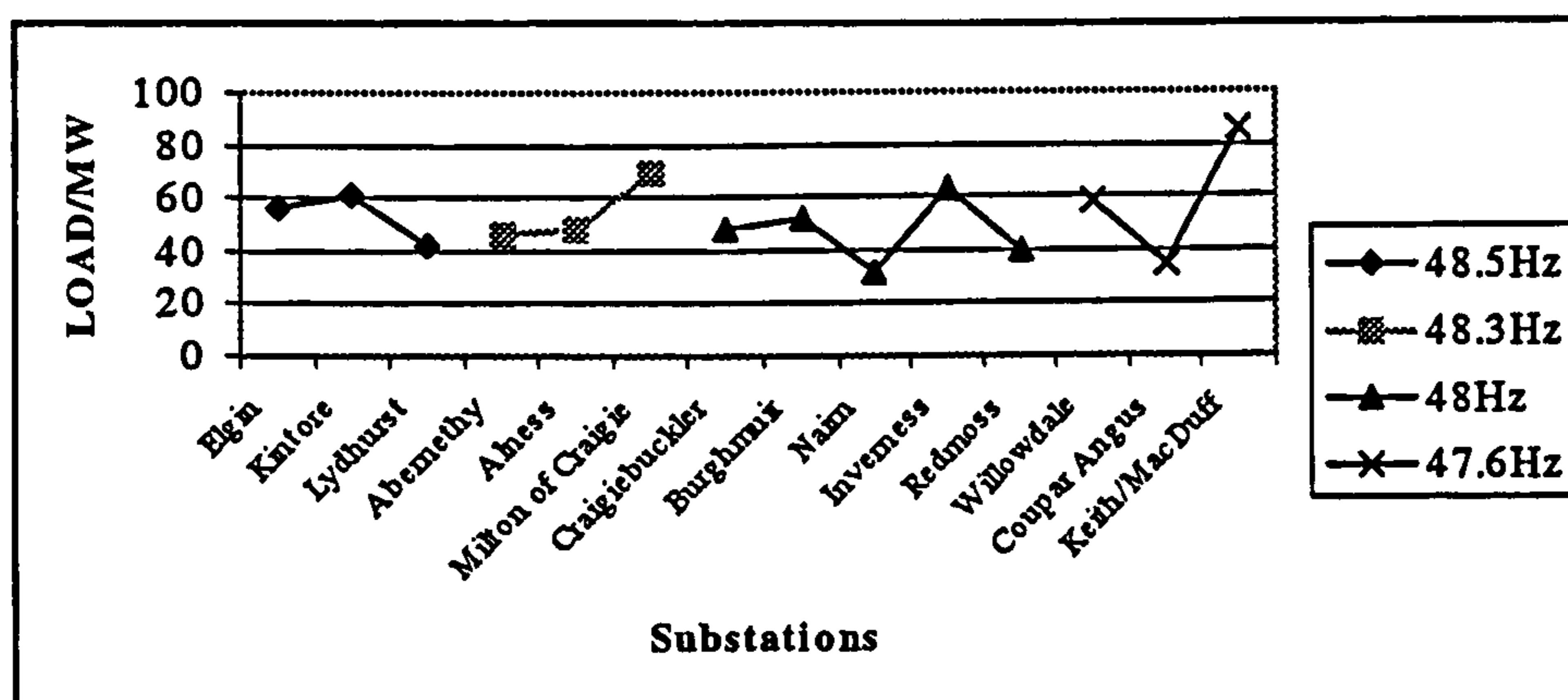


Figure 17 Action to be taken for a fall in frequency below 48.5Hz

Figure 17 shows that different substations are subject to peak load in the frequency range. The bulk supply points are controllable according to operators' heuristic knowledge where the load shedding can be carried out by manual switching from a remote point.

In respect of discussion 3, the results of simulating the frequency deviation indicate that operators need a human-factor-oriented system which will help them for controlling the load reduction. The range of frequency deviation can be applied to determine what circuit breakers should be controlled by remote switching in order to provide as many bulk supply points as possible.

4.6.1 Fault types

There are various types of faults that occur on transmission lines. These are required in the power system simulation. The fault types on 132kv transmission lines are segregated, as follows:

- ❖ Line-to-line fault
- ❖ Three phase fault
- ❖ Busbar fault
- ❖ Circuit breaker fault
- ❖ Relays fault
- ❖ Three-phase to ground fault
- ❖ Single line-to-ground fault
- ❖ Transformer fault
- ❖ Overload

These types are the protective devices tested by the diagnostic system in the proceeding chapters.

4.6.2 The line length

The 132kv transmission lines vary dependent on area in length. The construction of these transmission lines is a major undertaking, as routes pass through some of the most inhospitable territory in Britain, including the Corrieyairack Pass at 764m above sea level and the Lecht Pass at 661m. The overhead 132kv link supplies Skye; the sea crossing of the narrows at Kyle Rhea being made by cables strung between a giant pylon at either side. In this thesis, the core part of the simulation is based on the application of operators' heuristic knowledge where the line length needs to be inferred for fault identification.

4.6.3 The line reactance on line voltage regulation

There has been previous empirical study of co-ordinating protective relays for complex HV transmission networks. Aggarwal and Johns (1997) describe the process of generating relay setting using an expert system [Warwick 1997]. The system consists of relay setting rules.

These rules are to check the settings during the co-ordination process, and readjusted if necessary, to avoid improper relay operation due to the possible existence of forward lines which might be too short. On the basis of this, they report that the designed ES is very flexible in that it can accept any network configuration with arbitrary complex interconnections. This comprises a backward chaining inference engine and a hybrid knowledge base of rules and frames.

The clarification of these zone co-ordination rules may improve the operation of distance protective relays, but the cause of the improvement stems from uncertainty of the SCADA data acquisition. This suggests that all the necessary data are subject to acknowledgement before employing the mathematical based expert system.

In this respect, distance relays are most difficult to set in that they require heuristic knowledge. The current thesis investigates this premise of uncertain messages from the relay setting when such a non-mathematical modelling is required.

4.7 Practical considerations in the design of alarm processing and fault diagnosis system

Designing alarm processing and fault diagnosis system should be close to those experienced in practice. In this respect, the power system topology from the SCADA system is considered as the most appropriate and economic method. This is because the fault arrangement from the topology provides more comprehensive faulted feeder, as prescribed by [Lee 1996]. The design implemented in association with the alarm processing and fault diagnosis has attempted two requirements, as follows:

- 1) Consideration of alarm prioritisation for the view of operators
- 2) Consideration of decomposing uncertain alarms for fault diagnosis

The design of these experiments is based on the premise that operators will have more efficient time to control alarms if the diagnostic system provides reliable and faster solutions equivalent to that of the domain experts, under time pressure.

4.7.1 Primary system waveforms

The primary system waveforms are to determine the associated voltage and currents in the faulted feeder. They are the following complex relationships by R Aggawal[Warwick 1997]:

- Changing power system operating conditions such as changes in load or generation and changes to the topology of power systems
- Various power system configurations such as untransposed/transposed, horizontal/vertical, single/double circuit lines, and etc
- Many different fault conditions, including fault inception, fault location, fault types and fault resistance
- Inaccuracies caused by voltage and current transducers or noise introduced by electromagnetic interference

These problems are compounded by their random nature, which involves in choosing voltages, currents and their transients as inputs. The outcome of these system waveforms can be useful if their source values are available. However, for the nature of time consuming using the primary system waveforms for an AI based power system, this thesis attempts only available source values to the developed system using telemetry systems.

4.7.2 Fault inception time identification

Fault inception time identification is concerned with discerning abnormal currents and voltages. This includes an induced frequency and a deduced magnitude of the power frequency components in the voltage waveform, and sharp increases in the currents are clearly evident. Figure 18 illustrates a typical voltage and current waveforms, as follows:

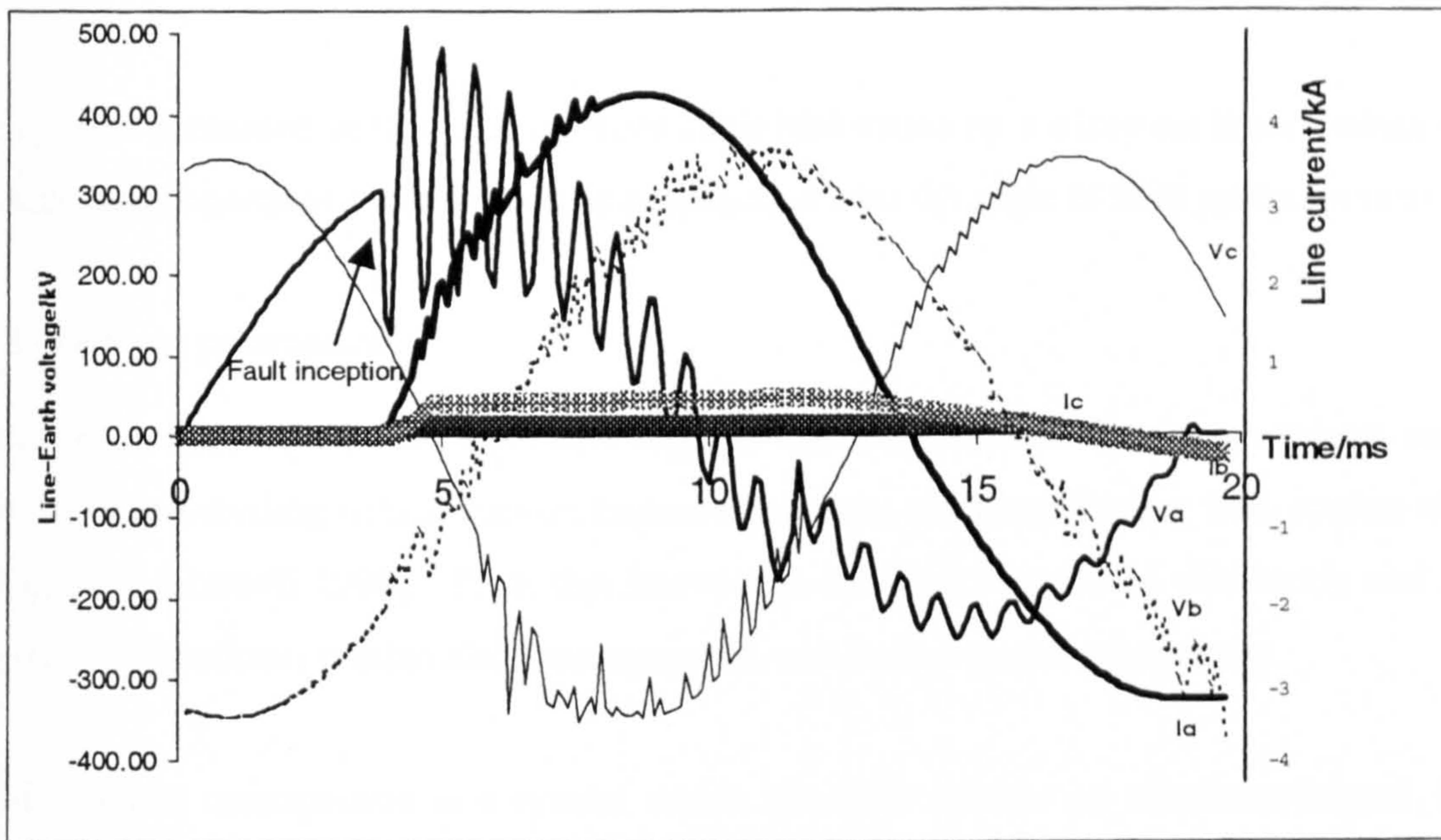


Figure 18 A faulted voltage and current wave forms in 400kV transmission networks

Note:

The output of A/D(Analogue/Digital) voltage and current waveforms for

Va,Vb,Vc: The three phase voltages

Ia,Ib,Ic: The three phase currents

This picture demonstrates many causes of faults using some A/D sensors, which constraints the protection system may maloperate such as over-reach or under-reach in a distance relay under certain conditions. Since digital technology has emerged in 1980s, these signals can be converted combinations of pulses, such as letters, words, or numbers. These data can be expressed in binary or binary-coded decimal notation. For example, a transmission line carries currents that consists of the following conversion:

Before outage:

$$\text{Reactive} = 400\text{kv} \times 4\text{kA} \times 1 (\text{at } \sin 90)$$

$$= 1600\text{kvar}$$

After outage:

$$\text{Reactive} = 400\text{kv} \times 3\text{kA} \times 0.93 (\text{at } \sin 70)$$

$$= 1116\text{kvar} (\text{fault location ratio} = 1116/1600 = 0.69/69\%)$$

The binary notation in the fault detector/telemetry system will be: $69 \Rightarrow 1\ 0\ 0\ 0\ 1\ 0\ 1$

The system presented in this thesis utilises such fault ratios by a fuzzy set theory when such distance relay operations malfunction, in conjunction with the angle of fault inception time.

4.7.3 Message prioritisation

Discussions with experienced operators suggest that the nature of the alarm analysis task is different when dealing with alarms on faulted equipment and when dealing with routine alarm traffic, says [Russell 1996]. Thus, this knowledge model is considered differently and falls into two applications; routine alarm management, and faulted alarm management.

Routine alarm management is a system which identifies circuits on unacknowledged. Four significant categories are suggested in the following ways:

- **RED:** Circuits which are live and have standing unacknowledged alarms;
- **AMBER:** Circuits which are live and have standing urgent alarms;
- **YELLOW:** Circuits which are live and have standing non-urgent alarms, and circuits which are deenergised for operational reasons and have any alarms acknowledged or unacknowledged;
- **GREEN:** Circuits which are dead and released for maintenance, or on which the engineer has suppressed alarm status;

The objective is to minimise the number of circuits in the red and amber categories. Faulted equipment alarm management is based on the need of outside advice before reenergisation, i.e. senior operators' opinion, field engineers' assistant, and fault recorder on the feeder. For HE' own experiment, a pilot study scheme was launched, as follows:

- **RED:** Faulted circuits which have standing protection operation alarms;
- **AMBER:** Faulted circuits which have standing non-urgent alarms;
- **YELLOW:** Faulted circuits which have standing urgent alarms;
- **GREEN:** Faulted circuits which have no standing alarms;

The system appears to be quite successful as the operators can monitor which alarms are mostly urgent. A key knowledge to develop further usable system is required such as employing character string recognition or topological transmission network representation. The key knowledge associated with these circuits must be available that falls into the following:

- Are the circuits live?
- What circuit is the alarm related to?
- Has the circuit tripped?

These factors are not easily interpreted with the existing SCADA database. The alarms were associated with nodes on the network. These three questions of the inference chain are designed and discussed in the proceeding Chapters.

4.7.4 Message synthesis

Message synthesis on the SCADA system is to provide alarm messages for power system operators in an ordered and logical form. [Warwick 1997; Dillon 1990] prescribes that the decomposition of alarms falls into seven categories, as below:

- Routine alarms
- Known fault alarms
- Emergency alarms
- Alarm equipment failure alarms
- Repeated alarms
- Sympathetic alarms
- Network circuit breaker alarms

These categorical messages can be developed individually in an AI based alarm processing system, but were studied to design an effective alarm synthesis system which consists of eight topological protection systems, i.e. “CB_INDEX”, “TYPE”, “EL_LIST”, “SORT”, “PHASE”, “CB_NO”, and “STATUS”.

The tasks were based on the power system changes of how the message synthesis status of relay operation and circuit breakers' operation has responded to a particular outage, in association with the conventional SCADA message processors. Some criteria of implementing these tasks were taken into account, as follows:

Criterion 1. Does the power system changes correspond to the simplified feeder?

Criterion 2. How much is the topological feeder representation effective against the proposed categories?

The procedure was carried out to test a performance of the developed message synthesis system. [Lee 1996] who has employed similar topological feeder knowledge representation that supports this method. His developed system was based on the conventional network circuit breaker alarms which present status of substation faulted feeder. However, the developed message synthesis was based on the simplification of alarm processing to the following requirements:

- Series equipment should be identified
- Status of relays' operation should be presented
- Status of circuit breakers' operation should be available
- Quantitative sources on the protective equipment should be available

The results are based on each requirement which was allocated to the two criteria, as follows:

Primary source used	Serial equipment	Status of relays' operation	Status of circuit breakers' operation	Quantitative sources	Actual performance
Minor alarms	100.00%	93.75%	90.63%		94.79%
Non_urgent alarms	100.00%	96.88%	93.75%		96.88%
Urgent alarms	100.00%	90.63%	100.00%	87.50%	94.53%
Means	100.00%	93.75%	94.79%	87.50%	95.40%

Table 8 A sampling test on alarm message synthesis of N=8 against independent variables

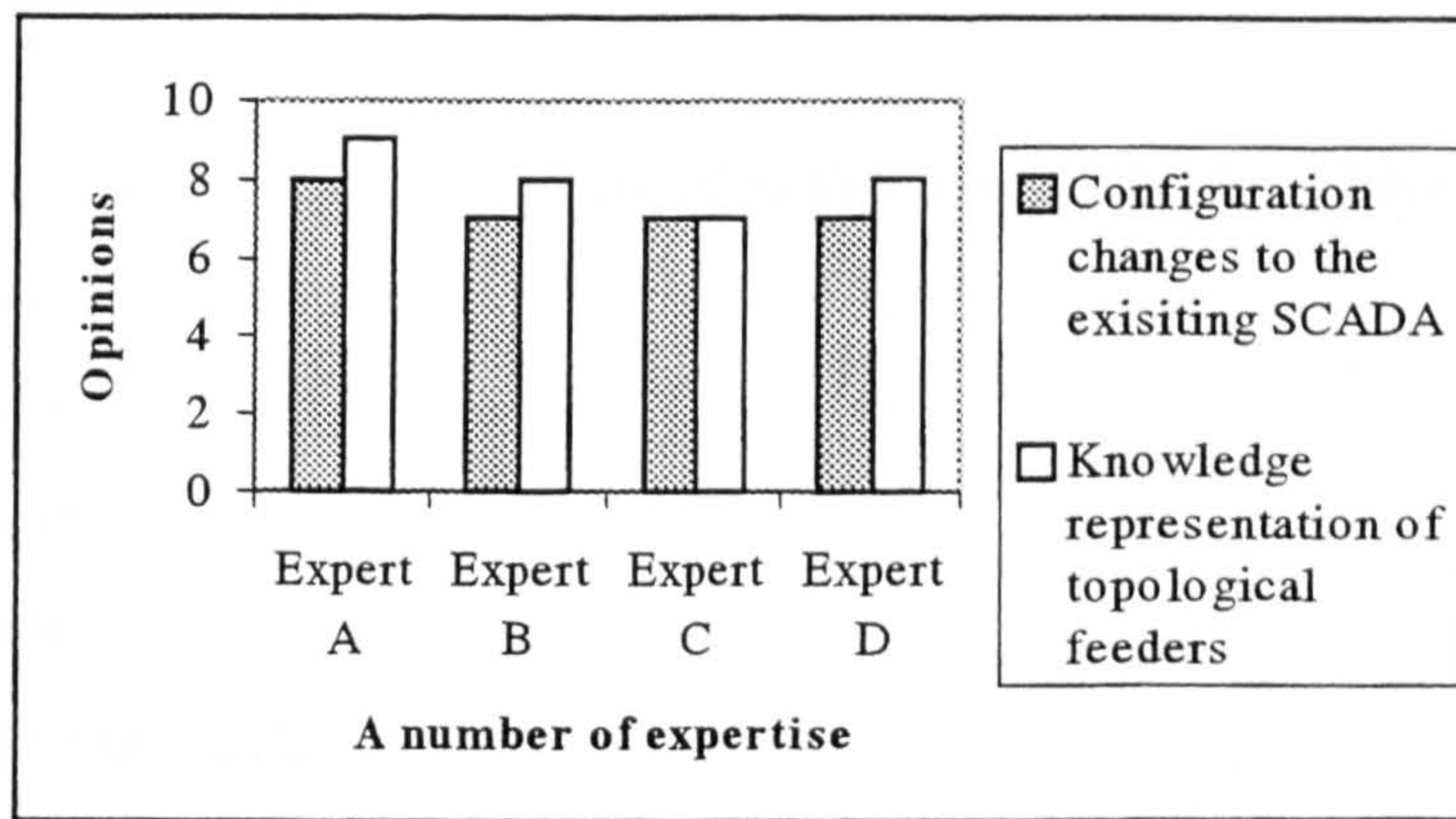


Figure 19 An assessment of the object-oriented alarm synthesis

Table 8 and figure 19 illustrate the performance of the message synthesis based on transmission networks. Table 8 was based on 8 different alarm categories which were tested to the three alarm types. The criterion 1 and 2 were applied to the four different expertise's opinion/ $N=4$. Individual requirement was implemented against they respond to the criteria of the message synthesis.

4.7.5 Process of multiple simultaneous events

The process of multiple simultaneous events is quite possible to occur on the power system network, which has been proved by severe weather conditions. The power system is subject to many fault outages for a short period. It is essential to perform analysis of several events at the same time, which will reduce a delay of operators' workload.

In this respect, alarm management should not adopt a serial approach to its analysis of events, instead, should adopt a parallel approach. This means that at any time during the operation of the alarm processor will hold several analyses in progress, with new ones being formed, and old ones being completed as time goes on. This is supported by [McDonald 1997], who claims that "If the alarm processor were not able to progress the analysis of several events at the same time there would be very significant delays before it produced any messages on the operator's console".

The forgoing problems are taken into account in conjunction with the diagnostic system presented in this thesis.

4.7.6 Fault type classification

Various types of fault classification are simulated in a power system. There are some faults that occur on transmission lines, as below:

- Three phase fault
- Three phase to ground fault
- Line to line fault
- Single line to ground fault
- Double line to ground fault

These outages fall into two distinctive faults, faults involving earth, and faults not involving earth. First, faults involving earth provide the travelling waves shorter. Second, faults not involving earth persist considerably longer than the former. The developed system utilises this knowledge and is subject to the available information provided by system analysts. A sample system was simulated to utilise these configuration values in this thesis, as follows:

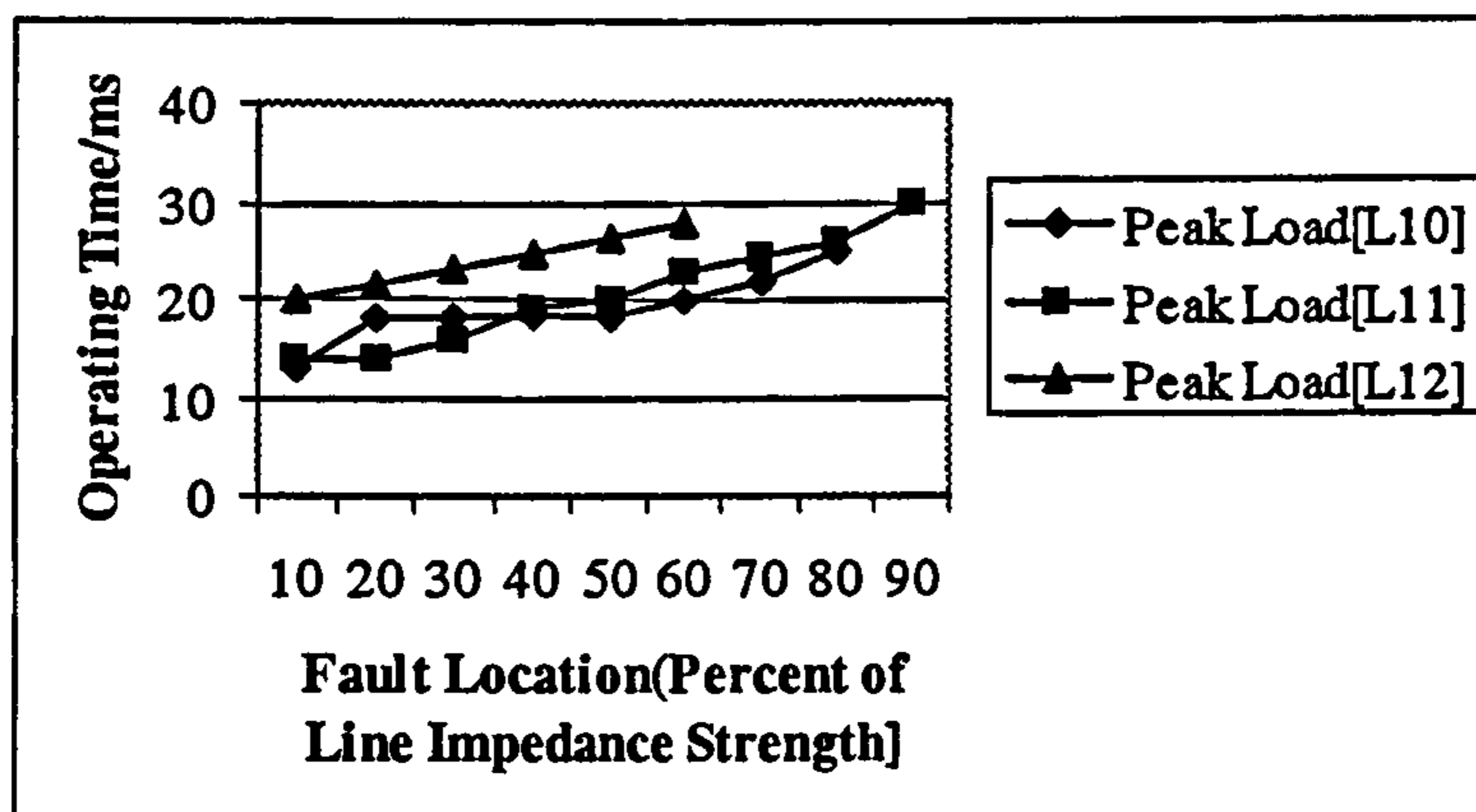


Figure 20 Feeder-to-Feeder element

Figure 20 illustrates that faulted lines were measured by a line fault detector which is based on faulted line voltage measurements employing transient fault scheme. At the same time, the line impedance was determined whether these lines are open, by the circuit breakers.

4.7.7 Relay setting parameters for distance relays

Distance relays are the most difficult to set, but in respect of time response requirement, it is not critical [Dillon 1990]. They employ non-unit measurement and require a multiplicity of

settings by expertise' knowledge. This is prescribed by R Aggarwal[Warwick 1997], who has summarised the following relay setting parameters:

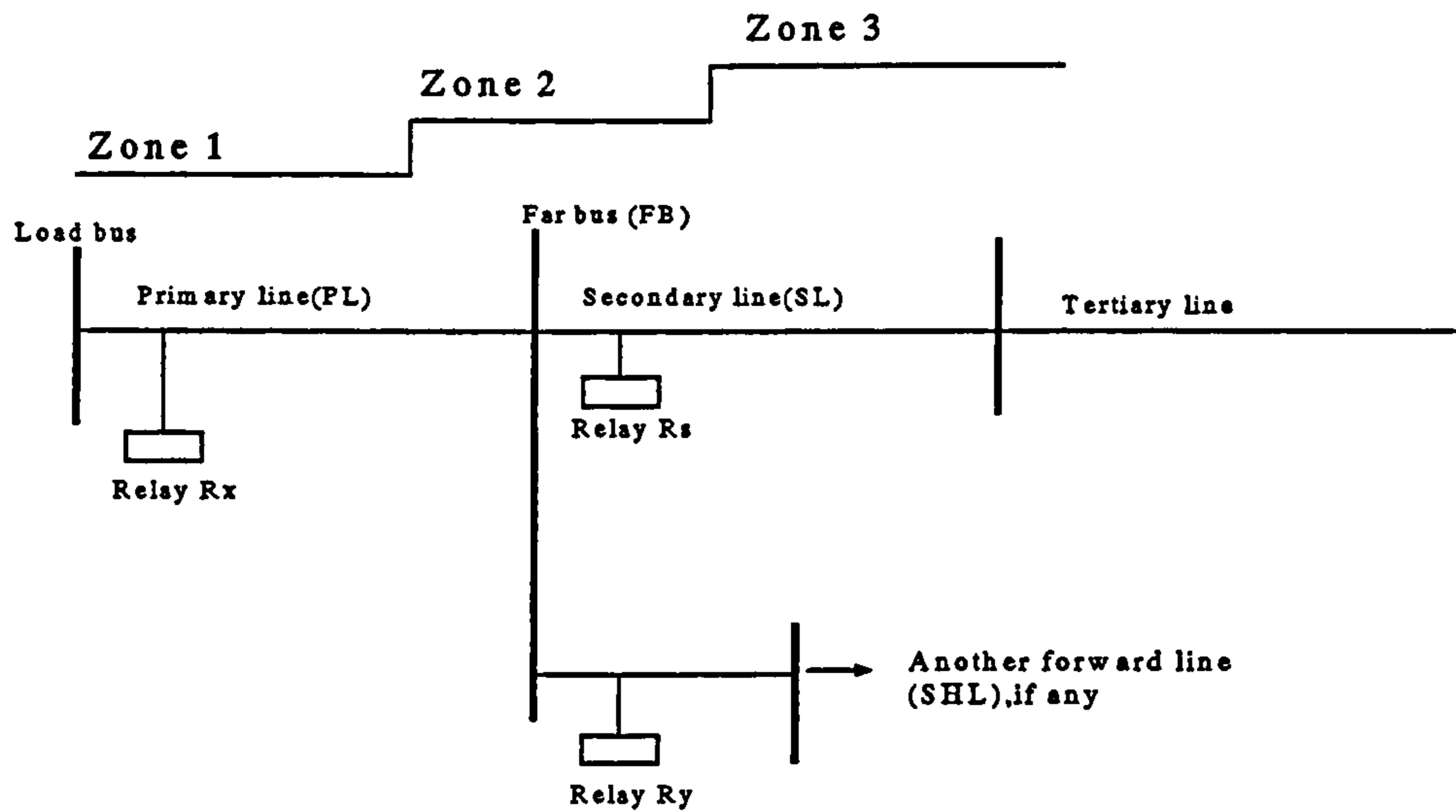


Figure 21 A model of relay settings for distance relays

Figure 21 illustrates an example of the dispersing plan for a transmission networks. The normal zones Z1, Z2, and Z3 operate independently from one another. The zone 1 is normally selected for the first 85% of the line length and operates at the time delay of 0.02s-0.03s. The subsequent stages of the delay time are increased by one grading time unit which covers normally between 0.3s and 0.4s. The reach setting is selected to provide 80% of the equal time stage for the next line section. For instance, the setting values for relay Rx would be as follows:

$$\begin{aligned}
 X_1 &= 0.85X_p \\
 X_2 &= 0.8[X_p + 0.85X_s] \dots\dots\dots 22 \\
 X_3 &= 0.8[X_p + 0.8(X_s + 0.85X_t)]
 \end{aligned}$$

Where X_1, X_2, X_3 are the reach settings for the normal distance stages and $X_p, X_s,$ and X_t are the reactances for primary, secondary and tertiary lines. The problem is that of the available reactances of the transmission networks as the network configuration is subject to heavy period of alarm processing. A sample system was attempted, as follows:

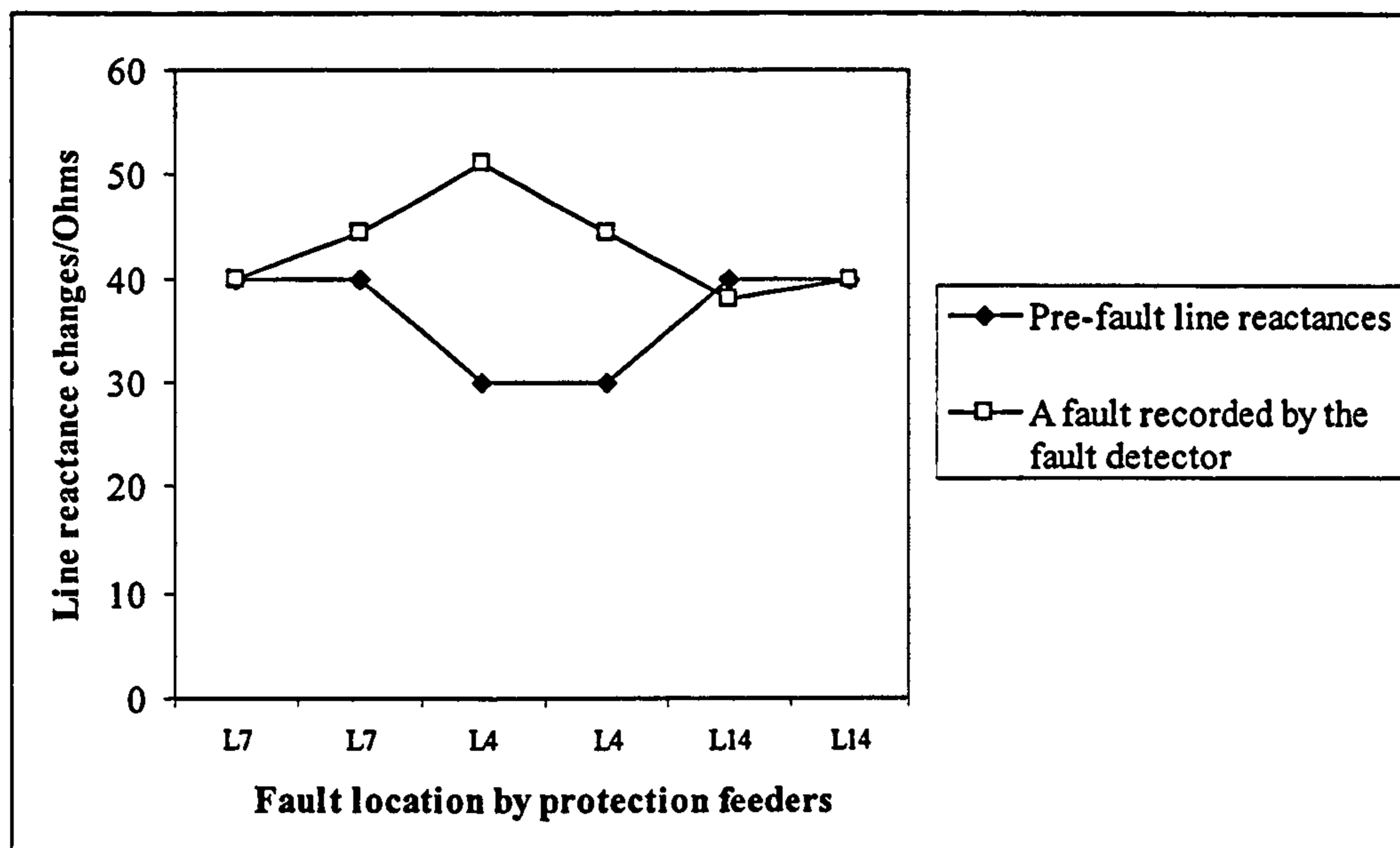


Figure 22 A sample simulation for relay settings between pre-fault and a fault recorded by the fault detector

Figure 22 shows a distance relay operation for the fault location suspected. For the distance element tests, a fault was applied at a location representing the reactance of the Zone 1 relay reach setting over the protection feeders. The experiment was performed for source impedance ratios between 30 and 40. The operating time include output contact closure time, provided that no pre-fault load current was included and system frequency is 50Hz.

However, the diagnostic tool presented in this thesis attempts to obtain the fault location of these relays employing an over-all discrepancy of the fault location, which will be discussed in Chapter 5.

4.7.8 Relays studied

Relays operate at the time scale of electromagnetic transients, and needs a reaction time in the order of microseconds. Power system operation varies depends on the state of the system. This system necessitates its relevant methods of forecasting and planning. These methods are applied to a wide set of measuring data for the real-time, which provides strictly defined intervals of time. The methods are very useful to determine faults of relays on the power system, but there are problems where obtaining these data are not always available within a

short period of time. The following operational categories were reviewed in association with various relays:

- Over-current protection;
- Feeder protection;
- Voltage and frequency protection
- Bus differential protection
- Transformer protection
- Capacitor bank protection and control
- Generator protection
- Transfer schemes
- Line protections
- Synch-check relays
- Motor protection

Over-current protection provides directional three phases and directional ground OC time. The directional elements may be set to directional or non-directional. Both of time and instantaneous over-current protection are provided, including auto-cold pickup detection, fast bus trip logic, and breaker fail logic.

Feeder protection provides a full-featured distribution feeder protection scheme which includes phase and ground over-current, negative sequence OC, reclosing frequency based load shedding and restoration, fuse fail, breaker fail, and panel metering etc.

Frequency and voltage protection is concerned with creation levels of over/under frequency with under-voltage inhibit, which consists of a versatile relay. This provides 2 levels of over/under frequency, 2 levels of over-excitation, 2 levels of over/under r.m.s. voltage, plus positive, negative, and zero sequence over-voltage elements.

Bus differential protection is to provide a scalable, modular low impedance bus differential system that:

- Accommodates any number of supply lines and feeders

- Accommodates single bus and double bus applications
- Provides an optional third, overall, check bus zone of protection
- Provides automatic CT saturation detection
- Provides automatic bus reconfiguration
- Offers programmable dual slope differential elements

Transformer protection provides 5th harmonic restraint, restricted earth fault scheme, sub-cycle trip times, and oscillographic capture. This also combines phase and ground over-current, thermal image, unbalance, I²t inrush protection elements, and breaker fail logic.

Capacitor bank protection and control is an impedance based capacitor unbalance relays that also serve comprehensive protection and control. This monitors the impedance of each phase of the capacitor bank in order to avoid the problems with capacitor failures which are distributed throughout the capacitor bank. These distributed failures mask the steady state over-voltages in the capacitor bank by balancing the unbalance.

Generator protection provides different systems, islanding conditions, reserve power, under power, loss-of field, negative sequence over-current, thermal image trip, instantaneous over-current, breaker failure, time-over-current, voltage-dependent time-over-current, positive sequence over-voltage, and two levels of frequency elements. Thus, So to speak, these relays monitor the bus and generator voltage, frequency, and phase angle and provides automatic control to the generator's governor and voltage regulator to bring the unit into synchronisation and initiate breaker closing.

Transfer schemes are to implement the over-current protection of two feeders connected by a tie breaker which performs the automatic transfer to the second source when the voltage is lost in the primary feeder. As complements to the standard scheme, synch-check elements may be added to any or all breakers.

Line protection relays usually provides 3 forward zones and one reverse zone of mho element based line protection, ground directional over-current, 4-shot reclosing, residual zone over-current elements, over-and-undervoltage protection, fuse failure and breaker failure.

Synch-check relays are to provide permissive synchronisation with one or two lines against a common bus. They check the voltage, frequency, and phase angle displacement between each line and the bus. For example, when the values are with the set parameters, the relays provide a contact output for permissive breaker closing and also provides the contact output for dead line and dead bus operation.

Motor protection relays are to inform thermal overload, unbalance, locked rotor, ground fault, no-load run, starter sequence control, and thermal probe (RTD) input. A relay provides differential protection for rotating machine including both motors and generators, which also serves protection against two or three-phase internal faults, inter-turn faults, and ground faults in equipment with low-impedance or solidly grounded neutrals.

4.8 Summary

The simulation of power systems and applicable systems has shown that the outages relating to transmission networks could be developed in conjunction with an AI based power system. This AI based power system will be based on the availability of how to provide an observed configuration on the transmission networks. Many different fault simulations were reviewed in order for the AI based power system. A common justification for the AI based power system was considered, as follows:

- 1) An effective topological knowledge acquisition on the feeders will provide readable transmission line identification.
- 2) A source configuration will enable users to enhance the developed diagnostic system in comparison with their heuristic knowledge.
- 3) Message prioritisation theme will provide operators to comprehend overall power system status and be implemented in the AI manner.
- 4) Process of multiple simultaneous events will help operators when a heavy alarm period is going through.

These four themes are essential findings to implement a proposed system in Chapter 5.

Chapter 5: Object-oriented expert system based alarm processing and fault diagnosis

5.1 Introduction

The investigation described in the previous chapter found the feasibility of employing the power system elements' representation for designing an AI based alarm processing and fault diagnosis system in power systems. The topological power system design is generally based on the empirical studies reviewed by [Dillons 1990; Lee 1996]. This survey of empirical approaches, which compared the relative advantages of different fault arrangements, shows the power system topology from the SCADA system to have an effective data acquisition system as this controls persistent alarms and permanent alarms through operators' control console. Some researchers in power systems have studied a model-based system of this fault arrangement approach in conventional AI languages [Lee 1996; Dillon 1990; McDonald 1997].

A new methodology presented in this chapter is to implement the model-based system which promotes use of object-oriented programming and abductive reasoning, in conjunction with power system changes. The design of these experiments is based on alarm prioritisation algorithms of the SCADA messages which fall into two. First, the alarm information has been encountered before in the KBS. Second the alarm information where it has not been encountered before in the KBS. The experiments reported in this chapter address three claims from the expert knowledge based power system. They are demonstrated, by testing object-oriented representations to the power system topology, alarm prioritisation using graphical assimilation, and plausible interpretation of events and their explanations using abductive inference technique.

5.2 Reasons for using expert systems

Since an evolution of successful expert systems such as MYCIN for medical diagnosis has influenced various industrial sectors, recognising these successes by power system operators was motivated to investigate the application of ES to power system problems during the 1980s. Most of the work involved was based on the development of expert systems as an operator' aid in control centres for transmission systems operating under abnormal

conditions, prescribed by Liu C C (1992). This was implemented in a conventional AI language. Application of ES to power system protection has also been investigated since 1990s, but a few applications have been implemented to the requirements of relaying functions, discussed by [Lee 1996]. Current applications are focused on problems for which the time respond requirement is not critical, e.g. relay setting and co-ordination, high impedance fault detection, fault location, substation fault diagnosis, and power transformer fault diagnosis. Expert systems with knowledge consisting of if-then rules are known heuristic knowledge based system, as the principal advantage of rule-based formalisms is knowledge can be acquired from experts or experience incrementally.

Thus, these reasons using expert systems are to contribute usable, maintainable, and portable systems. Many recent expert systems are evolving from neither rule-based nor case-based reasoning to model-based reasoning.

5.2.1 Advantages of expert systems

As discussed by [Kandel 1991], advantages of expert systems are that of the following contributions:

- Usability in limited domains
- Solutions for consultation systems in limited domains
- Development of a prototype

Usability in limited domains is applied to problems that have limited-domains and well-defined expertise. For example, robot activities require the knowledge of a human expert. This is most likely to be accepted in areas that do not need extensive user interface.

Solutions for consultation systems in limited domains are most accepted if they critique the expert's conclusions rather than independent conclusions. Developing explanation facilities, the ease of knowledge acquisition, and making the users feel comfortable with the systems are major obstacles for consultation systems.

Development of a prototype shows whether the expert system is feasible and appropriate for one or two problems. Expert systems are evolving into more intelligent systems which will

handle larger domains and those with a large amount of uncertainty. However, they currently are not useful in the extremes of the two environments aforementioned.

In respect of these, the developed object-oriented expert system employing alarm processing and fault diagnosis in this chapter presents more effective and practical alarm management.

5.2.2 Drawbacks of expert systems

Drawbacks of expert systems in protection equipment failure and event diagnosis are that of handling uncertainty and imprecision from power system changes. There were several sources of uncertainty and imprecision investigated in conjunction with protection equipment operation. They fall into three fundamental parts, as follows:

- 1) Failure diagnosis
- 2) Event diagnosis
- 3) Guidance for preventive maintenance

First, failure diagnosis by the protective device has caused potential damage to the transmission lines when alarm activity is increased for a short period. For this reason, the expert systems in power systems would essentially be able to analyse an event on the system and provide a recommendation as to a course of action. The significant difference is that the relays on the faulted feeders have a small number of parameters to decide what operation will be taken during the short period of time, i.e. 0.02~2 seconds. On the other hand, with an expert system, there are fewer limitations in terms of the number of measurement parameters or length of time required for such a decision. The system must have an ability to recognise typical failure mode of various protective schemes. Three distinctive surveys were carried out, internal relay equipment failure, external equipment failure, and human failure in design or setting. The investigation of these three problems is discussed in proceeding sections.

Second, event diagnosis is concerned with identifying faults on power system protection. This protection system complies with a role of monitoring the primary plant, and the SCADA system monitors and switchgear activity. The latter makes power system faults possible to identify although the task is quite often complicated by the behaviour of protection, protection maloperation, and SCADA system equipment. Fault diagnosis includes the

identification of system faults, protection maloperation, switchgear maloperations and telemetry malfunctions. These problems are unpredictable, widespread, and fast. They could cause complex changes in the network.

Third, guidance for preventive maintenance is based on SCADA system technology, and the computer systems have generally been upgraded with the existing protection systems. These improvements involve more equipment to be wired into SCADA systems. The guidance for preventive maintenance addresses these system upgrades when the collection of data from adjoining power systems and independent generators

For these reasons, dealing with uncertainty plays a major role in conjunction with such problems, and the use of conventional expert systems in power system protection may produce imprecision and limit of knowledge representation as the principle beyond the design of ESs constrains these problems. There can be plausibly more than one possible answer, as below [McDonald 1997]:

- 1) Lost alarms: telemetry system malfunctioning might cause an alarm to be lost. On the other hand, a failed device might result in no alarm being received.
- 2) Limits of SCADA system: utilities might not have wired all relays into their SCADA systems. Thus, the evidence is therefore incomplete.
- 3) Protection relay characteristics: an operated relay might have detected one of various fault types and locations.
- 4) Protection relay failure: relays could fail, and it can be difficult to distinguish between correct and incorrect non-operation when no alarm is received in either case.

Having studied these problems, the work described in this chapter presents a way to overcome these disadvantages using an object-oriented expert system based alarm processing and fault diagnosis when non-deterministic decision making occurs.

5.3 Expertise based scheme

Since a number of possible partial failures together with the number of pre-disturbance plant outages are considerable, expert based scheme has made an effort to deal with this problem. The actions recommended in the system employ two methods, computer analysis, and

heuristic knowledge of previous power system failures. In particular attention was drawn to the requirement of the heuristic knowledge of previous power system failures, which is to trip or open all circuit breakers at substations where prolongation of the shutdown during the early stages of restoration could be caused by subsequent indiscriminate re-energisation, as follows:

- 1) Too large increments of customer load
- 2) Weather conditions
- 3) Feeders with large MVA_r generation capacity in excess of the capacity of the connected generation

These three causal factors require general knowledge facts to minimise a potential damage on power system protection. These rules by the domain expertise are programmable to a knowledge-based system which produces the advice of senior operators' knowledge. The essential investigation was focused on the available power system topology of HE transmission lines. The previous research work has been performed by staff at Dundee University and Scottish Hydro Electric PLC, Scotland and has resulted in a package Kappa-PC utilising object-orientation and topological power system modelling. The objectives of developing such a preliminary AI based system were to consider the following feasibility:

- Application of SCADA messages
- Knowledge representation
- Knowledge acquisition process
- Knowledge base design
- Object-oriented power system modelling

These experimental results express a desirable improvement in performance utilising reusability, and maintainability. An expert based scheme was attempted to test such desirable improvements, in conjunction with 132kv HE transmission lines. A prototype of KBS (Knowledge Based System) for HE SCADA systems is illustrated, as follows:

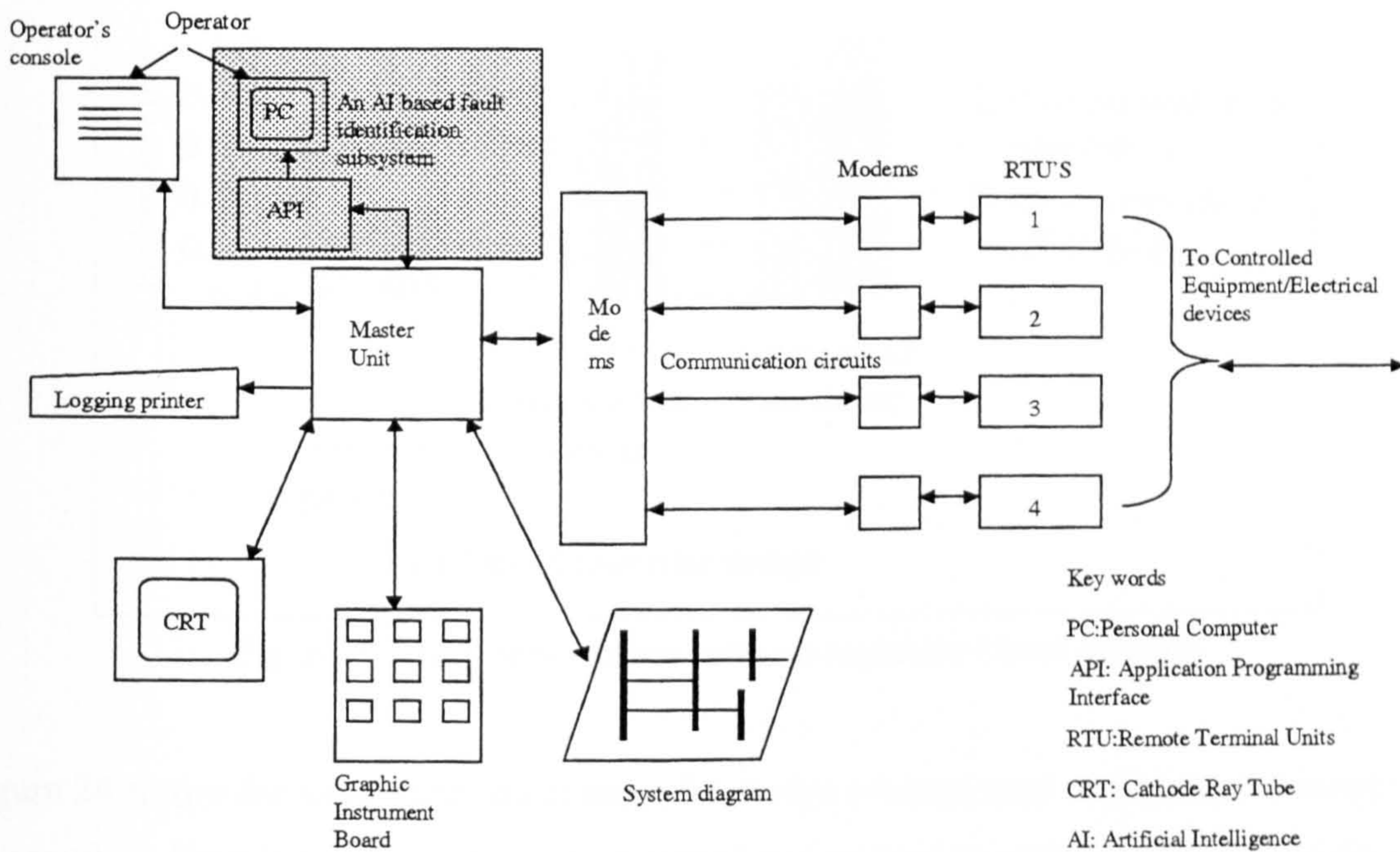


Figure 23 A prototype of expert based scheme to a SCADA system

This figure shows that the highlighted KBS shares a partial alarm processing which is composed of uncertain SCADA messages from outage areas. The objectives of the project are to build and enhance the preliminary AI based alarm processing and fault diagnosis system.

5.3.1 Performance

Performance was measured using three dependent variables. The first was the extensive object-oriented representation of the network that the alarm messages from outlying substations should correspond to the changes of power system on the developed tool. The second was the fault arrangement design that whether any unprocessed alarm stream is recognised to the topological protective equipment while the incomplete information is subject to further observation. The third was the degree of uncertainty when such outages are permanent or persistent, which employs certainty factors. This diagnostic tool utilises its graphical assimilation for the uncertainty process which deploys an inference technique, abduction, in order to determine best explanations.

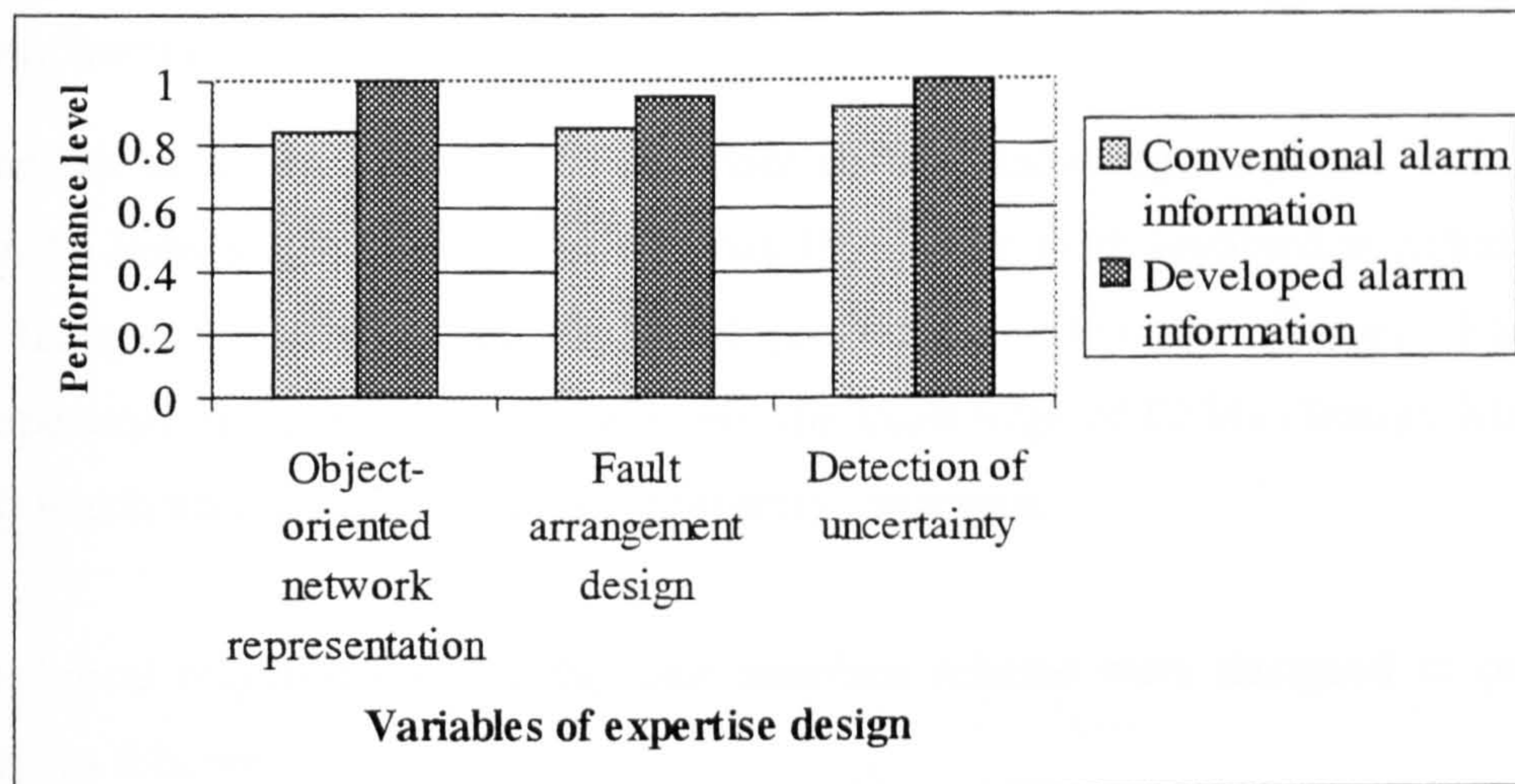


Figure 24 Key performance tests on expertise based scheme

Figure 24 shows the three variables of expertise design scheme were experimented employing 16 samples. Four levels of alarms were designed and applied to each requirement of the three variables to assess the two systems. The results indicate that the developed alarm processing system is well adopted, in particular, as there are two samples preferred by the participants, i.e. readability of power system changes, and explanation facilities.

5.3.2 Depth of analysis

Knowledge representation in power system protection was investigated that falls into two analytical methods, the minds of the experts, and a MBR (Model Based Reasoning) based engineering plant function. First, the knowledge of the experts was used in employing the traditional rule-based reasoning, which produces very reliable solutions to operators when certain events occur. Second, the MBR, which consists of the comparison between observed values and those values predicted by the model of expected behaviour.

These two analytical methods are called 'shallow reasoning', and 'deeper reasoning'. The shallow reasoning utilises pre-coded production rules from operators' heuristic knowledge. These rules of shallow reasoning consist of two models, distance relay operation, and fault diagnosis pattern table, in order to determine the status of their protective equipment. The two model schemes were capable of locating a faulted feeder which consists of such protective equipment. The deeper reasoning is attempted using certainty factors when the shallow reasoning can only suggest a suspected faulty feeder. The work experimented in the depth of analysis has resulted in a viable expert system approach.

5.3.3 User Interface

User interface is to provide both the end user and the knowledge engineer with means for applying the knowledge in the system [Lucas 1991]. The work involved is called a human-centred dialogue which was primarily developed for the wide range of users. For example, novice operators are able to learn effectively the knowledge of EMSs (Energy Management Systems) which was designed by senior operators' heuristics.

Some technical requirements for the user interface scheme were designed to perform the testability, as follows:

- Provision of "Why" facility; the best explanation is observed by the method of the generate-and-test, which is the function of explanation mode in the tool;
- Provision of "How" facility including Rule Editors, Methods, and Functions makes operators helpful;
- Capability of coping with parallel tasks enables operators to perform better tasks;

These three requirements were to obtain the following aims:

- the power system and SCADA system will react to the given situations
- they would interpret this information
- the alarm processor should report its information
- the form of its user interface should take a short period

An interview technique was conducted using these three requirements which were asked to different expertise whether the user interface scheme for the developed AI based alarm processing and fault diagnosis is generally accepted. The procedure was based on the identification of existing knowledge available within the control centre of HE PLC and other control centre such as KEPCO (Korea Electric Power Corporation), as follows:

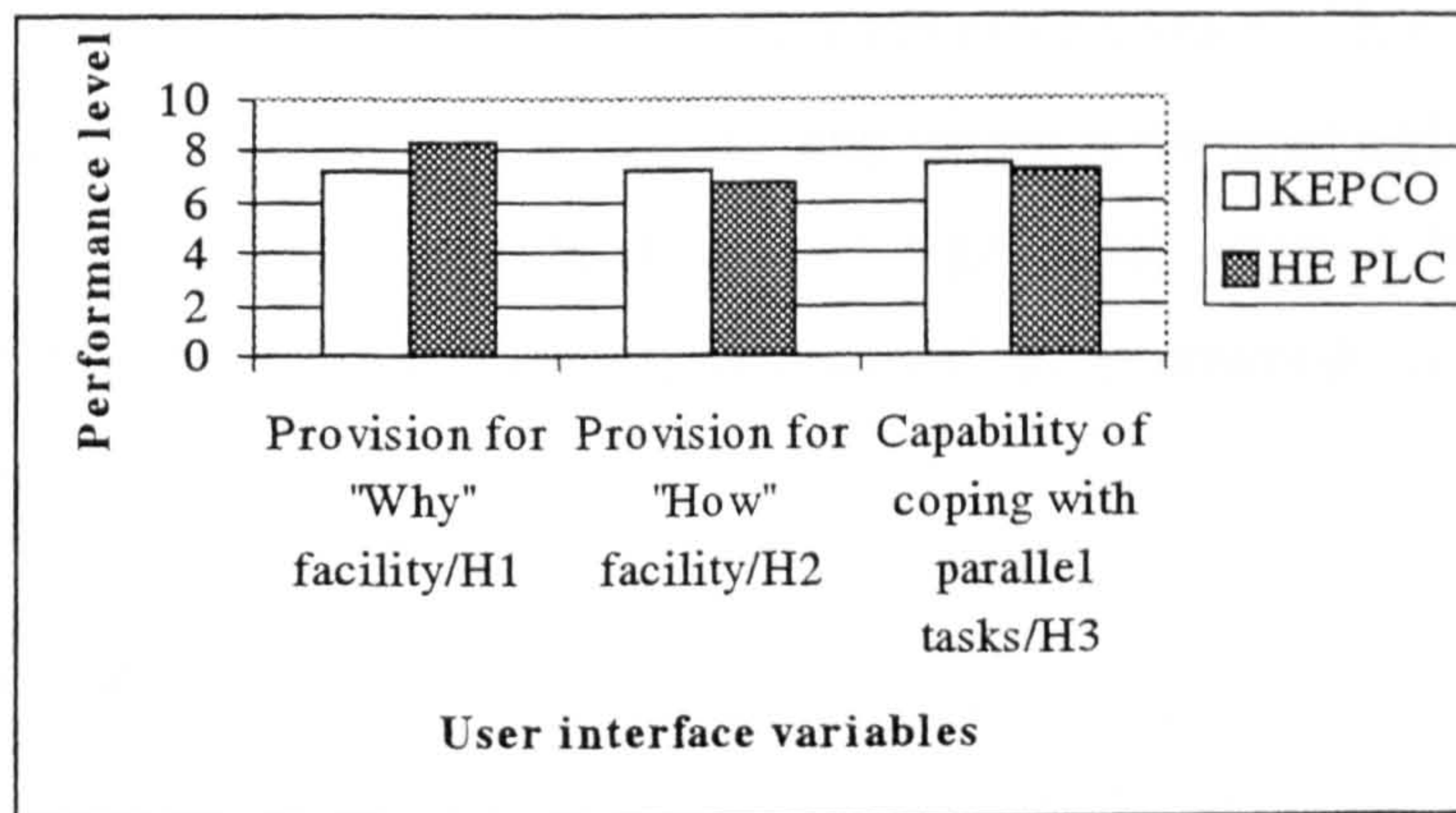


Figure 25 A survey of the developed user interface for alarm processing

Note: the performance level between 0 and 10 indicates that 100% signifies all tests satisfying to a given hypothesis

Figure 25 shows that two control centres were involved over the years of 1997 and 2000 to review these three hypotheses employing 13 questions. Four participants from each control centre were asked to test the developed system, as there are two fundamental factors to confirm.

First, operator based interviews provided a direct method which consists of extracted knowledge from identified experts through the formal question-and-answer session. Second, questionnaires were used to gather information from a group of experts.

On the basis of these opinions, the results of this survey suggest that these experts of two control centres share common requirements for a PC based alarm processing and fault diagnosis. These have shown an importance of user interface design which enables operators to process the relevant information for a solution.

5.3.4 Forms of message presentation

During the prototypes of the expert system, forms of message presentation were considered that dispenses into two, semantic interpretations, and symbolic processing. The former experiment was obtained that most participants were friendlier with textual formats rather than numerical values as this system is to assist operators when the period of alarm activity is high under the time pressure. The latter experiment was carried out that there were popular

demands where operators want to be able see an effective control. This is so that they can process of which alarms to look at first, whether any action is required and in what time scale. Thus, the effective symbolic processing will be a significant advance from the traditional systems. The work implemented in object-oriented programming is discussed in the proceeding sections.

5.4 Feature extraction

This section investigates the way that the features of an object-oriented alarm processing and fault diagnosis system presentation interact with operators during the design implementation. This system addresses some advantages using an object-oriented AI tool, Kappa-PC, i.e. reusability, extensibility, and maintainability.

5.4.1 Goal driven/backward chaining

The tasks were involved in an inference engine which tries to verify a fact (reach a goal) by finding rules which can prove the fact and then attempting to verify their premises. The premises in turn become new facts to be verified by other rules, and so on. In the AI based tool development, for example, backward chaining is used to determine the source of power system protection failure as a goal.

Participants in the control centre were asked to perform a task which consisted of several interview sessions whether capturing unstreamed alarms are adopted using the backward chaining. The criteria of designing the process in object-oriented manner were considered, as follows:

- Criterion 1. Does the power system change respond to the inference engine of alarm data acquisition?
- Criterion 2. Does the object-oriented techniques such as methods and functions fulfil the backward chaining process when the SCADA data are derived?
- Criterion 3. Is the acquisition of unstreamed alarm data consistent?
- Criterion 4. Is the backward chaining provable for new facts of the SCADA data?

These criteria were used to observe the benefits of employing object-orientation techniques and several points were attempted about backward chaining in general alarm processing, as below:

- ◆ The backward chainer requires a predefined goal.
- ◆ Goals are written in the Goal Editor.
- ◆ The backward chaining process is continually trying to satisfy the goal.
- ◆ Multiple pattern rules cannot be used with the backward chainer.

In respect of these, there are three phases available in the backward chaining process:

- 1) **Expanding:** occurs when the backward chainer tries to evaluate either 'if parts of rules' or the values of 'object:slot' pairs further in order to try and satisfy the goal. The expansion moves from left to right as you look at chaining as it occurs in the inference browser.
- 2) **Collapsing:** the goal is the process when the backward chainer tries to determine if the goal has been satisfied. The goal may have been satisfied by the recent addition of new facts caused by the expansion process. 'Object:slot' pairs and rules can be collapsed in order to satisfy the goal.
- 3) **Asking:** this is the phase where the backward chainer queries the user for the value of a slot once it has determined it cannot find that value on its own. The user is presented with a dialog box (if the slot has 'Allowable Values', these values will be presented) and asked to provide a value for that particular slot. (The user can also select 'Unknown'.)

The procedure was based on the utilisation of the editor functions which covered most advantageous design implementation. For instance, the functions provide an object-oriented hybrid system which falls into 13 parts; knowledge, math, string, list, logical, file, control, windows, user functions, classes, instances, rules, and goals. These were utilised to measure the maintainability of power system changes in the KBS (Knowledge Base System) modifiability when the backward chaining process acknowledges uncertain alarms.

The results of the requirements were responding accordingly to the pre-programmed goals of backward chaining editor. Having studied these four criteria in the tasks, diverse range of

requirements relating to alarm data was observed to the third option, 'Asking phase'. An experiment for the requirements was attempted, as follows:

- Based on the SCADA data acquisition of such abstract tasks observed in the questionnaires for the operators (Section 5.3.3.), the user-friendly interface should result in an interaction between finding rules and satisfying the relevant goals.
- On the basis of the previous research describing the use of object-oriented backward chaining for alarm processing and fault diagnosis system [Ramsay 1995], experimenting with the proposed task (Section 5.3.3.) developed a more usable system in the control centre.

Referring to the uncertainty task as aforementioned in section 5.3.4, the process of new alarm data should respond using backward chaining when the alarm prioritisation processor updates the change of the power system, as follows:

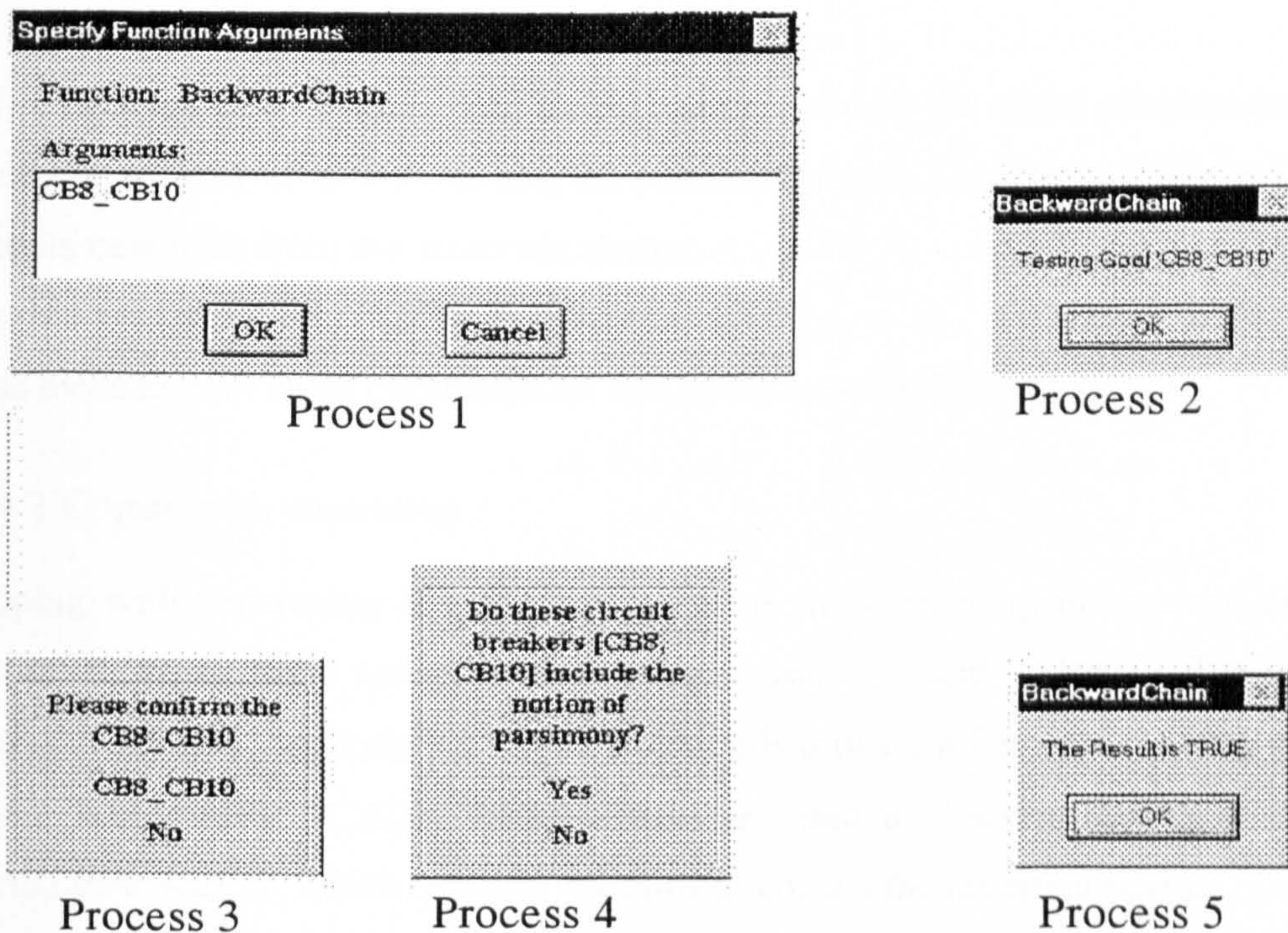


Figure 26 A backward chaining task completed in the diagnostic tool

Figure 26 illustrates a backward chaining task which is based on the feeder of CB8_CB10. This feeder information was provided by the inference engine which consists of abductive

reasoning. The experiment was attempted to obtain a result of uncertain SCADA data, and the inference engine searched for the rules using the backward chaining mechanism to resolve a goal. The goal was the uncertain SCADA data informed by the topological protective equipment which is composed of knowledge acquisition in the system. The results of these four criteria and the four requirements were implemented in the application tool that has conformed to the backward chaining task.

When participants had completed the criteria tasks, a debriefing questionnaire was asked to complete the results of how the experiments were resulted in, as follows:

- How easy it was to drive the process in GUI (Graphical User Interface);
- Which was the most difficult user dialogue to understand;
- Whether they felt that any persistent alarms can be solved using the GUI backward chainer;

How they felt that any uncertain alarms are captured by the alarm prioritisation process and then the goal driven starts inferring the particular alarms. Once trained by the KBS, the KBS adopts new rules from the uncertain alarms;

The evaluation of these questionnaires will be discussed in Chapter 7.

5.4.2 Coping with uncertainty

Coping with uncertainty is a fundamental issue in determining unstreamed alarm type and nature throughout the network. An operator may wait until he/she is able to establish the suspected area of network and further isolation before identifying the creation of the blackout area. The on-line SCADA system alarms are used to describe protective equipment and switchgear activity, which helps the operator to control the uncertain alarm.

In this respect, several tasks were carried out to design an expert knowledge based system using the application tool, Kappa-PC, in conjunction with substation operation. A major goal of designing this scheme was to assist operators when a heavy period of alarm activity is occurring. The tasks were based on the following criteria:

- Criterion 1. Does the qualitative simulation knowledge such as topological feeder index systems provide knowledge acquisition and less computation time whereas the computation time to calculate it requires excessive use of fault flows for every hypothesis?
- Criterion 2. Does the inference engine indicate the alarm to be uncertain?
- Criterion 3. Is the arrangement of the uncertainty consistent?

These three criteria were applied to assess some advantages of employing an object-oriented expert system. A number of points were attempted to test the following requirements:

- The inference engine should provide a form of alarm information.
- The uncertain SCADA data should include the information of tripped circuit breakers and relay operation in the system. For example, if the status of the breaker terminals is live on one side and dead on the other, then a new blackout area has been created.
- Does the operator understand the comprehensive power system changes when the uncertain data is outstanding in the inference engine?

These three requirements were classified as unaccounted scenarios. The procedure began at employing the use of the faulted feeder, including lines, buses, generators, transformers, loads, circuit breakers, and relays. This covered the three expected requirements as aforementioned, which was based on the process of eliciting the expertise. The process of coping with uncertainty was based on the following effective algorithm:

```
{ If Null?(Local:Expert rule1,2,3...n)
Then SetValue(Pattern:Alarm Summary,?);
};
```

This algorithm was tested on a symbolic process which consists of four categories, Urgent, Non_urgent, Minor, and Unknown. The information of the symbolic process, Unknown is concerned with uncertain SCADA data. Its GUI system is, as below:

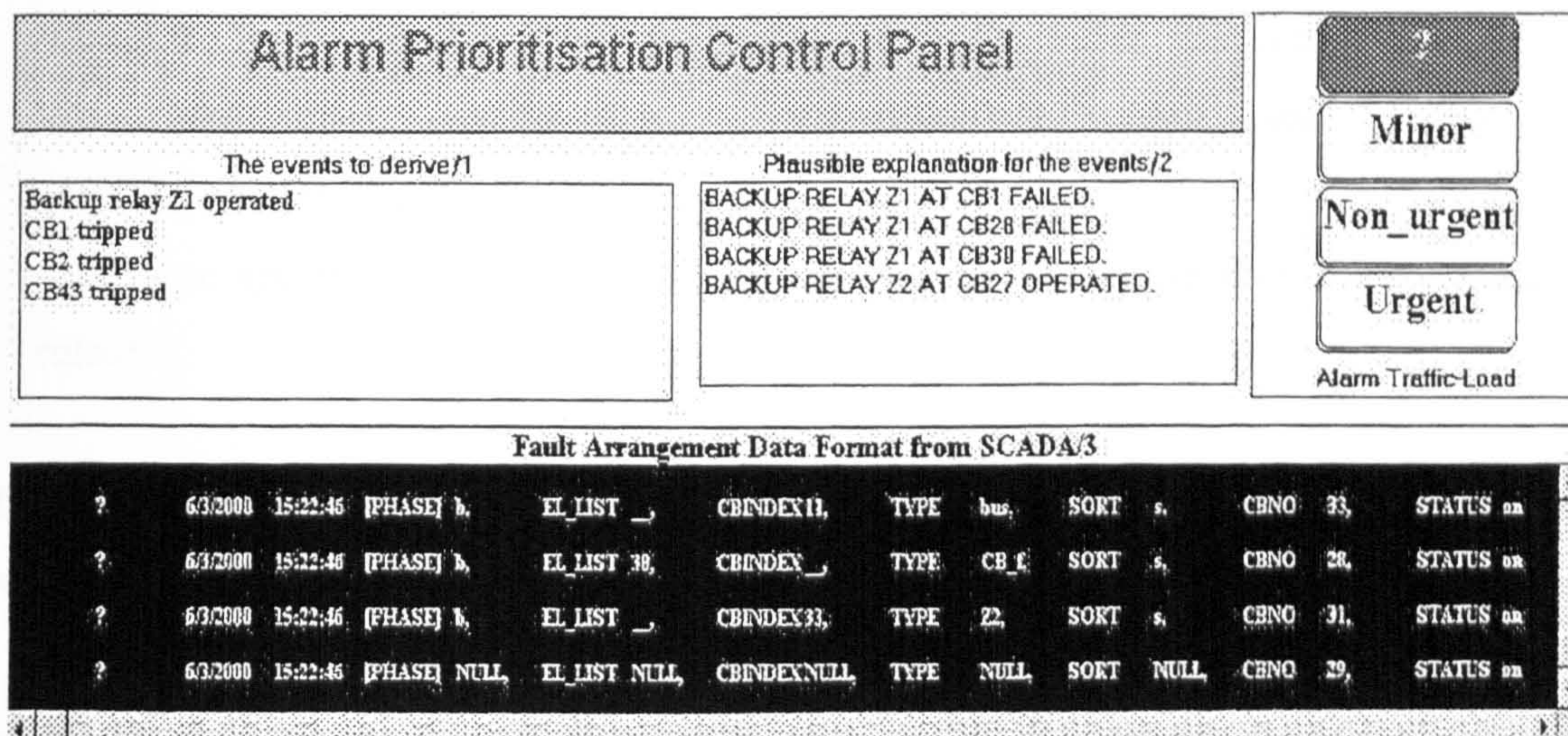


Figure 27 A symbolic process for coping with uncertain SCADA data in the developed tool

The results of determining uncertain SCADA data in the developed system suggest that previous studies of coping with uncertainty have been much emphasised on the form of message presentation which provides a single-line or multi-line summary [McDonald 1997; Russell 1996]. On the other hand, the results demonstrated in figure 27 attempts more effective alarm control whereby without looking at the alarm data the operator can assess which alarms to look at first. Also, this system provides whether or not any action is needed and in what time scale, from a single screen.

5.4.3 Data driven/forward reasoning

Forward reasoning is to initiate an optional goal which finally evaluates to TRUE or until both the agenda and the active rule list are empty. Before initiating forward chaining, placing an initial object:slot pair on the forward chaining agenda using the function 'Assert' is essential, or else use the '[NOASSERT]' argument to use all defined rules. However, operators are concerned with large alarm rules which consists of 7 different types, Routine alarms, Known fault alarms, Emergency alarms, Alarm equipment failure alarms, Repeated alarms, Sympathetic alarms, and Network circuit breaker alarms. These classified alarm messages provide complex nature of alarm management, which requires simpler alarm processing.

The related tasks were asked to the four operators and composed of the following questionnaires:

- Would the first successful alarm rule encountered be selected for alarm processing?
- Would the alarm rules be a conflict-resolution which could lead to inconsistent conclusions of the rules?
- Can more specific alarm rules such as prioritised rules be effective when adding new rules?

These three criteria were applied to obtain effective alarm processing, and four requirements were met, as follows:

- All the derived alarms should be acknowledged in a form of message.
- The object-oriented power system model should correspond to the alarm messages processed by the forward reasoning.
- Does the forward reasoning communicate with the designed power system model?
- Do the alarm rules read unique alarm IDs and produce a specific goal?

These four requirements were applied to test the three criteria in the developed system. These established tasks were measured in terms of number of opinions. The procedure started with deriving the unstreamed alarms from the simplified sample power system, which was shown to the operators by comparing the number of the SCADA data. These alarms were stored in the form of classes and instances and processed by the first requirement. The part of knowledge base, methods, functions was tested on the second requirement. The knowledge acquisition of power system changes was obtained and processed by the third requirement. During the search process, in respect of the fourth requirement, reading unique alarm IDs was tested using IDs of classes and instances, which resulted in consistent and specific goal and provided their explanations.

The process of forward reasoning was designed to the following effective algorithm:

```
{
If ( x #= 1,2,3,4)
    Then SetTimer( 1, 0, 2 ),(2,0,2),(3,0,2),(4,0,2)
PostBusy( ON, "SCADA message1 comes in 2 seconds!..." );
Wait(1.5);
```

```

    PostBusy(OFF, "");
    SendMessage( DBTable, Self_Change, Self_Change1, Self_Change2, Self_Change3 );
    SendMessage(Local, control_message,          control_message1,          control_message2,
    control_message3);
    ForwardChain();
    Busy_ON();
    Searching();
    ForAll [ Q|ALARMS ]
        SendMessage( Q, PrioritisationA, PrioritisationB, PrioritisationC, PrioritisationD );
    ForAll[p|ALARMS]
        SendMessage(p, Relay_StatusT);};

```

The results of testing this algorithm demonstrate that the forward chaining processes four different alarm messages using the GUI function, which combines 'Functions' and 'Methods' including 'TimerFunc' and 'SendMessage'. The forward chaining searches alarm rules and uncertainty employing symbolic process. This GUI function provides PLUGGED_IN SCADA connection and updates the KBS when the diagnostic system needs to be plugged in. The three criteria as aforementioned were applied to this algorithm and have resulted in reducing operators' workload when alarm activity is high for weather conditions and maintenance failure.

5.4.4 Data representation/knowledge acquisition

Knowledge acquisition is the process of eliciting and analysing the 'expertise' in a given application area which is the main activity of this system development. The expert's knowledge exists in chunks, which can be mined, represented as production rules, and hence seamlessly transferred into a rule base [McDonald 1997].

A number of knowledge elicitations are encoded into the diagnostic tool which is to ensure they stay within projected timescales and delivers reasonable results in condition monitoring. However, a few problems were raised during the system development. First, The lack of a shared language between the domain expert(s) and the knowledge acquisition engineer caused a delayed knowledge base design. Second, employing an appropriate AI tool and techniques

were discussed and often frustrated through a lack of mastering the tool and its project direction.

Thus, a structured approach to knowledge acquisition is likely to become more prevalent as the need for effective application and alarm management. For this reason, several tasks were implemented in that direction, as follows:

- Would the knowledge model assist the identification of power system changes?
- Does the data representation provide an inference engine?
- Does the structured archive carry consistent description of the expertise in the object-oriented alarm processing?

These three criteria were used to capture and retain valuable expertise when alarm messages are derived from the mainstream of the SCADA system. The knowledge archive is to communicate with the structured object-oriented power system model in conjunction with real-time transmission networks. This assists experts in expressing knowledge in a form for incorporation into a knowledge base to the following requirements:

- Is the form of object-orientation useful for knowledge archive?
- Does the object-oriented ID form deliver the contents to the KBS?

Testing these two requirements on the three criteria was carried out to observe some results. First, the designed knowledge acquisition contains another program and acknowledges the power system changes. This acts to acquire new alarms or rules to OODB. Second, the algorithm offers a mechanism for reasoning and provides the basis for the inference engine procedures in the developed system. The mechanism contains overall 480 rules including functions, goals, methods, and forward/backward coded rules. These two factors were experimented between the three criteria and the two requirements and four different SCADA data were analysed using these rules. The drawbacks are that of large rule bases which imply long inference time. This suggests that the usability is not appropriate during a heavy alarm period in order to produce speedy solutions. This means that the nature of analysing alarms is a critical area during the busy period such as the problems of cause-effect, implication, conflict, sub-sumption, unnecessary conditions etc.

In respect of this critical area, this diagnostic system attempts to improve the knowledge acquisition management employing a meta-knowledge system which is stored in the forward/backward coded rules. The symbolic process controls them. This knowledge acquisition interface provides unstreamed alarms that are captured and processed by the user interface, which will be discussed in the proceeding section of 5.4.5.

5.4.5 User interface

The user interface assists users by consulting the expert system, guiding them for necessary information required solving their problem, displaying the system's conclusions and explaining the reasoning [Warwick 1997].

In these respects, the relevant tasks were carried out to form a methodology, as follows:

- 1) Do these interfaces interact with a human expert?
- 2) Does the user interface provide effective control during the heavy alarm period?
- 3) Is the unstreamed alarms captured and shown by the user interface?
- 4) Can the unstreamed alarms be reasoned and added into the KBS as a new rule by the user interface?

These four criteria were considered that based on the following requirements:

- Does the GUI affect the users as a user-friendly system?
- Does the structure of object-oriented power system model respond to the user interfaces as designed?
- Does the usage of the SLOTT' values provide the displays of faulted feeders?
- Is the knowledge acquisition consistent to the user interfaces?

On the basis of these requirements, several specific procedures were used.

- i. Accessing to the control centre, at Pitlochry, was permitted to observe real-time SCADA alarm messages and action procedures against persistent, permanent, and transient faults.
- ii. These four requirements were evaluated by senior project operators and control operators who have evaluated various AI tools for a purpose of their own use.

- iii. They were given a pre-test and results that the project operators showed a high level of feasibility and the control operators showed a considerable level of feasibility with the concern of large alarm rules.
- iv. Both groups were given the developed system to assess its usability. In that the project/system operators carried out post-test, whose feedback appeared to be strongly consensus. The control engineers showed particular interest of symbolic process using the GUI system.

The data were analysed using several strategies against four SCADA messages. First, the data were chosen by the past events, which was available from the domain expertise. The events were applied to the criterion 3. Second, briefing the diagnostic system to the control operators was attempted to minimise a nuance of advanced technologies which could cause insufficient assessment. This task enabled them to evaluate the criterion 4. Third, the four SCADA messages were tested that was based on random alarm IDs in the tool whether the KBS were able to process any message synthesis on the user interfaces. The experiment was shown to the participants, which covered the criterion 1 and criterion 2.

5.4.6 Explanations

An explanation system allows the users to view the reasoning process of the KBS, which is very important to prove its credibility. The system provides a useful training tool for a new user. Several tasks were carried out to design a guideline of testing the explanation system. First, uncertain alarm data were based on the past events and identified after discussion with the operators using symbolic process. This provides knowledge acquisition was successfully obtained. Second, the explanation facility on the tool was pre-experimented before full implementation, which consists of “SetExplainMode()”, “ForwardChain(Goals)”, “BackwardChain(Goals)”, and “Explain(Object:Slot)”. These four tasks were applied to form the following criteria:

Criterion 1. Does the GUI-based inference engine provide the process of explanations?

Criterion 2. Does their forward chaining and backward chaining fire alarm rules?

These two criteria were used to assess reusability of the diagnostic tool against when uncertain alarms are concluded through the inference engine.

The experimental procedure was begun at collecting the four samples of the SCADA data under confirmation of the operators. The designed 'explanations' was tested on the object-oriented power system model. This model contains uncertain alarm data stored in the form of 'Classes' and 'Instances', which was tested by the four functions.

First, "SetExplainMode()" was applied to an uncertain alarm IDs whether an specific goal is driven by the function. The function, when invoked, scrolls through the history of objects, slots, values, etc. to determine how a particular value was set.

Second, "Forward Chain()" was tested on the designed KBS to observe the process of detecting uncertain SCADA data.

Third, "Backward Chain()" was applied to the particular temporary reasoning, "TimerFunc", which consists of four symbolic statements, Urgent, Non-urgent, Minor, and Unknown.

Fourth, the facility of "Explain(Object:Slot)" was tested to the conclusive outage interpretation as to why the outage has occurs. They were designed to the following algorithms:

```
{  
BackwardChain(CB8_CB10);  
BackwardChain(CB6_CB3);  
BackwardChain(CB4_CB35);  
BackwardChain(CB1_CB32);  
BackwardChain(CB5_CB36);  
BackwardChain(CB38_CB11);  
BackwardChain(CB12_CB13);  
BackwardChain(CB14_CB16);  
BackwardChain(CB19_CB20);  
BackwardChain(CB21_CB22);  
BackwardChain(CB23_CB24);  
BackwardChain(CB31_CB25);  
BackwardChain(CB28_CB39);  
BackwardChain(CB33_CB30);
```

```

BackwardChain(CB9_CB34);
BackwardChain(CB42_CB2);
BackwardChain(CB41_CB7);
BackwardChain(CB13_CB12);
BackwardChain(CB40_CB39);
BackwardChain(CB13_CB15);
};

```

These algorithms provide that the circuit breakers such as “BackwardChain(CB8_CB10)”, and etc. attached to the end of lines were applied to infer plausible explanations using inference engine against the specified uncertain SCADA data were processed by the abductive KBS. A sample goal program for the backward chaining is shown in figure 28:

```

Goal Editor - CB8_CB10
Update Edit Search Options Help
Let [Process PostMenu("Please confirm the CBS_CB10", CBS_CB10, No)]
Let [Ask PostMenu("Do these circuit breakers [CB8, CB10] include the notion of parsimony?",
  Yes, No)]
Body:
If (Process #= CBS_CB10 And Ask #= Yes)
Then {
  AskValue(M_d1:Parsimony_notion);
  If Null?(M_d1:Parsimony_notion)
  Then SetValue(M_d1:Parsimony_notion, _);
  AskValue(M_d1:Parsimony_notion1);
  If Null?(M_d1:Parsimony_notion1)
  Then SetValue(M_d1:Parsimony_notion1, _);
  AskValue(M_d1:Parsimony_notion2);
  If Null?(M_d1:Parsimony_notion2)
  Then SetValue(M_d1:Parsimony_notion2, _);
  AskValue(M_d1:Crisp_value_A);
  SendMessage(M_d1, diagnosis);
}
Else If (Process #= No And Ask #= No)
Then PostMessage("No Parsimony!");

```

Figure 28 A goal editor for the backward chaining

This picture illustrates the backward chaining of inferring plausible events against the feeder information of CB8 and CB10. This was attempted by using parsimony methods whether they could provide plausible events when the specified alarm data are subject to satisfactory conclusions through the inference engine.

The resultant data were analysed employing two strategies. First, experimental categories of alarm prioritisation were discussed with HE operators. To the extent, reading the transcripts of HE was carried out to identify the categories of each statement, which was based on the memorandums and project proposals provided by the control centre. Second, testing the tentative prioritised alarms was applied to the designed backward chaining inference by classifying responses in the first two hours of the interviews. The backward chaining process

was coded with the feeder information and its responses were observed by consistent prioritisation process.

This section has explained the methods used in explanation inference engine, which is referred to an abductive heuristic knowledge based system using the object-oriented AI tool. This suggests that the explanation facilities demonstrated are an adjusted system between case based reasoning and model-based reasoning, and well adopted in conjunction with the abductive inference while most KBSs are rule-based in nature as shallow reasoning systems [Dillon 1991;McDonald 1997].

5.5 Expert system topology for real-time interpretation

An expert system topology was designed to test real-time SCADA data based on an object-oriented technique. This task was begun by interviewing the operators of the Scottish HE control centre, at Pitlochry. The control centre at Port-na-Craig House organises the generation of electricity and programmes the output of power stations to keep generation in step with demand, within the capabilities of the transmission circuits. A major role of these operators is to monitor and control alarm information by means of analysing SCADA data and whether taking any action is necessary in order to minimise such constraints.

The contents of interviewing these operators were based on power system literature review and 5 sequential visits to the control centre that consists of 23 questionnaires (see the appendix D) , and they are summarised, as follows:

- Heuristic scenario availability is concerned with an effective control for persistent alarms or emergency. How do operators maintain the knowledge? For example, if a certain line is out of service, they know its flow would spread among other lines and where the voltage would drop.
- Benefits of employing expert systems are to assist these operators during the heavy alarm period. Are operators aware of these? For instance, while there are so many tasks in the control room, which are quite difficult to handle by conventional approaches including mass of data, complexity of network structures, and incomplete information.
- Benefits of object-oriented programming are to speed development of protective equipment knowledge representation and improve reliability of heuristic knowledge, by

simulating an event area. Do operators understand the features of object-oriented power system model?

- A proposal of alarm prioritisation is to distinguish the degree of potential severe damages over protective equipment. Do the participants identify some common improvement in association with other power control centres?

The participants have responded to the questionnaires of the proposed object-oriented transmission networks that are based on the following requirements:

- Object-orientation based network architecture
- Fault arrangement
- Integration with existing SCADA
- Inference engine
- Process representation
- Temporal representation
- GUI utilisation
- Object-oriented relational data access

In respect of these requirements, the following criteria were obtained from the reply of these participants and tested in conjunction with an expert knowledge based system:

- User interactions
- Processing capability of uncertain SCADA data
- Consistent knowledge acquisition

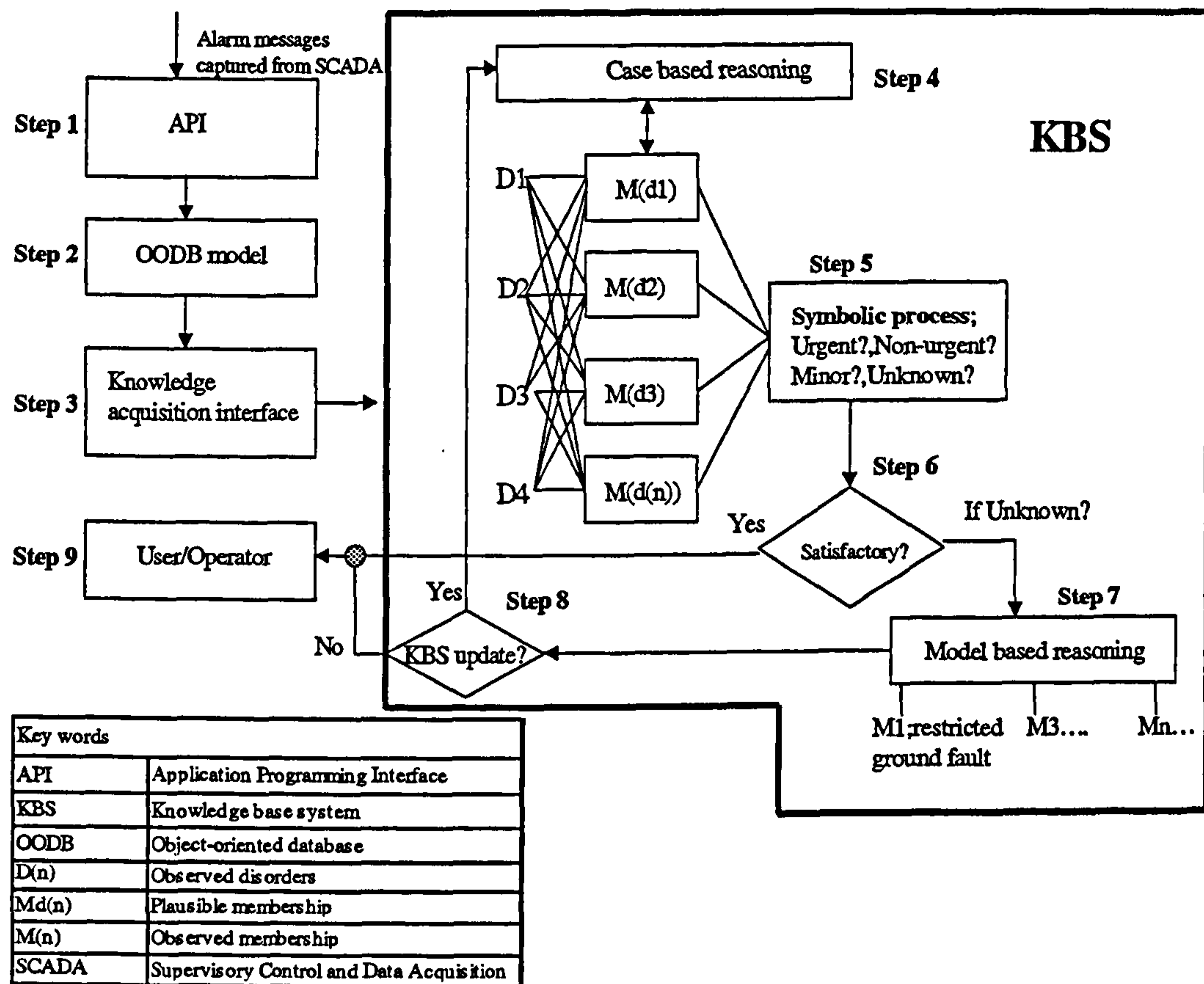


Figure 29 A topology of expert system to alarm processing

The procedure of testing these criteria for the topology was started with access to the control room, the questionnaires to domain experts including trainee and senior operators, and demonstration of pre-test rules. The control room consists of many groups including planning, scheduling, alarm analysis, project development, and SCADA maintenance. The twenty-three questionnaires were given to these groups. The participants attempted to evaluate the pre-test and some results of post-test were obtained to the following:

Primary source used	Conventional SCADA based alarm control and processing	The object-oriented expert system topology to the alarm processing
User interactions	Comprehensive	Simple
Processing capability of uncertain SCADA data	Quite difficult	Simple
Consistent knowledge acquisition	Very reliable	Excellent

Table 9 Effectiveness of the developed system topology to alarm interpretation process

Table 9 illustrates that the data were analysed employing several fundamental factors. First, the data were simplified by comparing the two systems to see whether any improvements are observed. Second, The simplified data were determined using six SCADA messages based on the participants' pre-test and post-test whether the topological feeder index system corresponds to real-time power system changes. Third, those data were interpreted using these requirements as aforementioned against how each requirement conforms to the three criteria.

5.5.1 Object-orientation based network architecture

The concept of "object" has been developed by many people for various purposes, i.e. simulation of discrete events, representation of special types of knowledge, parallel processing etc. The expression of "object-orientation" began to appear during the period from the end of 1960s to the beginning of 1970s. Currently, the object-orientation is becoming one of the most powerful AI techniques [Dillon 1990].

The designed system is based on an object representation of the Scottish HE transmission networks. This task was started with studies of the physical HE system, the representation of the physical constitution on Kappa-PC, and data specification on the feeders. First, the studies of the physical HE system resulted in comprehending the major roles of protective equipment. Second, the representation of the physical constitution on Kappa-PC was carried out and confirmatory evaluation of this AI tool was obtained, which is compatible to a real-time system. Third, the data specification on the feeders was simplified using a serial index system instead of existing labels, which resulted in less effort to implement. These three kinds of the task were to identify an example of object-oriented data structure in an alarm processing and fault diagnosis.

On the basis of these three requirements, several hypotheses were determined by reviewing power system literatures, as follows [Dillon 1990;Warwick 1997]:

- Hypothesis 1. Are equipment objects responsive in conjunction with a real-time power system change?
- Hypothesis 2. Do network objects recognise a faulted feeder ID?
- Hypothesis 3. Are control objects subject to knowledge acquisition?

First, in respect of the equipment objects, each piece of power system equipment is represented as an object such as a transmission line. To simplify these system structures, the elements of power systems are limited to a group of transmission lines, buses, generators, circuit breakers, relays, transformers, and loads. For example, Line_group is a set of parallel lines between two buses. The data structures and these objects are described in the definition of class object, and the instance object is created for the processing of the power system changes. A test method was applied employing “SendMessage(objName, methodName, x, y...)”;SendMessage(CB8_CB10,diagnosis),(CB6_CB3,diagnosis1).....(CB13_CB15,diagnosis18). The method was expanded the other alarm components whether communication between equipment objects is efficient.

Second, the network objects consist of a 12 buses-16 lines sample system. They are classes, instances, and values of slot, and inheriting these objects are processed using functions and methods. An experiment was carried out to identify faulted feeders in the OOP network, which consists of graphical assimilation, and Functions in the tool. This experiment has resulted in utilising re-use of code for alarm processing, which is seen as an applicable model based system.

Third, the control objects are to represent operation of CBs, and relays in substation configuration changes. Objects such as BUS1 and BUS2 constitute a hierarchy and multiple subsystems co-operate with each other by message passing between them, which enables switchgear problems to solve. A method of testing the knowledge acquisition was attempted, which consists of Graphical assimilation/User Request dialogue, Function/Observe, and Backward chaining, as follows:

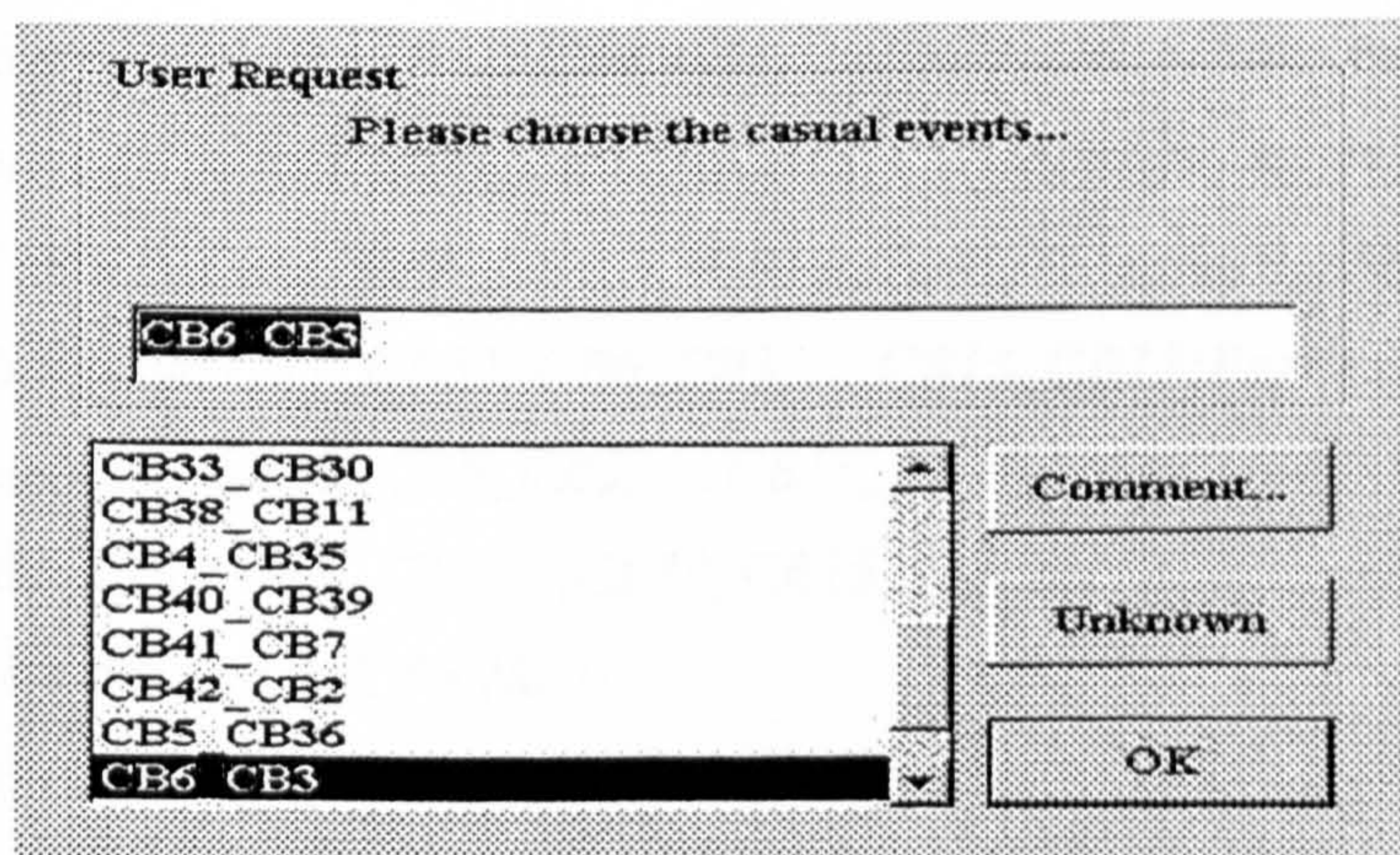


Figure 30 Graphical assimilation/User Request dialogue

Function/Observe:

```

{
SetExplainMode(ON);
ResetValue(CB8_CB10, CB6_CB3.....CB13_CB15:LineGroup);
ResetValue(CB8_CB10, CB6_CB3, .....CB13_CB15:Crisp_value_A);
AskValue(Plau_manifestation:Observed_configuration);
If (Plau_manifestation:Observed_configuration# = CB8_CB10, CB6_CB3,.....CB13_CB15)
Then BackwardChain(CB8_CB10, CB6_CB3,.....CB13_CB15)
Else
If (Plau_manifestation:Observed_configuration# = CB8_CB10, CB6_CB3,.....CB13_CB15)
Then BackwardChain(CB8_CB10, CB6_CB3,.....CB13_CB15);
};

```

Backward chaining:

```

(Let [Process PostMenu( "Please confirm the CB1_CB32", CB1_CB32, No, "Please confirm
the CB6_CB3", CB6_CB3, No,..... "Please confirm the CB13_CB15", CB13_CB15, No
)]

```

```

If( Process # = CB1_CB32, CB6_CB3,.... CB13_CB15 And Ask # = Yes )

```

```

Then {

```

```

    AskValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion );

```

```

    If Null?( CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion )

```

```

        Then SetValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion, _ );

```

```

    AskValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion1 );

```

```

    If Null?( CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion1 )

```

```

        Then SetValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion1, _ );

```

```

    AskValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion2 );

```

```

    If Null?( CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion2 )

```

```

        Then SetValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Parsimony_notion2, _ );

```

```

    AskValue(CB1_CB32, CB6_CB3,.... CB13_CB15:Crisp_value_A );

```

```

    SendMessage(CB1_CB32, CB6_CB3,....CB13_CB15,diagnosis,diagnosis1,...diagnosis13));

```

```

Else If( Process # = No And Ask # = No )

```

```

    Then PostMessage( "No Parsimony!" );

```

The following figure illustrates the distribution of overall object-orientation based power system implemented in Kappa-PC, as below:

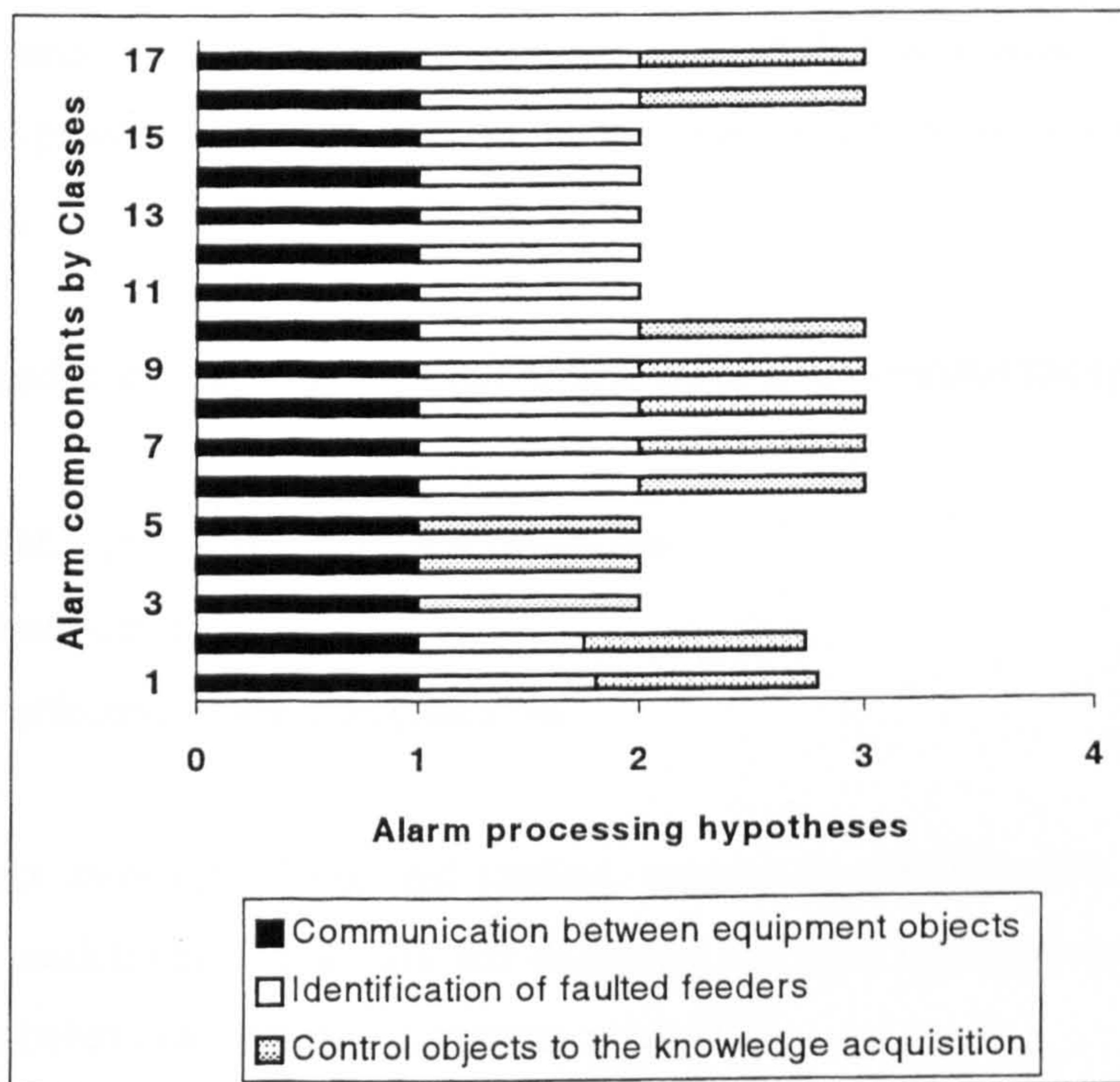


Figure 31 A sample test on object-orientation based network

Keywords:

1	BusGroup	10	Membership_grade
2	GenGroup	11	Not_known?
3	TransGroup	12	Not_knownA?
4	Connector	13	Not_knownB?
5	AuxGroup	14	ALARM_RELAY
6	LoadGroup	15	ALARM_CB_GROUP
7	Loaded	16	SCHED
8	Unloaded	17	ALARMS
9	Plau_manifestation		

Figure 31 shows the distribution is compared to those three hypotheses. The classification category designed in each alarm component was varied in accordance with an algorithm of each hypothesis, such as identification of the faulted feeders by forward chaining process. The algorithm was addressed to the specified alarm objects which do not affect the other alarm components. The test receiving most attention was that of very effective maintainability, which is seen as a fundamental reason for introducing object-oriented AI programming.

5.5.2 Fault arrangement

Fault arrangement is concerned with effective knowledge acquisition techniques that require interview, case study, fundamentals of protection, rapid prototyping and frequent user evaluation, verbal protocol analysis method, testing with analytical tools, and published work [McDonald 1997].

The principle behind implementing this fault arrangement is to consider the following factors:

- To improve alarm processing and fault diagnosis
- To reduce human error
- To determine effective alarm interpretation

These three factors were introduced and studied, suggest that an effective fault arrangement design is that of readability. The task for designing the fault arrangement was involved in studying human's behaviour and expert system capabilities.

First, in respect of human, there were two different points reviewed, advantages, and drawbacks. The advantages were that of identifying and distinguishing patterns and connections. For instance, the wood from the trees and human can isolate the profitable lines of attack. At the same time, they can correlate data from a very wide base of knowledge and experience, and are intuitive in nature. The drawbacks were based on limited arithmetic capability and difficulty of extracting line of reasoning.

Second, expert system capabilities were demonstrated to the HE operators. A major goal of introducing these capabilities was to comprehend power system changes using an effective fault arrangement which could help the operators to determine alarm interpretation from the transmission networks.

The procedure of implementing this part was begun by simulating the elements of protective equipment, operation of circuit breakers and relays, and the utilisation of routine alarm information.

First, simulating the elements of protective equipment was carried out to test the changes of power systems on the transmission networks, as follows:

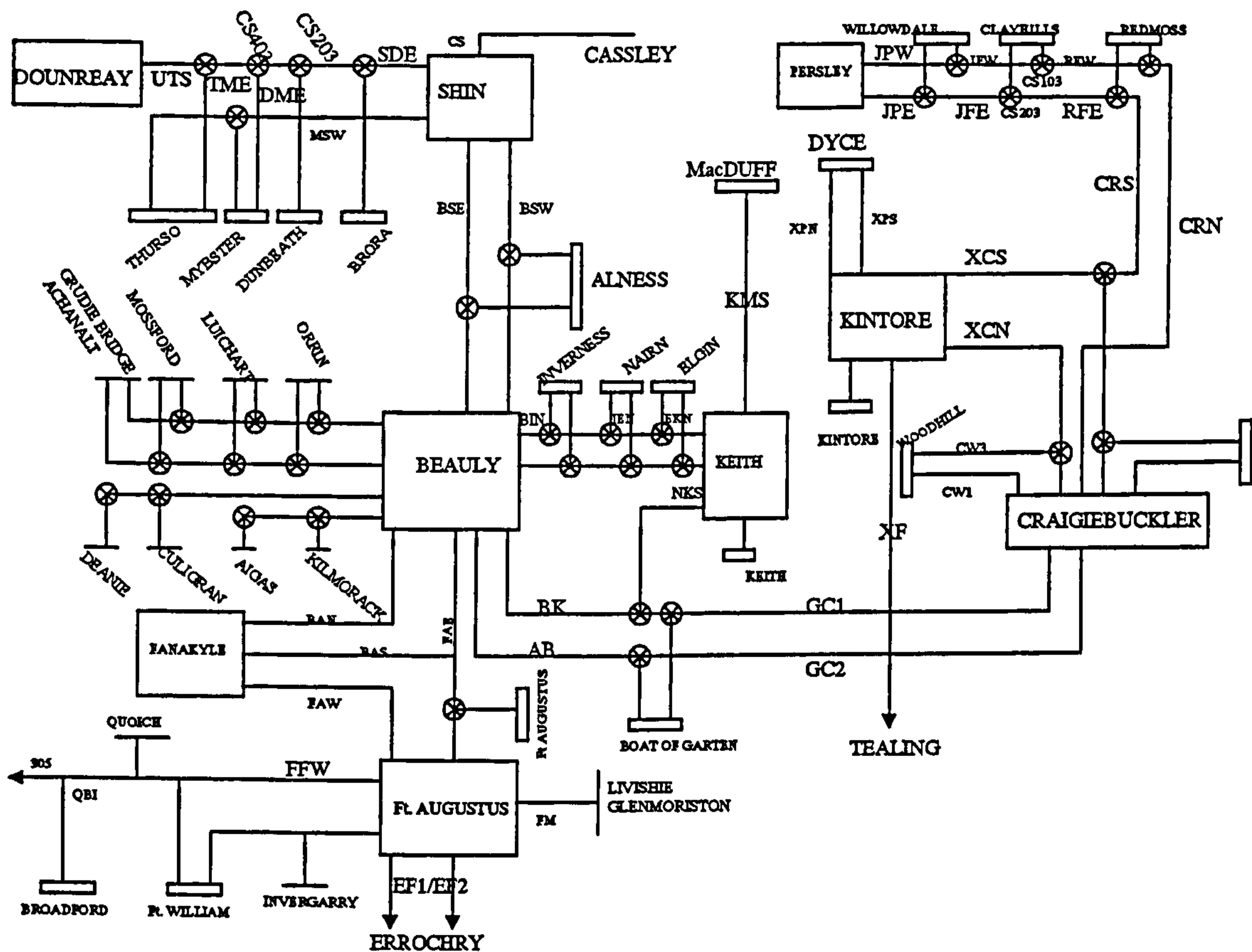


Figure 32 132kv Substations on HE transmission networks

Figure 32 illustrates actual configuration on 132kv substations and Northern Hydro Group in Scotland controls the catchment area.

Second, operation of circuit breakers and relays was applied using the following labelled system. This configuration was based on the 132kv Substations. Circuit breakers provide three types of operational states, open (on), close (off), and failed (Appendix H). This switching operation is applied, in conjunction with faulted feeders. Relays are to report operational problems over the transmission networks in the timescale of electromagnetic transients, and need a reaction time in the order of microseconds. This relay protection was included in the fault arrangement of alarm messages.

Third, the utilisation of routine alarm information was tested on the classes and instances of object-orientation. The procedure of implementing this task consists of three stages, API

(Application Programming Interface), OODB (Object-oriented database), and a hierarchy of object-orientation. These three stages were designed by storing the SCADA messages. The essential fault arrangement is based on the following simplified configuration:

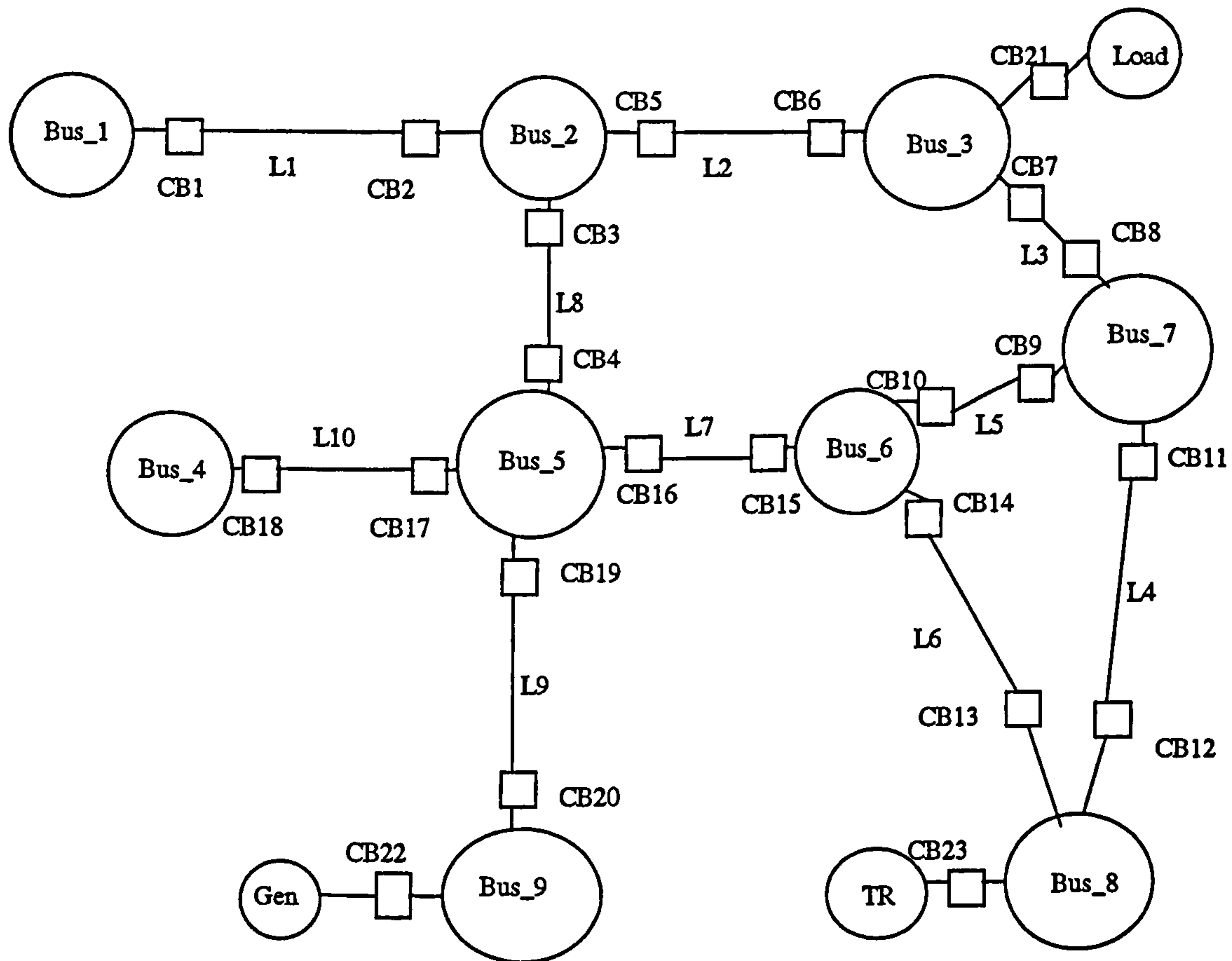


Figure 33 Simplified transmission networks from figure 32

Figure 33 consists of a generator, lines, circuit breakers, loads, and buses. These elements were deployed to design an object representation of power system modelling. For example, classes are used to represent the whole elements as alarms. At the same time, instance objects are used to represent lines/transmission lines, plants, buses/various substations, and loads. A sample fault arrangement is illustrated, as below:

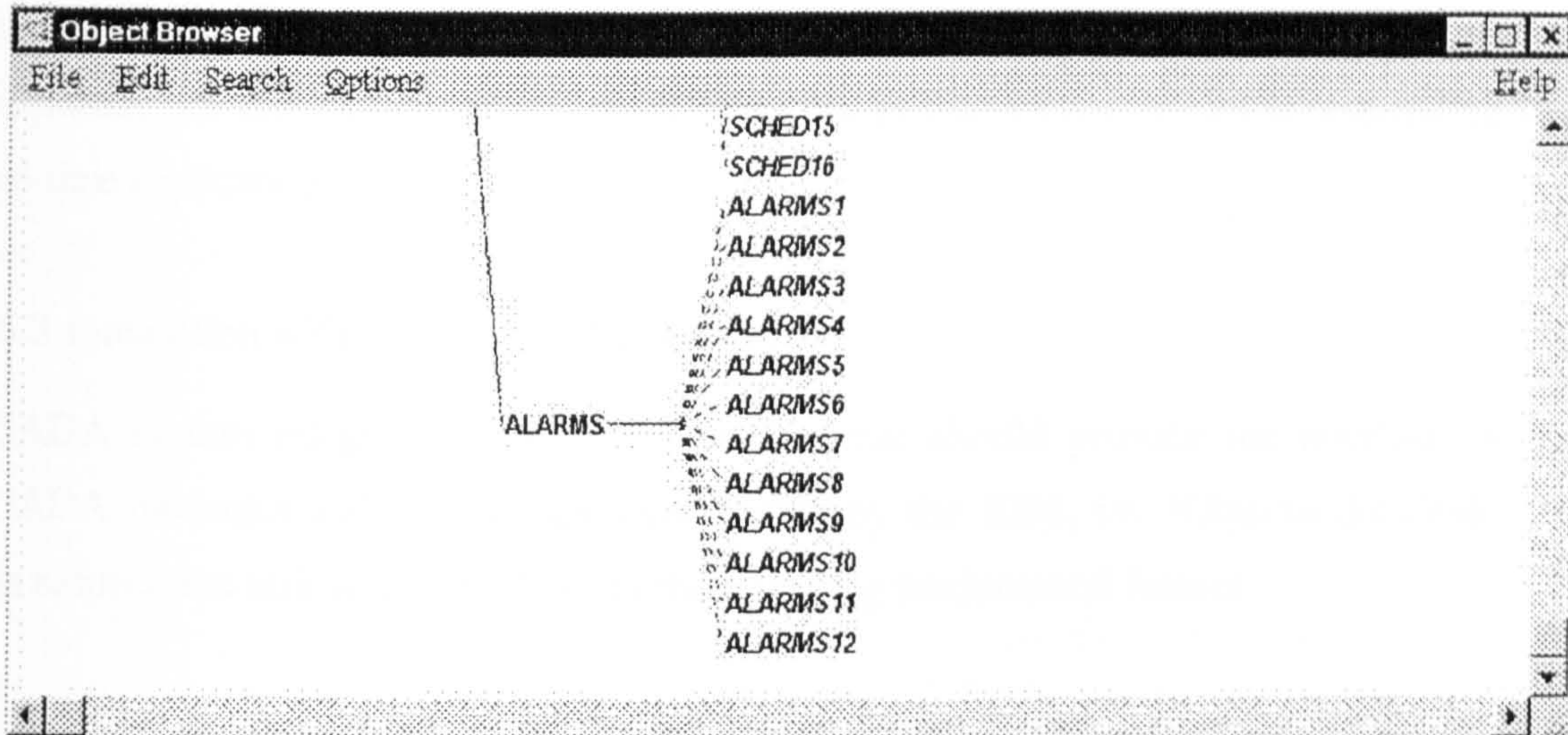


Figure 34 An object representation of alarms from the transmission networks

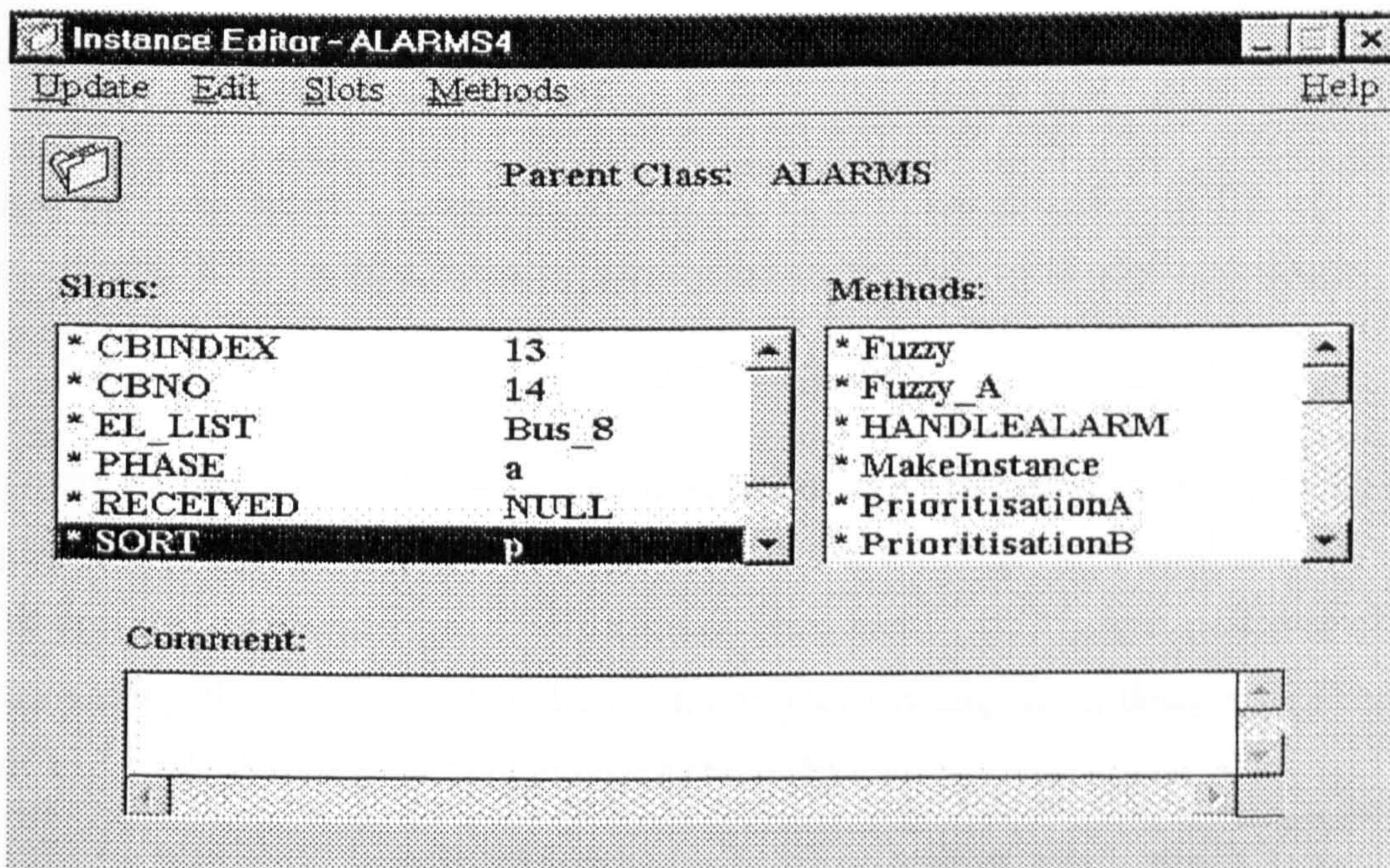


Figure 35 An instance object of alarm messages from the transmission networks

Figure 34 and 35 demonstrate fault arrangement using object-orientation. They provide knowledge processing which consists of methods and functions and are the knowledge-based system. The methods are based on procedural knowledge which determines the appropriate algorithm against faulted feeders. The functions are most powerful batch processing, a message passing system, in conjunction with production rules.

The results of testing fault arrangement design show that those benefits of using object-orientation are that of hierarchical modelling. The power system model is responding to the real-time application of alarm processing.

5.5.3 Integration with existing SCADA system

SCADA system integration with the expert system should provide the interface between SCADA messages and the messages interpreted by the KBS, i.e. 'Object=Slot=Value'. In this respect, the task was carried out to the following fundamental factors:

- Does existing SCADA system communicate with API (Application Programming Interface), OODB, and the application tool?
- Is the value of the power system changes on the tool updatable?

These factors were tested by accessing to new messages of the incoming OODB whether the object-oriented KBS enables users to correspond to the faulted feeder information when necessary.

The procedure of testing SCADA system integration with the expert system was began by downloading several post-events from the OODB implemented in Visual FoxPro. This OODB provided alarm messages in the form of Field and Row. The encapsulation of such messages using Kappa-PC was based on a number of opening files, designed 12 instance alarms, and resulted in effective fault arrangement, as below:

The screenshot displays the 'Alarm Prioritisation Control Panel' with several sections:

- The events to derive/1:**
 - CB1 tripped
 - CB3 tripped
 - CB43 tripped
 - Primary relay operated
- Plausible explanation for the events/2:**
 - BACKUP RELAY Z1 AT CB1 FAILED.
 - PRIMARY RELAY AT CB2 FAILED.
 - PRIMARY RELAY AT CB3 FAILED.
 - PRIMARY RELAY AT CB43 FAILED.
- Alarm Traffic-Load:**
 - Minor
 - Non_urgent
 - Urgent
- Fault Arrangement Data Format from SCADA/3:**

ID	Time	Phase	EL_LIST	CBINDEX	TYPE	SORT	CBNO	STATUS
7	19/5/2000 15:33:33	[PHASE]	NULL	CBINDEX	TYPE	NULL	CBNO	STATUS NULL
7	19/5/2000 15:33:33	[PHASE]	NULL	CBINDEX	TYPE	NULL	CBNO	STATUS NULL
7	19/5/2000 15:33:33	[PHASE]	4	CBINDEX4	TYPE 4	SORT 4	CBNO 4	STATUS on
- Alarm display/4:**

ID	Time	Phase	EL_LIST	CBINDEX	TYPE	SORT
19/5/2000	15:33:33	[PHASE]	NULL	CBINDEX	TYPE	NULL
19/5/2000	15:33:33	[PHASE]	NULL	CBINDEX	TYPE	NULL
19/5/2000	15:33:33	[PHASE]	NULL	CBINDEX	TYPE	NULL
19/5/2000	15:33:33	[PHASE]	4	CBINDEX4	TYPE 4	SORT 4

Figure 36 An expert system integration with existing SCADA

The tool, Kappa-PC was responded with the opening files which consist of two object-oriented forms, class, and instance. The class was referred to alarms and the instance was referred to a number of alarms such as alarms1, alarms2, etc. The results of the task suggest that the SCADA system integration with the expert system designed by object-orientation provide an effective power system model, and an experiment was carried out, as follows:

A number of opening alarm files	1	2	3	4	5	6	7	8	9	10
API	Y	Y	N	N	Y	Y	Y	Y	Y	Y
OODB	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
The object-oriented tool	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Update of power system change	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 10 One object-orientation at a time in 4 different trials over ten times of existing SCADA connection

Table 10 shows the designed KBS integration with the SCADA connection is subject to static instance objects such as ALARMS1, ALARMS2,.....ALARMS12. This is because the KBS requires to increase production rules as the number of alarms by instance objects is incremented.

5.5.4 Inference engine

Inference engine is concerned with new knowledge whether search strategies such as backward chaining and forward chaining are capable of reasoning a method designed by the KBS for the new knowledge.

The task of designing the inference engine was carried out to test the two search techniques. Referring to [Dillon 1990], the information available for alarm interpretation comes from several sources:

- Alarm data from the SCADA system
- Power system topology from the SCADA system
- Interpretation knowledge obtained from the control centre operating staff
- Detailed alarm information from alarm design notes and schematics

These alarm techniques suggest that the interpretation of alarms should employ a combination of alarm message types including single alarms, multiple alarms, and expected event alarms.

First, single alarms consist of the following examples:

- Some alarms are acknowledged that do not agree with other information available in the SCADA system. These alarms should be suppressed.
- Alarms that arise as a result of emergencies should be displayed without further interpretation, i.e. fire alarms.
- All other single alarm messages should be displayed.

Second, multiple alarms occur for a number of reasons, as follows:

- Repeated alarm messages are received many times.
- Some alarm messages that are best described as systematic alarms.
- The most difficult to deal with are those alarm messages that result from multiple plant failures.

Third, expected events are received that are expected by control room operator. These alarms occur as a result of correct operations, and initiated by the operator, which should be suppressed. Alarm messages concerning maloperation are not available and have to be deduced by control engineer.

In respect of these three categories, investigating the requirements of an object-oriented inference engine was carried out that fall into the following studies:

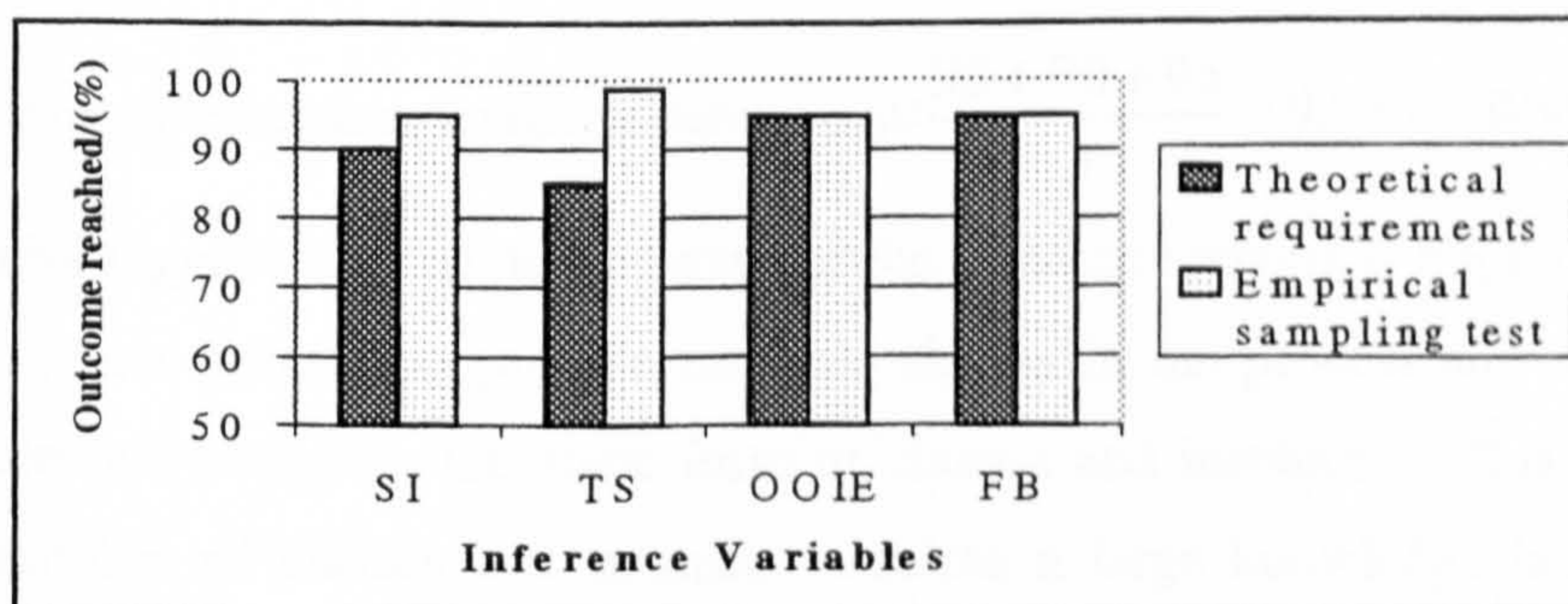


Figure 37 An object-oriented sampling performance for 4 variables of inference engine

Keyword:

SI: Does the tool provide the SCADA data import for an OODB access (10 questions)?

TS: Is the topological SCADA system applicable to the form of classes and instances (5 questions)?

OOIE: Are the SCADA messages corresponding to the object-oriented inference engine (10 questions)?

FB: Do the forward and backward chaining recognise the captured SCADA data using the rule editor (5 questions)?

Figure 37 shows that there are two types of hypotheses employed, theoretical sampling claimed by [Dabbaghchi 1992], and empirical sampling proposed by the system. The theoretical sampling test indicates that TS was quite outperformed as the captured outage data provided by his theme was conventional SCADA data, which required much more heuristic knowledge than the proposed outage data representation in order to program the post outages in the knowledge base. On the basis of these experiments, testing alarms/outages was carried on the developed power system topology from the SCADA system, as follows:

Alarm types	Single alarms	Multiple alarms	Expected alarms	\bar{x}
1 – 20(No of trials)	95	90	95	93.75
21- 40	95	90	95	93.75
41-60	95	95	95	95
61- 80	95	95	95	95

Table 11 Inference engine test in four trials using three types of alarm messages

Table 11 illustrates the experiment on the three different alarms was carried out to obtain a result of the inference engine design, where $\bar{x}_{1-20} = \frac{95 + 90 + 95}{3} = 93.75$. With analysing 80

trials, the results suggest that the performance of the inference engine is highly feasible as the characteristic object-orientation provide multiple alarms in the process and will improve if production rules are based on the static form of classes and instances. This is because the incremental number of classes and instances requires a large knowledge base as dynamic access to the OODB increments the number of instances since a number of instances were

stored a buffer in the tool. The number of instances was being programmed, i.e. maximum 12 alarms.

5.5.5 Process representation

Operating a physical system like power systems, the process representation of employing an object-oriented programming has been developed over the two decades. For example, in a switching operation system, each piece of power system equipment such as a transmission line is represented as an object.

The tasks of implementing this process representation in OOP were carried out, as follows:

- 1) Collecting raw SCADA messages
- 2) Transferring the SCADA data into API(Application Programming Interface)
- 3) Storing the raw data in OODB(Object-oriented database)
- 4) Applying the data to the developed object-oriented tool

These tasks were applied to HE object-oriented power system model. There have been similarities of this object-oriented power system model proposed by a number of researchers; [Ramsay 1994;Ironmonger 1996]. First, Ramsay (1994) has considered a primary object-oriented alarm processing and fault diagnose using the transmission line of Scottish Hydro systems. He suggests the initiative of developing an object-oriented power system is feasible as an integration with existing HE SCADA was achieved by Kappa-PC, which responded to the process representation of HE power system model. Second, Ironmonger (1996) insists that a diagnosis module correctly detected the following faults:

- a) Transmission line transient earth fault
- b) Transmission line earth fault
- c) Transmission line earth fault plus primary protection relay refuse to operate
- d) Transmission line earth fault plus one breaker refuse to open
- e) Protection relay missing operate
- f) Breaker missing operate

These patterns were based on a sample knowledge which included one thousands Breaker objects. These objects were divided into 33 groups and each group included 30 Breaker objects. His results show that testing alarm processing for the substations has been effective, as follows:

T	SUB	EQUIP	COMMENT
12:20:12	S5	RELAY10	OPERATE
12:20:12	S5	CB3	OPEN
12:20:12	S5	CB9	OPEN
12:20:12	S5	RELAY11	OPERATE
12:20:12	S5	G2	DISCONNECT
Alarms before processing			

T	SUB	EQUIP	COMMENT	LEV
12:20:12	S5	G2	DICONNECT	1
12:20:12	S5	B1	FAULT	2
12:20:12	S5	CB6	REFUSE OPEN	2
Alarms after processing				

Table 12 Results of alarm processing for earth fault in substation5

Table 12 suggests that the power system object-orientation into the substation representation is effective in conjunction with Off-line-abnormal conditions, but the tool has not addressed a process representation of dynamic knowledge acquisition using a knowledge base algorithm.

Aforementioned four tasks were attempted to overcome the limit of [Ironmonger 1996] and the procedures used in carrying out the design fall into three steps.

First, access to the control centre of Pitlochry was confirmed that the transmission line of a 132kv to Scottish Hydro Electric PLC was used to simulate the process representation of object-oriented power system model.

Second, the tasks of the process representation by object-orientation were asked to the control engineers that involved three organisation strategies, simplification to existing HE transmission lines, minor modification, and maintainability.

Third, a number of SCADA messages were observed, which consist of 20 different alarms. These different alarms were interviewed to senior operators of HE, Mr Ray Kelly, and Ian Moyes. Those alarms divide into four, unknown, urgent, non-urgent, and minor. Four raw SCADA messages were determined in accordance with these four categories. These procedures were designed for two objectives. One was used to test the process of object-oriented alarm prioritisation. The other was to determine uncertainty from the SCADA data. The four SCADA data were applied to the knowledge acquisition, and each data was tested in conjunction with the following requirements:

- Acknowledgement of new alarms in the power system model
- Power system changes when updating the KBS

These requirements were experimented using a temporal reasoning which consists of symbolic process of alarm prioritisation as aforementioned. This symbolic process has resulted in more qualitative alarm management while operators rely on textual SCADA messages. The overall process representation for the power system model was concerned with objects of each protective equipment which should represent information of the power system in the tool.

This means that a real-time power system change from the transmission network should respond to the developed process representation, and result in providing a solution.

5.5.6 Temporal representation

Reasoning with temporal information is essential in Artificial Intelligence as the internal representation language deals with temporally qualified propositions and constraints on the ordering of time points, claims [Ramsay 1994]. The inference system relies on a set of constraint primitives providing temporal consistency both for points and for intervals.

A primary investigation was carried out that as [McDonald 1997] does, there are a number of practical problems inherent in the alarm processing tasks, as below:

- Achieving adequate speed of operation
- The limited scope of telemetry
- Missing alarm messages

- Unreliable time ordering of alarms
- The unpredictable arrival late of alarms
- Simultaneous occurrence of many separate events

These problems were taken into account in the design. There were three tasks proposed whether the application tool, Kappa-PC, complies with the temporal reasoning, as follows:

- Task 1. Does Timer function in Kappa-PC cope with existing SCADA system and proposed topological power system changes?
- Task 2. Is a heuristic rule base efficient to overcome these problems?
- Task 3. Will a KBS determine uncertain SCADA messages using an object-oriented algorithm?

On the basis of these tasks, the practical implementation of power alarm processing was attempted utilising four samples of developed SCADA data. The procedures of implementing these tasks were begun at assessing fault arrangement design. These protection systems consists of serial equipment device including some information, such that:

B 06:52:08 HECATE SYSTEM B?? plant?? Fault on Plant??

B 06:52:08 HECASTE SYSTEM A?? plant?? Fault on plant??
--

Table 13 Routine alarm information from HE protection systems

Slots:	Methods:
* CBINDEX 13	* Fuzzy
* CBNO 14	* Fuzzy_A
* EL_LIST Bus_8	* HANDLEALARM
* PHASE a	* MakeInstance
* RECEIVED NULL	* PrioritisationA
* SORT p	* PrioritisationB

Figure 38 The proposed object-oriented alarm information

Table 13 and figure 38 illustrate alarm messages from Scottish Hydro SCADA system. Operators monitor the routine alarms daily, and this information contains important clues to identify any faults in the transmission networks. However, this conventional system shows that the operators have certain limit to control alarms effectively when an alarm activity is high. For this reason, an experimentation of improving the alarm processing was carried out,

as shown in table 14. The motivation behind the fault arrangement design from the conventional alarm processing was to test the following protection schemes:

Respondents	Domain experts(2)	System engineers(3)
Minimising human error	Strongly agreed	Strongly agreed
Maintaining effective topological system knowledge	Strongly agreed	Agreed
Reducing operators' workloads	Strongly agreed	Strongly agreed
Improving inefficient analytical programs	Strongly agreed	Strongly agreed

Table 14 A survey of the proposed fault arrangement design

Table 14 shows that there were 5 participants and testing the proposed fault arrangement was satisfactory, as there is no doubt from their experiences. This enabled the temporal representation to run in parallel utilising timer function of the development tool, i.e. the use of GIS (Geographical Information System) to pinpoint the fault location and the collection of recycling updated alarm messages every 2 seconds. This experiment was carried out employing the use of the edit functions in the tool, including Knowledge, Math, String, Lists, Logical, File, Control, Classes, Instances, Rules, and Goals, which covered these tasks. The results of this experiment were obtained, as follows:

Tasks	Recycling messages every 2 seconds	GIS operation
Timer function	87.5%	99%
Heuristic rule base	99%	99%
Uncertainty process	99%	99%

Table 15 An experimentation of temporal representation in parallel processing employing the object-oriented data acquisition

Table 15 shows that there were three tasks and two factors carried out. The perspective of this temporal representation is to observe 17 hypothesised questions, whether they are identifiable for this system. This study was conducted when interviewing with HE operators was available, and three participants in the study were involved. The methods to collect the SCADA data were confirmed by the participants. The collected SCADA data were based on post outages and consist of four. These data were analysed to program a heuristic knowledge in the diagnostic tool whether the knowledge base responds to these two factors.

5.5.7 GUI utilisation

The history of graphical user interfaces (GUI) goes back to 1970s. Project Smalltalk was established at Xerox Palo Alto Research Centre, which attempted to look into the future. The idea was to assume that in the future computing power would be abundant and inexpensive. Two influential developments resulted; object-oriented programming and the graphical user interface [Dix 1993].

GUIs are effective and provide the use of pictures rather than just words to represent the input and output of a program. They provide a very broad bandwidth for humans since some windowing systems have proven to be significant of using them, such as the X windows system, Microsoft window, Acorn RISCOS, and NEXTSTEP. They present much information on the screen but can rely on the power of sight, by humans. The use of GUIs was discussed with the three participants in Pitlochry control centre. Two tasks suggested by these operators were attempted to identify current GUIs, as follows:

- Is the GUI-based knowledge acquisition assessable?
- In terms of displays, how much is the symbolic alarm prioritisation system helpful to operators?

These tasks were based on the following requirements of employing GUIs:

- The forward chainer requires pre-defined rules and they should match with similar outages.
- Multiple pattern events should function in the parallel function
- Does display of irrelevant or poorly processed information lead to confusion?

- Is an abductive model processional?
- Are observed disorders acquisitive from the proposed fault arrangement design?
- Does the GUI provide a plausible solution to the problem of concurrent faults while a rule based system is inconvenient to perform data abstraction?
- Would an observed solution be presented?

These tasks were experimented employing the use of the editor functions in the tool, including Knowledge, Math, String, Lists, Logical, File, Control, Classes, Instances, Rules, and Goals, which covered the three expected design requirements as aforementioned. The results of implementing these editor functions were obtained, as below:

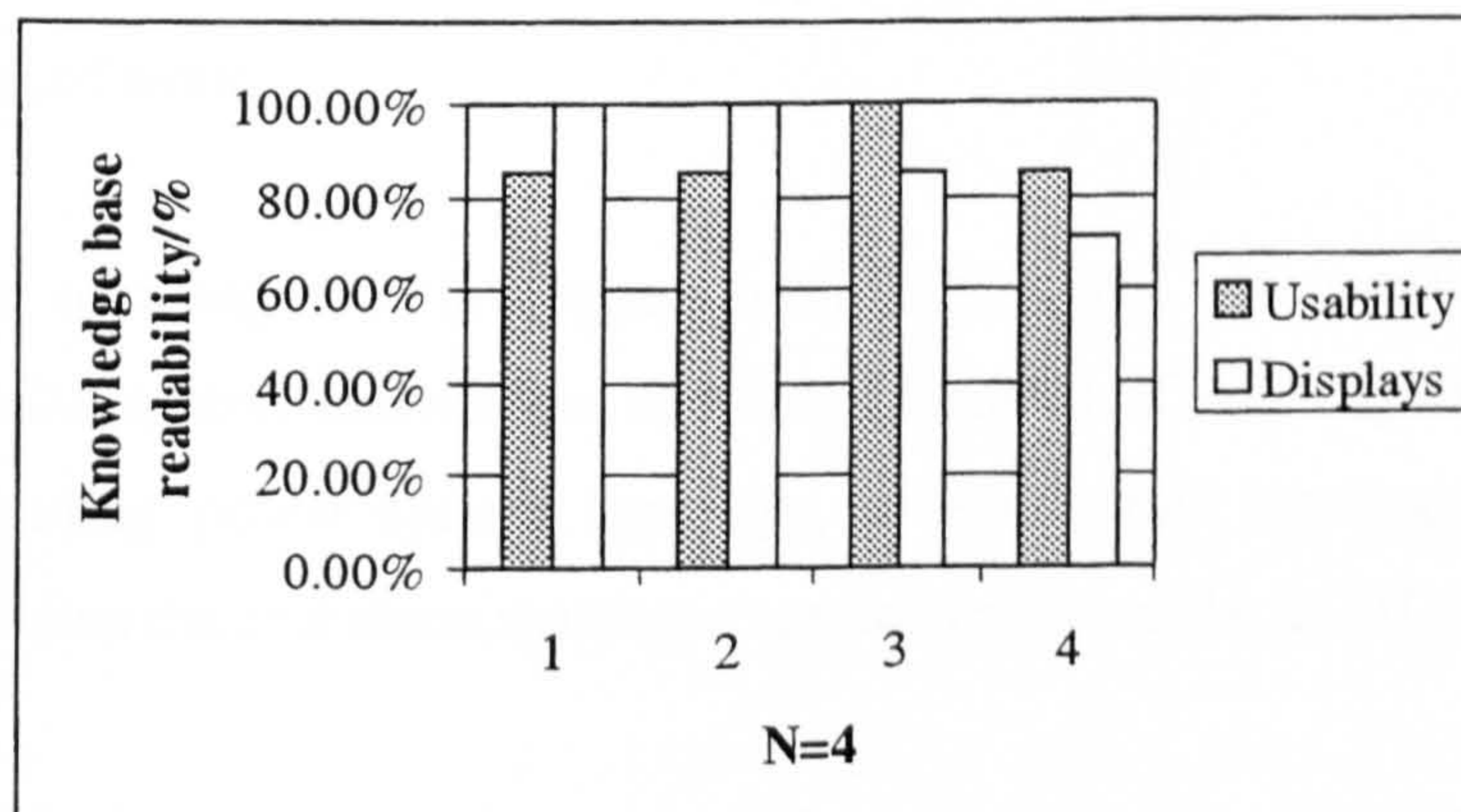


Figure 39 A sampling test of the mean for 11 samples of N=4 to the user friendly system

Figure 39 describes the performance of the user-friendly system. The two factors, assessability, and display were applied to the four different expertise' opinion/N=4. A group of editor functions were compromised against they respond to the requirements of knowledge base readability. These results suggest that two factors were performed similarly, but the effective displays such as a GUI was taken into many aspects including text sizes and colour, use of windows, mouse, and graphical assimilation. The displays was quite effective as these GUIs were involved in human-based object-oriented power system model.

5.5.8 Object-oriented relational database link

Object-oriented databases (OODBs) evolved from a need to support object-oriented programming and to reap the benefits, such as system maintainability, from applying object orientation to developing complex software systems. The first OODBs appeared in the late

1980s. OODBs are based on the object model and use the same conceptual models as object-oriented analysis, object-oriented design and object-oriented programming.

OODBs are designed for the purpose of storing and sharing objects, which provide a solution for persistent handling. Some commonality in OODBs is, as follows:

- OODBs allow for the storage of complex data structures that can not be easily stored using conventional database technology
- OODBs support all the persistence necessary when working with object-oriented languages
- OODBs contain active object servers that support not only the distribution of data but also the distribution of work

In respect of these advantages, an investigation for OODB link was carried out that falls into two, general SCADA system knowledge, and data. General SCADA system knowledge was that of comprehending power system topology, in which this topology was designed to inform operators when the real alarm messages are derived from the SCADA information.

Generally, SCADA data are not often practical to have access to a live SCADA system message stream as describing the connectivity between major items of power system plant. For example, lines, transformers, busbars and circuit breakers are available from the recorded power system alarms [McDonald 1997]. The proposed system is as follows:

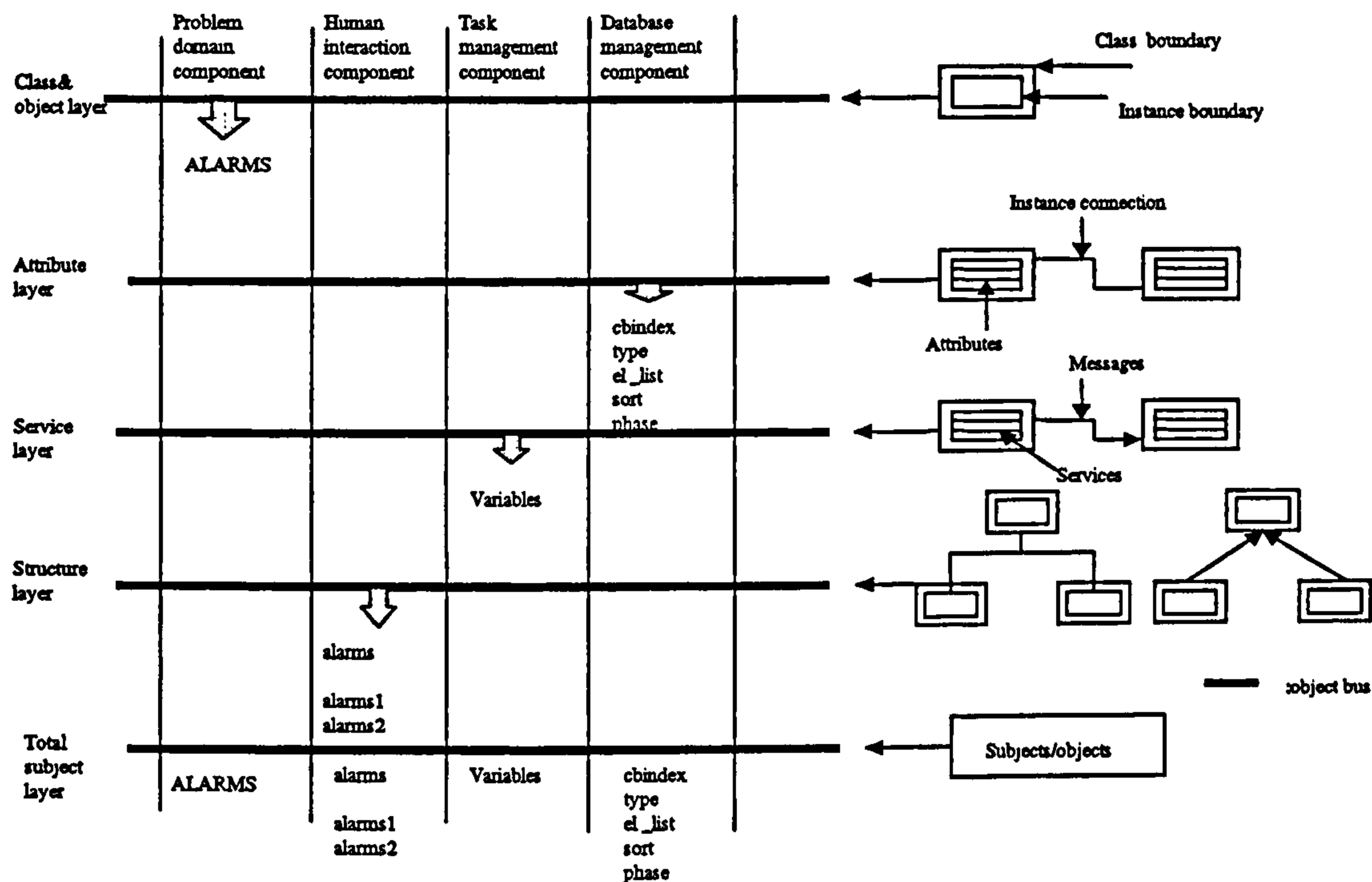


Figure 40 Architecture of OODB employing the topology data

Figure 40 describes the process of OODB from the power system topology data. This experimental method of designing a OODB was began in early 1995, carried out in Pitlochry control centre, interviewed by a SCADA operator, Jim Murdoch who reviewed these aforementioned advantages using the OODB as sub SCADA data storage for persistent alarms.

A major requirement was access to the main stream of SCADA information from an API (Application Programming Interface) which is to store and download those highlighted alarms in its API. The next task was that automatically transferring these alarms to the OODB, Visual FoxPro, was attempted using OODB algorithms. The procedure of implementing this system consists of two, the API design, and data storage by OODB algorithms.

Several requirements were discussed that are SCADA test files, derived SCADA messages, topology networks' components, and inference engine support, and a number of accessing time were used. The motivation behind these two tasks was to test the topology model available at each substation in the network so that these data would allow this developed system to determine the outage areas from a particular substation, as below:

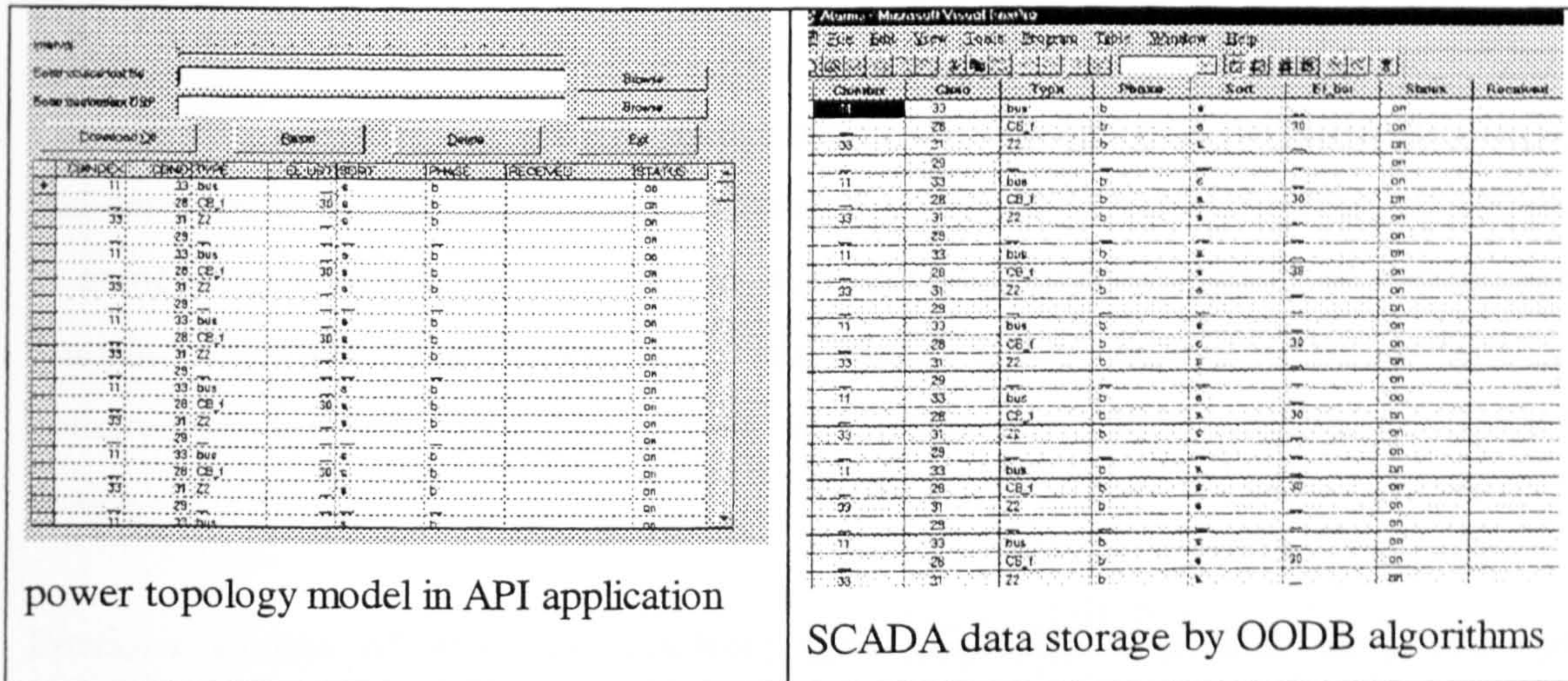


Figure 41 A sample application in conjunction with the alarm processing

Figure 41 shows that the transition of SCADA data is consistent that minimises lost alarms during the alarm processing. The OODB link to the derived SCADA data has demonstrated that the OODB structure is compatible to the real power topology networks operational and behavioural network data are provided. Details of these two systems as aforementioned in figure 41 are illustrated in appendix G and some methods of these observed results are, as follows:

SCADA data acquisition methods	SCADA text files	Derived SCADA messages	Topology networks' components	Inference engine support
API design	99%	99%	99%	N/A
Data storage by OODB algorithms	N/A	99%	99%	99%

Table 16 A functional test of OODB alarm data storage

Table 16 shows the experiment was attempted employing four different derived alarm messages whether the information of particular substation is given by the topological power system components. The methods were based on a number of design tests which consist of four requirements, and 20 repeated tests were carried out when different alarm messages are derived from the main stream of SCADA. The results presented above suggest that OODB link for the derived SCADA in this study was conducted quite satisfactorily.

5.6 Summary

The object-oriented expert system based alarm processing and fault diagnosis were analysed and designed using the development toolkits, Visual Basic 5, Visual FoxPro, and Kappa-PC, in association with HE operators. This study demonstrated three parts, implementation of domain expertise' knowledge using the tool, alarm message prioritisation using comprehensive power topology networks, and an abductive object-oriented knowledge base design.

Previous studies of effective principles have concluded that OOP in power system applications may either run on the same workstation as the OOP itself, or on separate machines connected by a network. [Dabbaghchi 1992] claims that outages in power topology networks are quite complex nature to resolve. An abductive inference was applied to resolve these outages and his experiment was quite well incorporated with heuristic knowledge in the power alarm processing and fault diagnosis.

There was a GRIDS (Graphical Information Display System) introduced, which does not require full power system datasets. This system was based on a GOLD (General-purpose On Line Database), and developed by [Ironmonger 1996], who attempted to access to the existing Energy Management System (EMS) at the National Control Centre, including other sources of data. However, they have ceased further development of employing AI techniques for more effective alarm management.

Although this study alone can not provide a sound basis for the OO expert system based alarm processing and fault diagnosis, this study would suggest that newly developed OO expert system based alarm processing and fault diagnosis should provide more intuitive solutions to operators. The results show that the system specification designed is applicable to existing SCADA.

Chapter 6: The integration of fuzzy logic to the expert system

6.1 Introduction

This chapter describes a fault processing technique using fuzzy-expert system (FE). This technique is an extension from previous chapter 5, in which an object-oriented system based alarm processing and fault diagnosis is applied. As such the method in this chapter is based on the topological power network and consists of two stages. The first stage is based solely on an abductive object-oriented expert system in order to determine alarm classifications for fault locations, which provides four symbolic alarms, Urgent, Non-urgent, Minor, and Unknown. Particularly, the expert system determines the unknown SCADA information employing the abductive inference engine. The second stage is based on an object-oriented fuzzy rules which is designed to process the uncertain SCADA data when the abductive expert system does not provide the best explanation.

Expert systems have shown potential advantages over conventional alarm management and fault diagnosis in improving the controllability in EMSs (Energy Management Systems). In particular, a virtue of the fact is that of utilising heuristic knowledge, which provides a reliable solution to operators employing the KBS while alarm activity is high due to weather conditions and etc. However, there are a number of contingent outages during the abductive expert system's performance which can be adverse for potential users. The technique delineated hereof proposes the use of fuzzy rules to determine these contingent outages.

6.2 Introduction to Fuzzy logic

Fuzzy rule based approximate reasoning was attempted by [Zadeh 1965] who provided the basic machinery for the system. In his approach, each granule of knowledge is represented by a fuzzy set or a fuzzy relation on the approximate universe. The fuzzy set representation of the different granules is combined and the result of this combination is projected into the universe of interest.

The basic motivation for fuzzy logic is clear that while ideas resemble traditional assertions, they are not naturally either true or false. [Elkan 1994] claims that fuzzy logic is an attempt to capture valid reasoning patterns about uncertainty and the notion is now well accepted that there are many different types of uncertainty, such as vagueness, and ignorance. The question

of uncertainty is more empirical whether fuzzy logic is in practice an adequate formalism in knowledge based systems.

In respect of this question, applications of fuzzy set theory in power systems are receiving much attention among power systems researchers. Dhar (1979) introduced fuzzy sets to solve “power system long-range decision analysis under fuzzy environment” over two decades ago. However, the growing number of publications on applications of fuzzy set based approaches to power systems is fairly recent, which indicates its potential role in solving power system problems [Momoh 1995]. This chapter presents further one step in that direction of employing fuzzy set theory for fault diagnosis in a power system.

6.2.1 Fuzzy logic technology

The application of fuzzy logic technology has been most successful in heuristic control, where there is wide consensus that traditional techniques of mathematical control theory are often inadequate [Elkan 1994]. The mathematical formulations of real-world problems are derived under certain restrictive assumptions, and the solutions of large-scale power systems are not easy.

Most of the current applications of fuzzy logic are FNN (fuzzy neural networks) and FE (fuzzy expert systems). First, FNN is based on a hybrid approach between ANN (artificial neural networks) and FL (Fuzzy logic). The technique was used to further improve an accuracy of an ANN-based technique. Second, FE is an expert control system which smoothly interpolates between otherwise crisp rules. These rules fire to continuous degrees and the multiple resultant actions are combined into an interpolated result. The attention of fuzzy technology is growing in EMSs (Energy Management Systems).

6.2.2 Characteristics of fuzzy logic applications

There are some reasons for rapid growth in the number, variety, and visibility of fuzzy logic applications. What fuzzy logic provides is a methodology for representing and analysing dependencies. They are approximate rather than exact. In respect of these, fuzzy logic provides an inference morphology which enables approximate human reasoning capabilities to be adopted in knowledge based systems, such as a linguistic variable, and a fuzzy if-then

rule. The inference in fuzzy logic reduces a solution of non-linear programs while standard techniques for the solution of such programs may be computationally expensive.

6.2.3 Fuzzy set

Fuzzy set theory was introduced by [Zadeh 1965] who has attempted a theory of the union by fuzzified crisp logics. Its primary aim is to provide a formal, computationally oriented system of concepts and techniques for dealing with modes of reasoning, e.g. the modes are approximate rather than exact. There are two fundamental factors in fuzzy sets, granularity and similarity-based approximate reasoning employing natural semantics, and composition of fuzzy relations by a Cartesian product. Testing these methods for fault diagnosis in a power system is presented in this chapter.

6.2.4 Fuzzy set representation

Representing a fuzzy set is concerned with how to introduce membership functions. For instance, let X be the universe of objects with elements x , where A is called a fuzzy sub-set of X (a fuzzy set). Membership of x in classical set A can be viewed as a characteristic function μ_A from X to $(0,1)$, as below:

- $\mu_A(x)$

Where μ is called the membership function or grade and x is the elements of the fuzzy sets.

6.2.5 Linguistic variables

Linguistic variables are composed of expressions such as words, phrases or sentences. These statements can be manipulated to determine the meaning of the natural language, which is a similar way of logic calculation employing logical statements. For example, in respect of the linguistic variable size terms, a linguistic description about transformer overloads is, as follows:

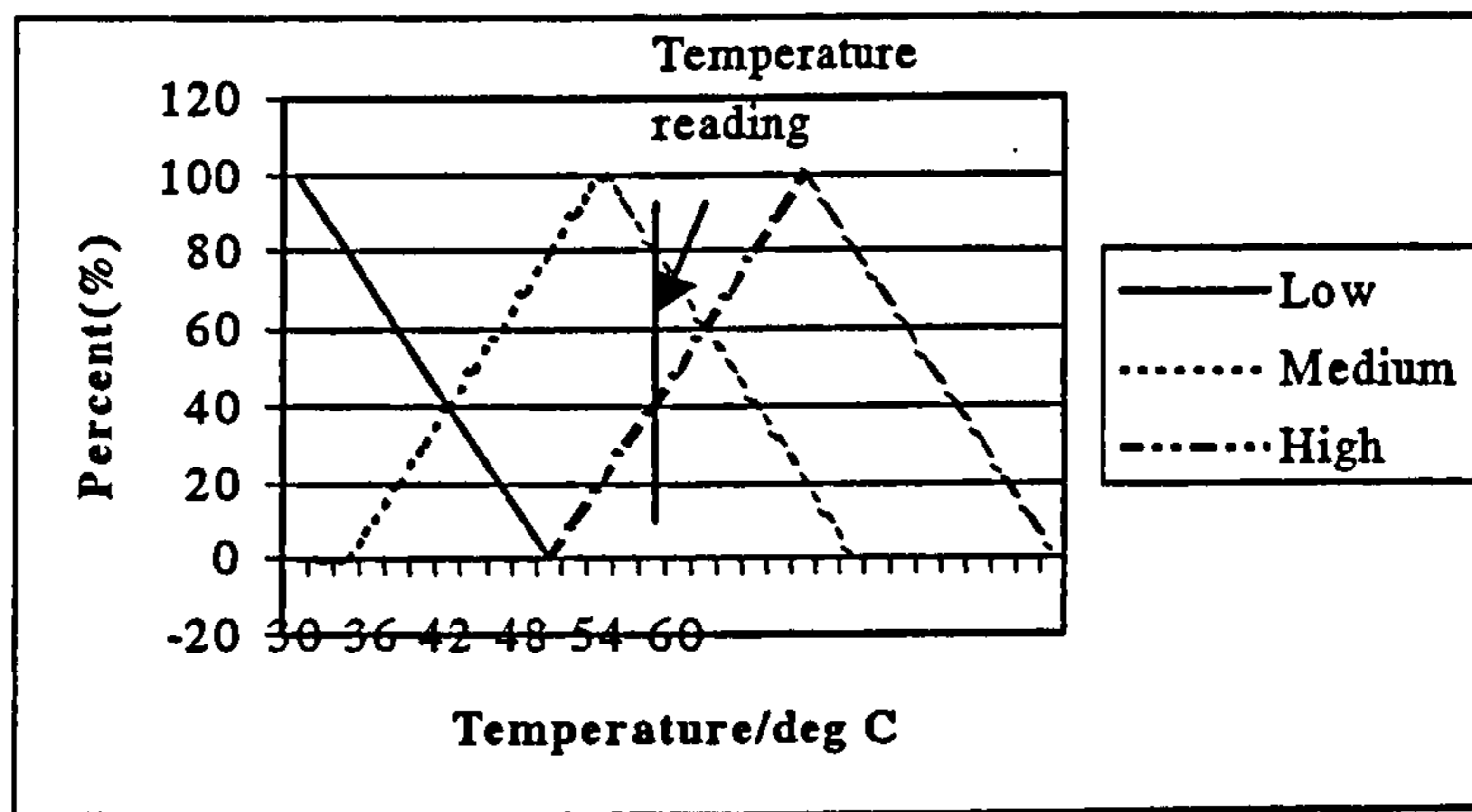


Figure 42 Composition of linguistic variables

Figure 42 show that operators try to keep the transformer temperature as low as possible if overloads are unavoidable in order to restore the electricity service completely. This linguistic expression proposes that the term, “low” is imprecise, but how low is “low” in a mathematical form? Thus, the technique presented here uses linguistic variables, whose values are words rather than numbers.

6.2.6 Fuzzy set operations

A fuzzy set that is defined via their membership functions, as follows:

Intersection:

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)) \dots \dots \dots 23$$

Union:

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)) \dots \dots \dots 24$$

Complement:

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x) \dots \dots \dots 25$$

These basic principles such as $\mu_{A \cap B}(x)$, $\mu_{A \cup B}(x)$, and $\mu_{\bar{A}}(x)$ are the membership functions or grades. They describe the degree to which the elements x belong to the fuzzy sets.

On the basis of these membership functions, there were three major fuzzy sets investigated in association with the one, fuzzy union.

First, generation of alternative hypothesis, different rules concerning fault location are processed one by one during the inference. They consist of two inference mechanisms,

plausible fault locations by heuristic knowledge and configuration values by fault detectors. These two mechanisms are called generation of alternative hypothesis, which forms a fuzzy set R_i with a membership function. If a rule is composed, fuzzy set R_i is combined with fuzzy set F_{fault} employing algebraic sum. This algebraic sum is based on the fuzzy union of F_{fault} and R_i , as follows:

$$\mu_{F_{\text{fault}} \cup R_i}(X) = \mu_{F_{\text{fault}}}(X) + \mu_{R_i}(X) - \mu_{F_{\text{fault}}}(X) \mu_{R_i}(X) \dots \dots \dots 26$$

This algebraic sum increases the degree of possibility of a faulted feeder, claimed by [Castro 1980], which shows natural in conjunction with the fuzzy union as there is one more reason why the component of the faulted feeder could be the place of the fault. When all these memberships of the rules have been processed, fuzzy set F_{fault} contains all alternative hypotheses. A case study will be discussed in the proceeding chapter 7.

Second, generation of deductions, provides the most likely fault location which is selected from fuzzy set F_{fault} based on the membership grades, by alternative hypotheses. The decision can be reached using maximum selection and alpha level selection, as follows:

- Maximum selection: the most likely place for the fault is the component with the highest grade of membership in F_{fault}
- Alpha level selection: the alpha level set of F_{fault} includes all components with a grade of membership greater than the given value of α

The application presented in this chapter attempts to resolve faulted feeders using these theoretical fuzzy sets.

6.2.7 Fuzzy logic systems

A fuzzy logic system consists of four principal components as shown in figure 43, a fuzzification interface, a user interface, an inference engine, and a defuzzification interface.

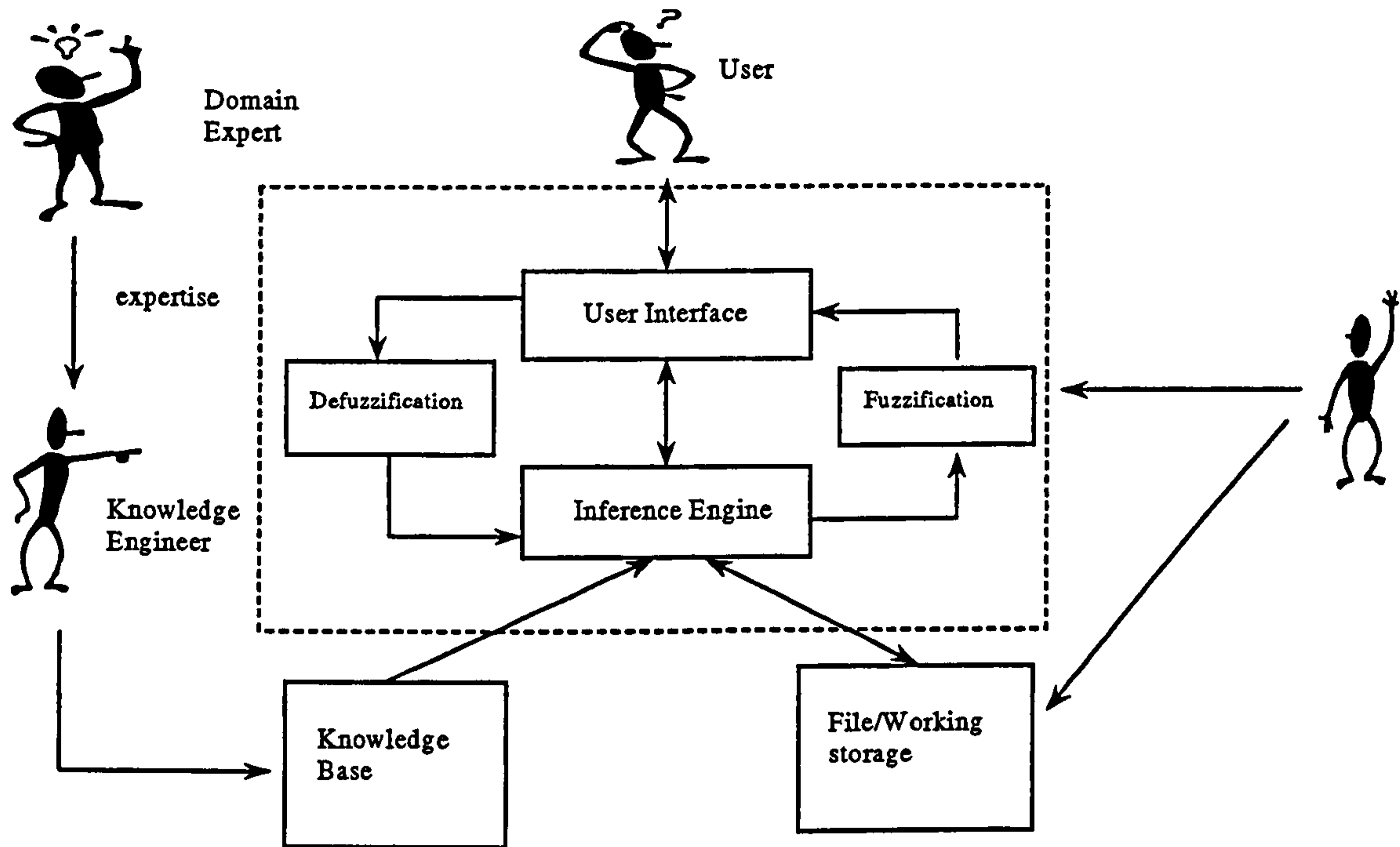


Figure 43 Fuzzy logic components and human interfaces

First, the fuzzification interface provides the following functions;

- Measures the values of input variables
- Performs a scale mapping that transforms the range of value of input variables into the corresponding universe of discourse
- Performs the function of fuzzification that converts input data into suitable linguistic values

Second, the user interface is to support fuzzy rules, which consists of linguistic control rules, i.e. an IF situation THEN action pair. The IF portion of the rule is called the premise or antecedent, while the THEN part is the consequent.

Third, the inference engine is a decision-making logic which deploys forward chaining through rules to reach conclusions as to how suitable control actions are determined from a given evidence. There are two fundamental keys in the execution of the rules, the treatment of multiple evidences, and implication. The treatment of multiple evidences is concerned with the connection of fuzzy propositions. For example, x is A and y is B through AND where A

and B are fuzzy sets. Their evidences are resolved into a single evidence by applying some operator for each pair of singletons in the universe of A and B. The implication is determined from operators that perform a transition from the universe of the antecedent to the consequent. This is so that a conclusion in the universe of the consequent employing a fuzzy relation can be inferred from any premise in the universe of the antecedent. The antecedent of a fuzzy rule may combine multiple simple conditions into a complex one using three connectives; AND/conjunction, OR/disjunction, and NOT/negation, such that

IF the outage of substation A is high likely by the experience of operators AND the outage of substation A is medium-likely by a fault detector, THEN recommend the outage of substation A is upper-medium likely.

The consequence from these rules can be classified into three categories:

Crisp consequence: IF...THEN $y=a$ where a is non-fuzzy numeric value or symbolic value.

Fuzzy consequence: IF.....THEN y is A where A is a fuzzy set.

Functional consequence: IF x_1 is A_1 AND x_2 is A_2 ... x_n is A_n

$$y = a_0 + \sum_{i=1}^n a_i \times x_i \dots\dots\dots 27$$

Where a_0, a_1, \dots, a_n are constants.

Since the inputs to fuzzy control systems are crisp, the truth-value is computed and related to the conclusion part of the outage rule.

In respect of these two keys, an application of the compositional rule is defined, as follows:

Let X and Y be the universe of discourse for variables x and y, respectively, and x_i and y_j be elements of X and Y. Let R be a fuzzy relation that maps $X \times Y$ to [0,1] and the possibility distribution of X is known to be $\Pi_x(x_i)$. The compositional rule of inference infers the possibility distribution of Y,

$$\Pi_Y(y_j) = \bigoplus_x (\Pi_x(x_i) \otimes \Pi_R(x_i, y_j)) \dots\dots\dots 28$$

The fuzzy conjunction and disjunction operations in Equation 4.1 correspond respectively to the multiplication and summation steps in matrix multiplication. This equation suggests that the compositional rule of inference is not uniquely defined. Thus, different compositional rules of inference are required, by choosing different fuzzy conjunction and fuzzy disjunction operators, as below:

max-min composition:

$$\Pi_Y(y_i) = \max_{x_i} (\min(\Pi_X(x_i), \Pi_R(x_i, y_j))) \dots\dots\dots 29$$

max-product composition:

$$\Pi_Y(y_i) = \max_{x_i} (\Pi_X(x_i) \times \Pi_R(x_i, y_j)) \dots\dots\dots 30$$

These two methods are commonly used in practice and processed by employing a fuzzy graph which is illustrated, as follows:

Let X, Y, and Z denote fuzzy set in universe of discourse U, V, and W respectively. Then, figure x and figure y demonstrate the graphical interpretation of the max-min and max-product inference methods for the single rule of the power system outage, e.g. IF X and Y THEN Z.

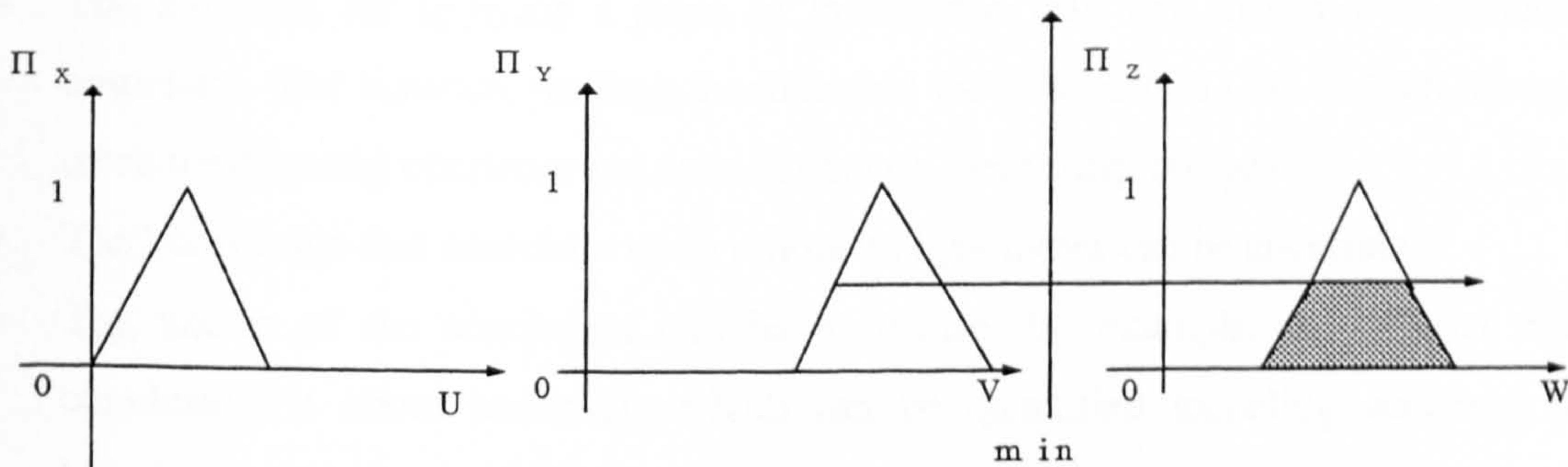


Figure 44 Fuzzy graph of max-min inference method

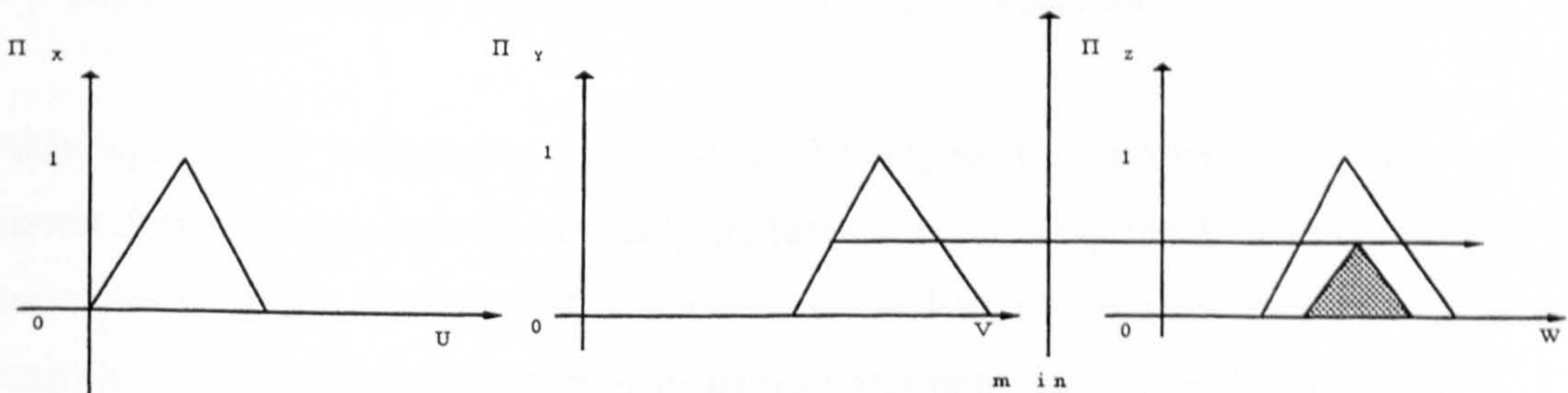


Figure 45 Fuzzy graph of max-product inference method

Fourth, defuzzification is the final output to be in a crisp form in that fourth step, which falls into two major techniques; the Means of Maximum method, and the centroid method. The mean of maximum defuzzification calculates the average of all variable values with maximum degrees. The centroid defuzzification calculates the weighted average of a fuzzy set.

6.2.8 Fuzzy logic applications to alarm management

A power system consists of a number of generating plants, busbars, transmission lines that constraints a high order of non-linearity in alarm management. Human experts play central roles in trouble shooting or fault analysis in power systems. Operators attempt to diagnosis equipment malfunctions as well as disturbances. Equipment malfunctions occur quite often, are caused by many factors, and the information on these factors available is limited for a short period.

The expert system presented in Chapter 5 has demonstrated to be useful in alarm management including dealing with uncertain SCADA data. In respect of uncertainty, there are at least four kinds of uncertainty in expert systems when compared with fuzzy logic-based approaches, claims Yen (1999).

- The situation for applying a piece of knowledge may not have a well-defined sharp boundary. For instance, the fault location that the relay trip in CB1 is high likely, this is often used among operators and does not have a clear sharp boundary.
- The knowledge that associates observations to hypotheses can be uncertain.
- The nature of the conclusion can be imprecise, for example, this occurs when the conclusion is about something which can be quantified including accuracy of fault location.
- The data to which the knowledge is applied may be uncertain.

Although many techniques have been developed to resolve such various types of uncertainties, fuzzy logic is uniquely suitable for handling the first and the third kind of uncertainty, claims Shafer (1990). This is because both of them are imprecise by nature. The fuzzy knowledge applied to alarm management attempts one step in that direction.

6.3 Intelligent Hybrid systems

Intelligent hybrid systems have appeared in the literature of control theory [Funabashi 1995; Song 1996]. The hybrid system techniques can be developed in a variety of ways, as below:

- **Combination:** current intelligent techniques mimic certain brain activities in a complementary way. Typical hybrid architecture is the sequential combination of neural networks and expert or fuzzy systems.
- **Integration:** combination is a basic hybrid architecture, but in some cases the integration of other intelligent elements helps to determine the total system behaviour.
- **Fusion:** a distinctive feature of neural technology is its capability of learning and adaptation. When other techniques incorporate this feature, they are able to increase their learning efficiency.
- **Association:** flexible intelligent system requires a distributed architecture where each element works autonomously and co-operatively. This advanced architecture will allow developers to create a variety of intelligent agents for different situations.

These techniques can be summarised as fuzzy-neural networks, fuzzy-expert systems, fuzzy-controlled genetic algorithms, genetic based fuzzy systems and genetic neural networks. Recently, intelligent hybrid systems have been applied to wide range of power system problems, including load forecasting, static security assessment, and power system stability are prescribed by [Dash 1996; Bakirtzis 1995; Mori 1994]. To design the basic concepts of fault diagnosis technique, this chapter delineates fuzzy-expert systems that are discussed in the proceeding section.

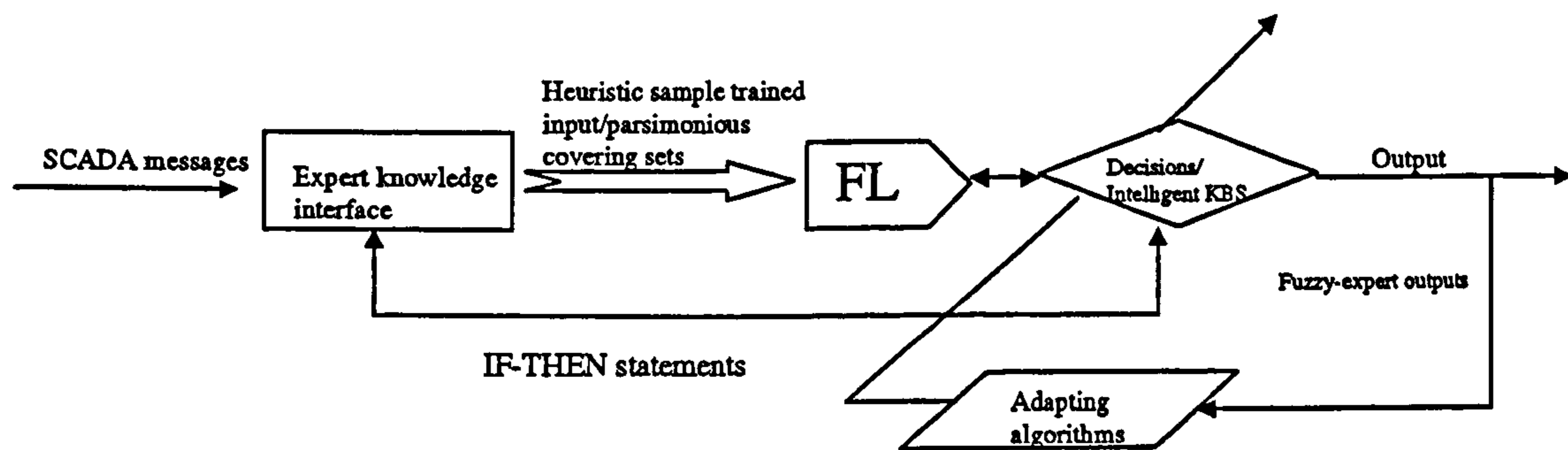
6.3.1 Fuzzy-expert system

Fuzzy-expert systems are taken over from conventional production-rule based expert systems, as there are some advantages when compared with fuzzy logic, as follows:

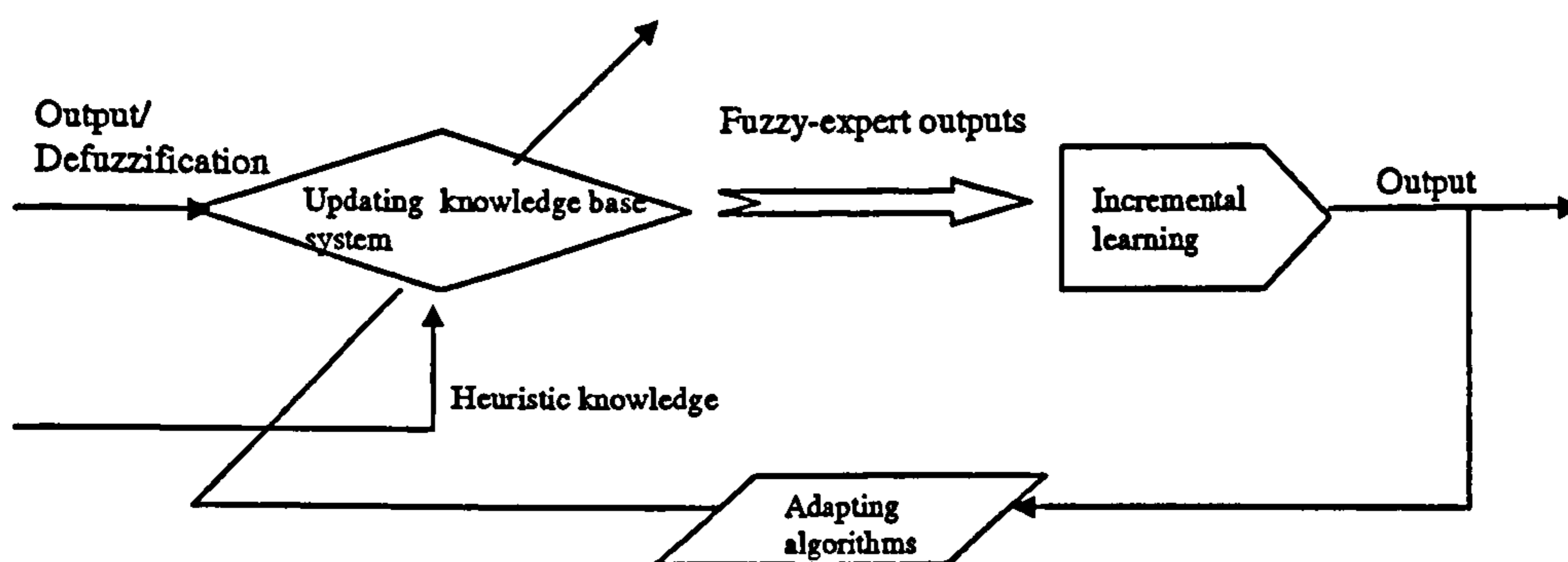
- Fuzzy sets neatly symbolise natural language terms used by experts, since knowledge captured in IF-THEN statements is often not naturally true or false. Fuzzy sets provide representation of the knowledge in a smaller number of rules;
- Fuzzy rules can be tuned on-off;
- A smooth mapping can be obtained between input and output data.

These literature studies show that expert systems represent knowledge in sets of IF-THEN-ELSE. Propositions are proven by discovering a chain of rules, which is determined through forward or backward chaining [Warwick 1997]. In forward chaining, expert systems have provided a probability of success on certain well-defined problems. However, many failures have occurred as most of such problems have been caused by the difficulty of obtaining a consistent, complete set of heuristic rules. In backward chaining, it starts with evidence and tries to deduce one conclusion. Important aspects of heuristic knowledge by human are far from a simple rule for human experts' knowledge is often in the form of natural language, with imprecision or vague information.

Likewise, fuzzy systems rely on a set of rules which is similar to expert systems, superficially. However, the set of rules allows the input to be fuzzy where humans express knowledge in that natural way. For example, a control engineer refers to a power system, as an outage on the suspected circuit breakers is high, which can be expressed directly by a fuzzy system, as follows:



(a) Feedforward architecture: IKBS responds to the rule based expert and FL



(b) Feedback architecture: IKBS drives the fuzzy-expert inference mechanism

Figure 46 Two models of fuzzy-expert approach

Figure 46 shows that two models are illustrated, Feedforward architecture, and feedback architecture. The former model in fuzzy logic can represent knowledge in which an expert system may need a large set of rules. The latter model shows an incremental learning by updating the KBS.

In respect of these, fuzzy rule based system employed in the expert system presents the representation of imprecise operators' knowledge in a natural and logical way rather than forcing the use of precise statements.

6.4 Fuzzy-expert system based fault diagnosis schemes

The fuzzy-expert system applied in this scheme consists of four stages, observed disorders, plausible values, crisp values, and defuzzification, which were designed to determine the best explanations from the proposed system. In FE, the expert system is primary used to maximise its heuristic knowledge in conjunction with an abductive reasoning. The ES part provides plausible values and fuzzy rules during the reasoning when uncertain SCADA data are encountered by the KBS. Furthermore, the fuzzy rules are used to infer and provide a crisp or defuzzified output when plausible values exist.

6.4.1 Primary configuration of the technique

The FE-based fault diagnosis as developed in this work is shown in figure 42 and 43. The technique consists of two stages; alarm interpretations based solely on heuristic knowledge system, and approximate location of a fault on the line compromising the expert system and fuzzy sets. The experimental method is based on utilising a source of fault detectors at the end of faulted feeders and operation of circuit breakers and relays. The fault diagnosis processed throughout the FE is very close to where operators use semantic interpretations rather than mathematical rigidity.

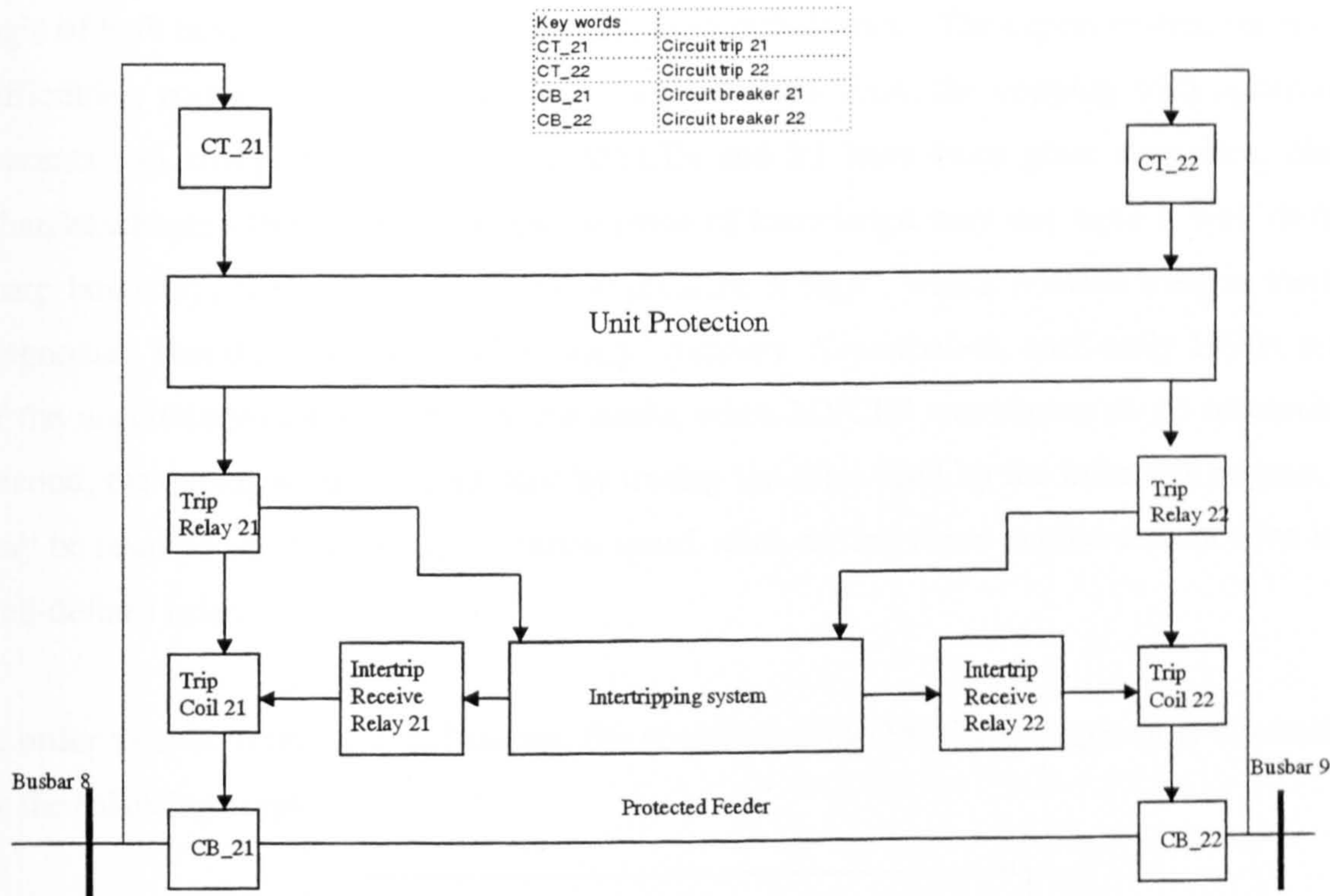


Figure 47 An operation of circuit breakers and relays

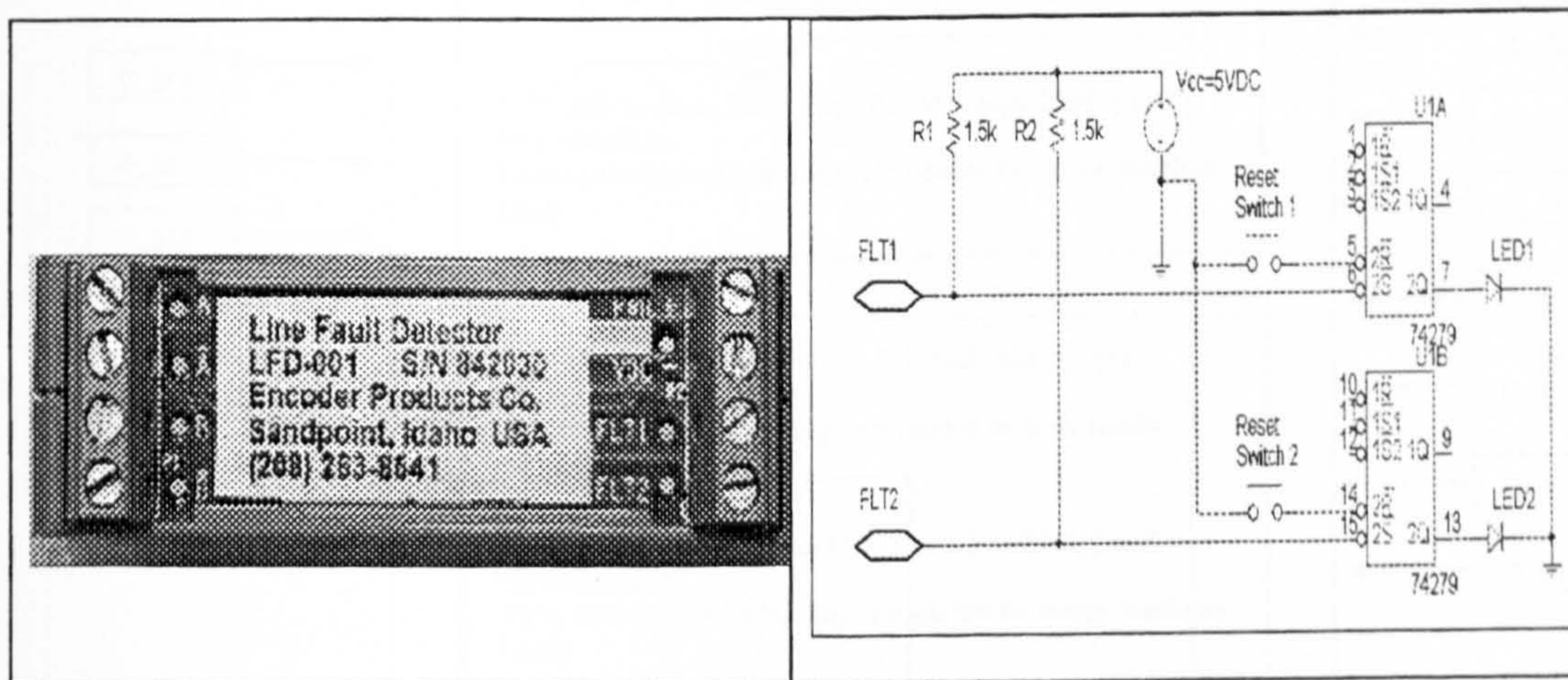


Figure 48 A line fault detector used on the feeders in association with figure 47

The fault diagnosis technique demonstrated in this work is achieved through a combination between heuristic knowledge and observed configurations on uncertain SCADA data, in conjunction with these two primary configurations.

6.4.2 FE fault diagnosis structure

Fuzzy logic is defined as an extension of Boolean Logic which is the transition from membership to non-membership and gradual rather than abrupt. The expert system and fuzzy

logic of both have some disadvantages when used in their own. The expert system shows two difficulties, coping with uncertainty, and explanations. First, the coping with uncertainty presents still complex problems since MYCIN and R1 have been great successes, claims Chandrasekaran (1994). For example, a piece of knowledge may not have a well defined sharp boundary; the symptom that “blood pressure is high”, which is often used in medical diagnosis. This does not have a clear sharp boundary. Nevertheless, until early 1990s, much of the uncertainty-factor formalism was made, when MYCIN was shown to AI researchers. Second, the explanations are generated by tracing the rules fired by the inference engine, but may be resulted in constraining execution speed when the inference engine searches for large well-defined rules.

In order to overcome these difficulties, the structure of the FE fault diagnosis is determined by the following steps:

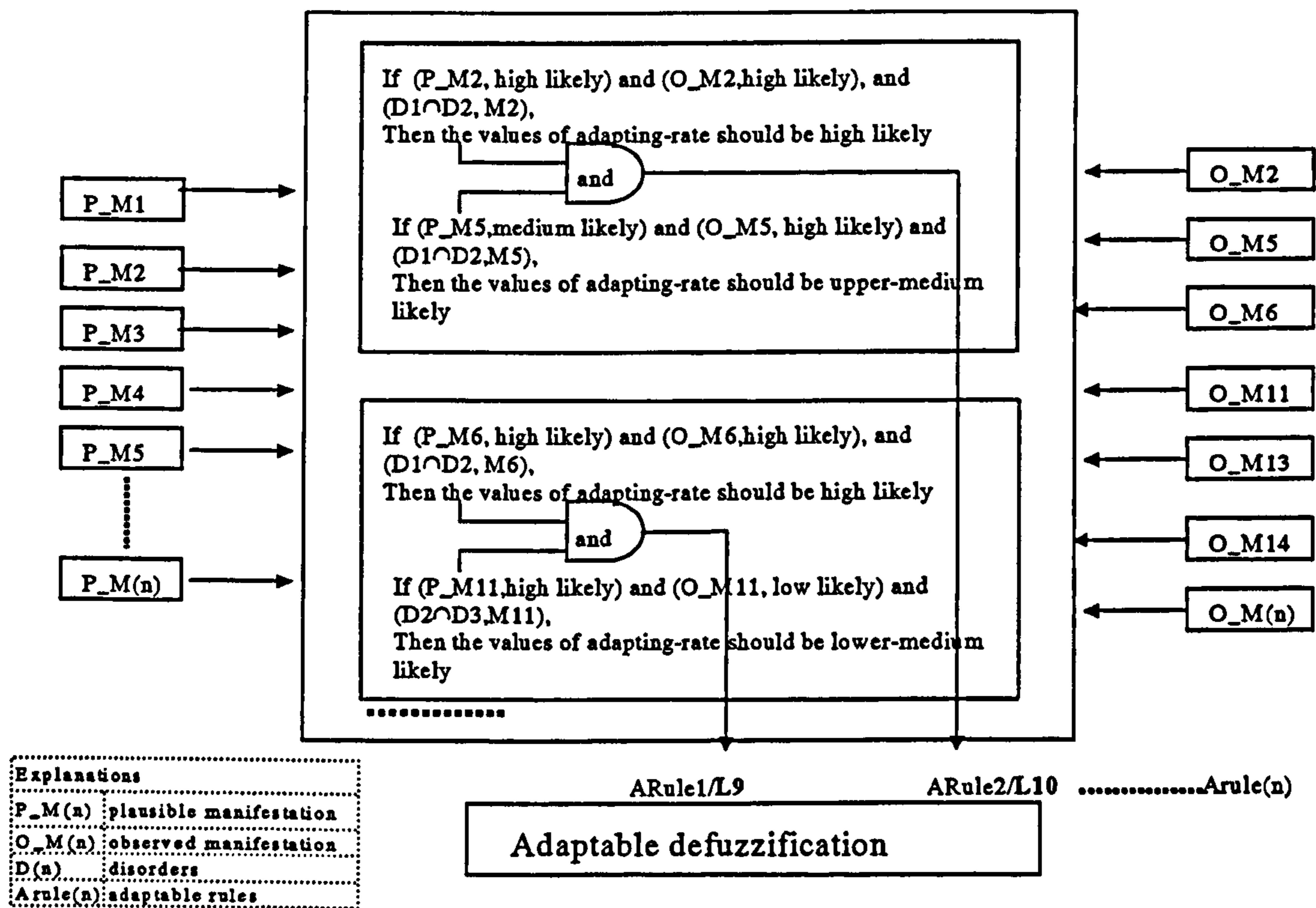


Figure 49 Fuzzy-expert system structure

Figure 49 illustrates that the FE employed compromises of three components, plausible inputs, crisp/observed configuration inputs, and defuzzification. The FE carries out fuzzification with the parameters between plausible inputs and crisp configuration inputs.

6.4.2.1 Fuzzification

Fuzzification concerns the findings of the degree in which the truth of a proposition exists such as O_M1 is high likely when O_M1 is 0.9. This fuzzification developed in this work employs the fuzzy if-then rules, which is by far the most visible one due to its wide range of successful applications. Triangle membership functions are used to determine the fuzziness of the problem.

6.4.2.2 Acquisition of fuzzy knowledge and inference by expert system

The foundation of fuzzy rules in expert systems is fuzzy implication rules. The inference of these rules is based on approximate reasoning using fuzzy implication functions. These are; representing the meaning of a fuzzy implication rule using a fuzzy relation, and obtaining an inferred conclusion by applying the compositional rule of inference to the fuzzy implication relation. A sample system for inferring an outage on transmission lines was attempted, as follows;

- IF Ground fault occurred at line9 is Medium likely AND Ground fault occurred at line10 is High likely AND observed configuration sources on the outage feeders are High likely at line9 and at line10, THEN the outage is high likely caused by the busbar failure.

This shows that the location of the fault is constituted by the interaction of linguistic variables under different fault conditions, which is determined by the observed fault detectors' sources.

6.4.2.3 Defuzzification

As shown in figure 50, for a fuzzy system whose final output needs to be in an adaptable form which falls into two major techniques, the Mean of Maximum method (MOM), and the Centre of Area (COA)/the centroid method. For example, a fault location was determined using centroid defuzzification, in the proceeding figure 60 of section 7.4.

6.4.3 Adapting sample data

Adapting sample data for FE is achieved the same way as aforementioned in chapter 5. The fault diagnosis technique is based on solely on an abductive heuristic knowledge structure. The plausible values to the heuristic knowledge base compromise of a set of features based on

the observed disorders, plausible memberships, and observed configuration sources in conjunction with fault detectors. In respect of utilising fault detectors, the following components are taken into account to generate the plausible inputs to FE:

- Phases
- Relay operation
- Circuit breaker trip
- Lines
- Buses

These components are quite complex when an outage occurs. [Momoh 1995] claims that “there are many uncertain factors in various power system problems as power systems are large, complex, geographically widely distributed systems and influenced by unexpected events. These facts make it difficult to effectively deal with many power system problems through strict mathematical formulation alone”. For these reasons, by using fuzzy sets, the problem of uncertain SCADA data can be overcome by mapping the membership of plausible manifestations in the different classes.

6.4.3.1 Fuzzification of crisp information for the FE

An interpretation on faulted feeders is attempted employing triangular membership functions in this section. These are to convert the previously extracted features into fuzzy sets for the FE. The transmission system consists of a number of feeders which describes degree of the truth value when the parameters are conclusive, as below:

6.5 Summary

Expert systems show unsatisfactory for the uncertainty as there are four important aspects, such that:

- They do not provide the means for dealing with the fuzziness of antecedents and consequences.
- They assume that probabilities can be estimated as crisp numbers.
- They do not offer a mechanism for inference from rules in which the qualifying probabilities are fuzzy.

- The rules for composition of probabilities depend on unsupported assumption about conditional independence.

Although MYCIN has provided a significance of employing heuristic knowledge which is represented in a confidence factor, the technique presented here attempts to improve the uncertainty of an expert system based fault diagnosis in a power system.

Chapter 7: Performance evaluation of the fault diagnosis techniques

7.1 Introduction

As stated in Chapter 6, the design of fuzzy-expert based fault diagnosis scheme was examined in detail. In particular, the uncertain SCADA messages processed by the diagnostic tool were inferred employing an abductive reasoning while the KBS resolved derived SCADA messages. This chapter presents performance evaluation of the system, an abductive fuzzy knowledge based system for fault diagnosis in a power system. This research was evaluated employing a qualitative analysis by observation, questionnaires and interviews using a number of participants.

A major goal of implementing this system is to assist operators when a heavy alarm period occurs. In this respect, the participants were potential users of the system in the field of power system operators and alarm analysts. Their heuristic knowledge was included in the questionnaires in which a qualitative analysis was attempted to establish conclusions of human based fuzzy knowledge system in alarm processing and fault diagnosis.

The performance evaluation was based on the proposed system methodology as described in Chapter 5 and 6 for processing alarm information and fault diagnosis. This involved participants testing the developed system from the derived SCADA data. The proposed system was implemented in an object-oriented AI development toolkit, Kappa-PC. The method of assessing the performance consists of repeated batches of trials from features of object-oriented power topology networks, and the analysis for the evaluation was attempted.

7.2 Performance evaluation of the technique based solely on the expert system

This AI system should behave effectively in power system changes it has not previously encountered. The proposed alarm prioritisation deploying a symbolic process in condition monitoring should cope with novel combinations of SCADA based vague data, including the developed power topology networks, and conventional alarm messages.

A power system model of 132kv to HE plc was employed, which consists of 12 Buses and 16 Lines. This model was slightly modified from the actual complicated networks for an effective experiment and applied to assess the developed system, as follows:

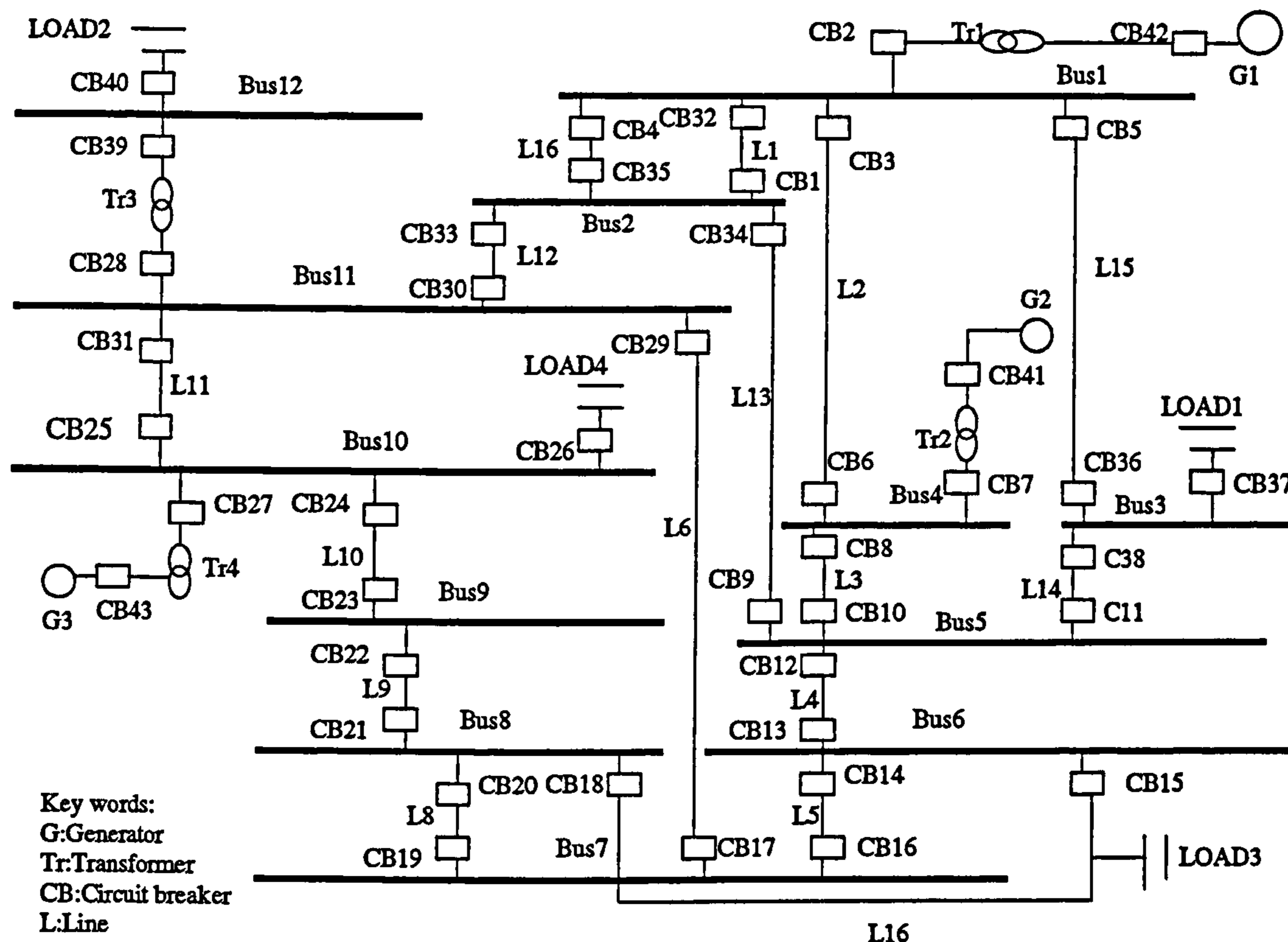


Figure 50 Simplified 132kv substation networks in Scottish Hydro Electric PLC

Figure 50 illustrates a transmission system which consists of lines, buses, loads, transformers, and generators. The transmission system delivers power to the customers and circuit breakers and relays control the elements of alarm processing. This power system model was applied to the developed system and the technique employed in the system consists of 8 steps as shown in figure 51, but was tested from step 1 to step 5. Further steps from 5 will be discussed in the proceeding chapter.

- Step 1 The API activates a text retrieval of the event log.
- Step 2 The OODB receives and store the information in the form of class and instance.
- Step 3 The information is retrieved by Kappa-PC function and created to the behaviour of encapsulation.

- Step 4 The rules in the system knowledge base are expected to find all the events, in which the opening of a circuit breaker might be expected to occur, utilising forward chain, method, and function.
- Step 5 The derived events enter the KBS session of the tool, the lists of pre-coded hypothesis are examined as to whether the uncertain information is conclusive, i.e. urgent, non-urgent, minor, and unknown.

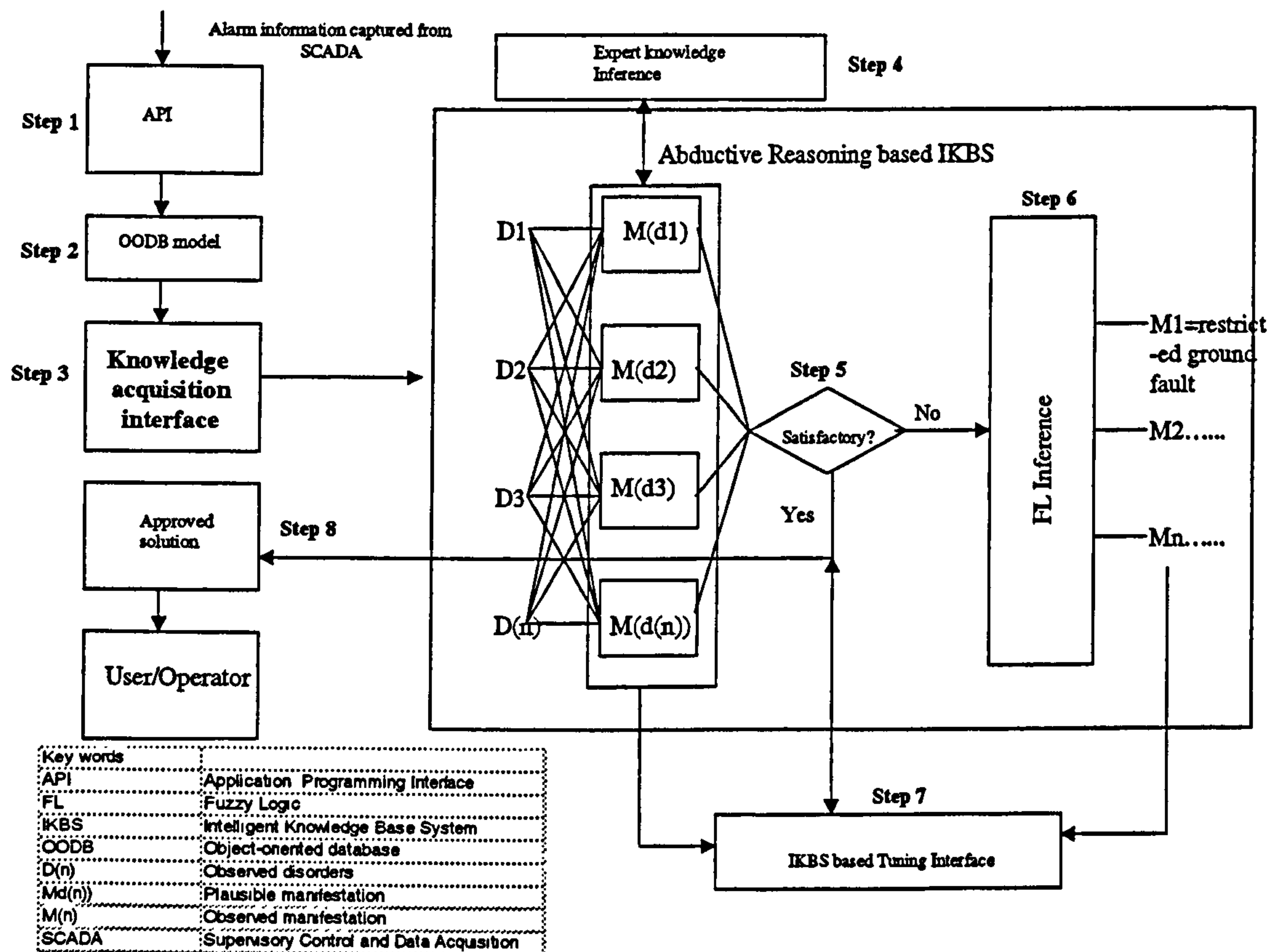


Figure 51 The approach of hypothesis in the diagnostic tool

Figure 51 delineates an effective alarm prioritisation and new uncertainty process. The object-oriented expert system was designed within the steps, which performed two fundamentals, alarm prioritisation, and new uncertainty process.

Experimental method using the diagnostic tool was carried out to test these tasks, as follows:

- This system was demonstrated in Nov. 1998
- Access to HE control centre was confirmed

- Participating control engineers and system engineers responded to the questionnaires which were based on the developed knowledge base system an AI based power system and empirical literature review
- 13 questions were asked to 5 operators
- Features of object-orientation were employed in conjunction with the designed knowledge base, such as reusability, encapsulation, extensibility, and maintainability
- The experimentation was attempted to observe tangible cost benefits by minimisation of system unavailability for potential real users

The procedure of testing these 5 steps was begun at collecting twenty raw SCADA data. Those data were studied and reduced to four SCADA data, as not all the alarms were necessary to process. This means that every item of plant in the power system network transmits appropriate data to the central SCADA which would provide its current state. However, this system was designed to focus on circuit breakers and protections in the power topology network. Thus, items of switching gear information were utilised from existing SCADA in which operation of such faulted feeders was tested.

A number of hypothesis tested	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	ST DEV
API Design	8.17	8.67	8.50	8.67	8.50	0.20
OODB storage	8.75	8.25	8.50	8.50	8.25	0.21
Knowledge acquisition interface	8.75	9.00	9.00	8.50	8.50	0.25
Expert knowledge inference engine	7.56	8.11	8.11	8.00	7.89	0.23
Decision presented	8.67	8.67	8.33	8.67	8.33	0.18
Average	8.38	8.54	8.49	8.47	8.29	0.21

Table 17 A survey of the developed expert system counterpart

Opinions scored:

(10~8): Strongly agreed;(7.9~7):Quite agreed;(6.9~6):Fairly agreed;(5.9~5):Agreed;(4.9~):Disagreed

Table 17 shows that the analysis approach is based on the sampling distributions, using n=5 scores from the 13 criteria. The sampling distributions implicate performance from the

object-oriented expert system was obtained, employing these thirteen questionnaires (referring to appendix B).

7.2.1 Simplifying complex alarm management

Simplifying complex alarm management is that of improving EMS (Energy Management System) capabilities. The proposed alarm management was based on the collection of disturbance data, showing alarm prioritisation of the outages from the changes of power topology networks. The following experiment shows a comparable alarm management:

Alarm management methods	% Alarm processing performance					Overall performance
	Knowledge modification	Inference speed	Disturbance data collection	Solution presented	Multiple faults applied	
The proposed alarm processing	92.00%	100.00%	100.00%	92.00%	83.00%	93.40%
The existing alarm processing	75.00%	100.00%	75.00%	83.00%	58.00%	78.20%

Table 18 A performance test on simplifying complex alarm management

Table 18 describes that two hypotheses were deployed in conjunction with 5 dependent variables and 12 different SCADA data sets were applied. This task was set up to test usability in a given simulation which consists of two criteria, as follows:

- Criterion 1. Alarm prioritisation should reduce volume of alarm on faulted equipment.
- Criterion 2. Symbolic alarm processing will help operators in which alarms are highly alerted.

The procedure of testing this simplifying alarm management was begun at collecting past outages in HE control centre. There were 60 routine alarm messages which contained those persistent alarms. These persistent alarms were examined to exclude unnecessary alarm messages such as daily operational alarms and etc, which have been reduced 12 different SCADA data sets. Each of the five dependent variables was focused on the sequential new SCADA messages which were observed in order to update power system models in the developed system.

The methods presented in table 18 consist of the proposed alarm messages as proposed in section 4.4, and the existing alarm messages. These two methods were the same alarms, but

composed of different formats. The experimental results show that there are two distinctive factors to explain. First, systematic alarm design has resulted in simplifying complex alarm management. Second, testing short alarm messages through the five system components shows that less effort and time is made to update the knowledge base when new alarms are input.

Thus, these two criteria aforementioned are quite satisfied by the alarm prioritisation which has attempted one step in that direction of simplifying complex alarm management.

7.2.2 Feature extraction

To assess the object-oriented expert system in alarm management, standard features of expert systems were used for the field experiments. The experiments were carried out at the control centre of HE, Scotland, which were made using the existing SCADA data to the derived SCADA data. In previous studies, the physical installation of object-oriented alarm processing to the SCADA was attempted by [Ramsay 1995], who proposed a primary investigation employing object-oriented features in association with same control centre. The results of carrying out the project have shown that some features of object-oriented techniques were advantageous in comparison with conventional AI languages. The power system model simulated in the OOP toolkit was similar to the actual power topology networks, and parallel processing was tested while operators are limited to cope with multiple functions.

To the extent, the experiments presented in this chapter were not made in a physical plug-in into the existing SCADA system, instead, the developed expert system was demonstrated to the HE operators. Series of interviews to the participants were carried out, in order to validate the proposed system.

The following sample test shows that the alarm processing was evaluated using the application tool, Kappa-PC on a IBM compatible PC, Pentium, 200MHz:

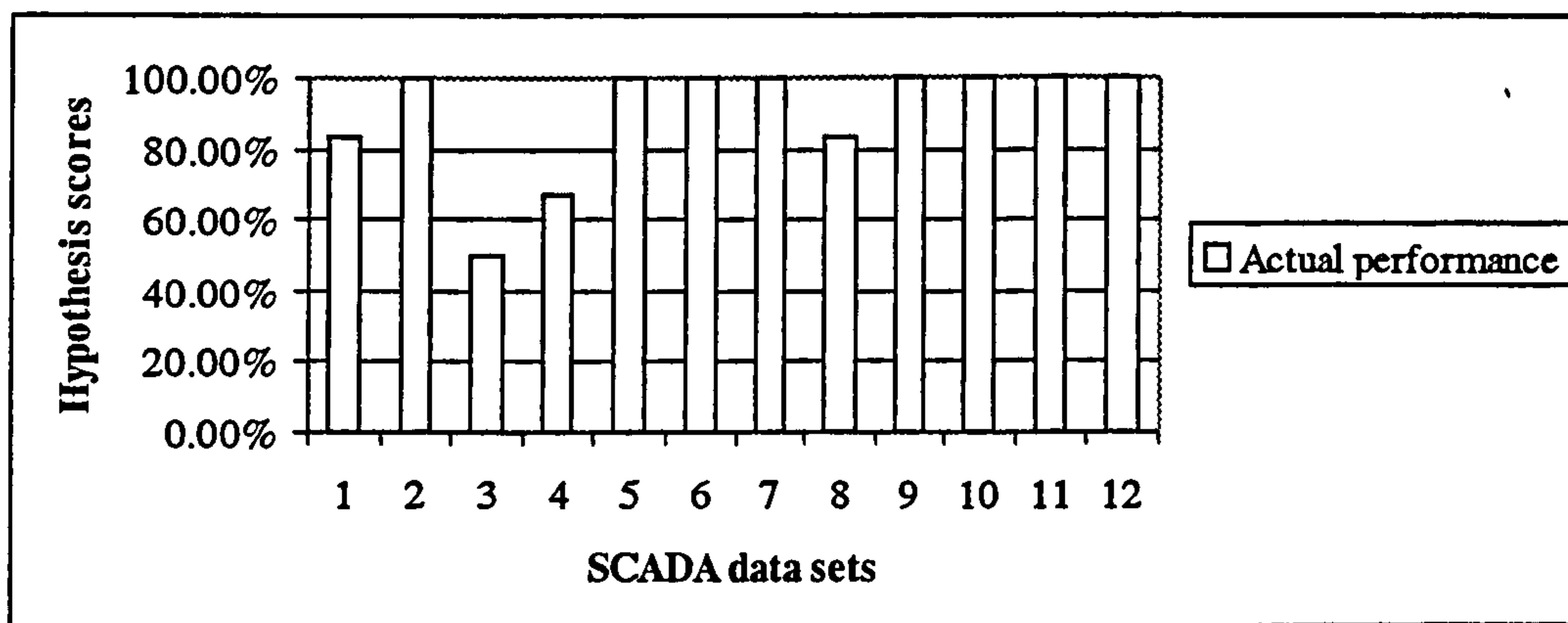


Figure 52 A sample test in the feature extraction

Figure 52 illustrates that 6 hypotheses were employed to test 12 SCADA data sets. Each categorical scale was assigned as an individual. The individual primary source was asked to the operators and confirmed against 12 data sets. The results show that the SCADA data sets applied to the requirements are adjusting of the existing configuration.

A number of trial	Forward chaining by Edit Rules	Backward chaining by Goal Editor	Knowledge acquisition from the SCADA configuration	Fault arrangement by Instances	User interface by graphical assimilation	Explanations by User request	Actual performance
Data set1	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%	83.33%
Data set2	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set3	100.00%	0.00%	100.00%	100.00%	0.00%	0.00%	50.00%
Data set4	100.00%	100.00%	100.00%	100.00%	0.00%	0.00%	66.67%
Data set5	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set6	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set7	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set8	100.00%	0.00%	100.00%	100.00%	100.00%	100.00%	83.33%
Data set9	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set10	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set11	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Data set12	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Average	100.00%	83.33%	100.00%	100.00%	83.33%	75.00%	90.28%

Table 19 Assessment categories in the feature extraction

Table 19 shows there were some data sets outperformed such as data set 3 and 4. First, data set3 was not responded when the backward chaining searched the appropriate feeders. The problem was identified using “message errors”, which showed the appropriate written goal was omitted in the KBS. Consequently, User Interface by graphical assimilation and Explanation by User request were not functioned. Second, data set4 was not responded to the designed user interface and explanations when the inheritance of Object:Slot was prohibited at the label of feeders.

Overall, performance suggests that new alarms can be adopted and maintained effectively using the developed alarm processing and diagnostic tool although minor problems are subject to rigorous test.

7.2.3 Performance of ES for prioritised fault

In order to test the capability of ES for the prioritised fault, an existing design of the hydraulic power system was simulated. A task to which the object-oriented expert system has been applied is that of fault arrangement design, referring to the electrical protection systems of HE transmission networks. These outage data were programmed to the KBS and a major goal of prioritised fault in alarm processing is to achieve an improved control and elimination of hand logging. A sample test was carried out, as follows:

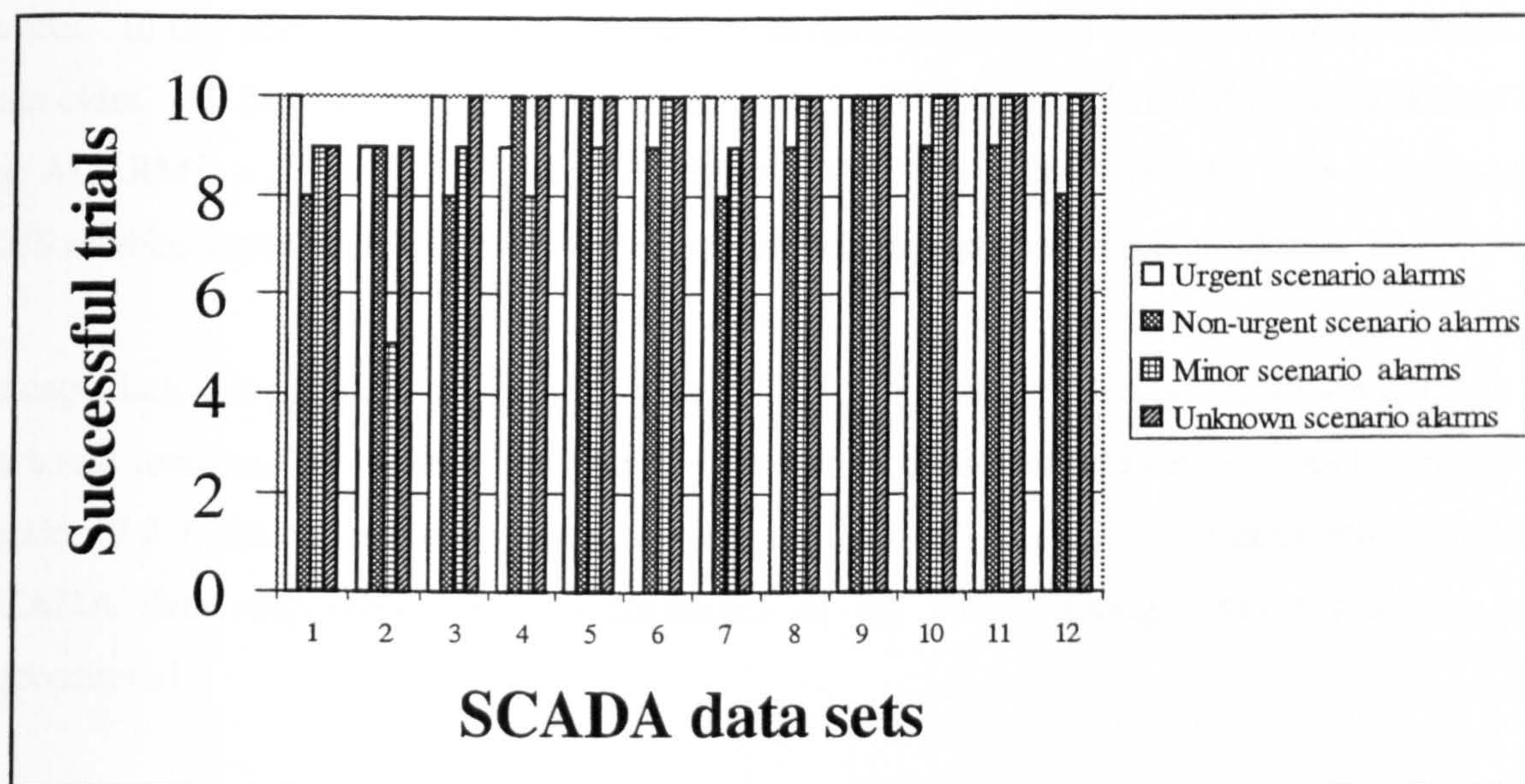


Figure 53 A sample test on symbolic alarm prioritisation

Figure 53 shows that the successful trials were measured employing 48 different combinations of alarms. The criteria to assess this experiment were based on the following three fundamentals:

- Knowledge acquisition process was observed.
- Symbolic process was observed.
- GUI should provide appropriate interpretations of those alarms

These three observables were applied to each individual of the four categories. Further discussions are drawn in the proceeding sections.

7.2.3.1 Analysis of the results

The results of alarm/fault prioritisation performance suggest that the derived outages from the existing SCADA system are well adopted into the object-oriented expert system as there are several features provided in the object-orientation techniques, inheritance, encapsulation, and parallel processing.

Inheritance is the mechanism used in defining new classes of object. A new class is defined as a child of some parent class and inherits all the data slots and methods associated with the parent. In this respect, an ALARMS class is defined as the child of a more general SCADA data class. All the data values and methods associated with the SCADA data are inherited by the ALARMS, e.g. a data slot indicating the state of the protection switch. This is so that the KBS enables forward chaining to search any existing hypotheses' expected alarms.

Encapsulation is primary support for the realisation of abstract data types, which consists of data and functionality. These are thought of as a single encapsulated entity. As illustrated in section 7.2.3, the experiment reveals that each ALARMS, in addition to containing slots for SCADA data responds to certain messages in the KBS although minor problems are encountered.

Parallel processing is introduced by having multiple and simultaneous active objects, and its communication between the active objects occurs by means of rendezvous, claims Elliens (1995). The advantage of this approach is quite successful to the alarm processing, informing that the symbolic alarm prioritisation and plausible outage areas employing GIS are willing to process the captured outages between method invocations.

However, there are two disadvantages observed, processing speed and large memory storage. The processing speed tends to slow down when forward chaining fires large rules, which is based on lengthy conventional alarm messages. The large memory storage is concerned with programming heuristic rules in the KBS, in conjunction with existing alarms. The operators have shown sceptical replies when developing the KBS was discussed with them. Instead,

they suggest those deriving persistent alarms from the main stream of SCADA would be very helpful for an effective control.

7.2.3.2 Performance evaluation

In order to evaluate the performance of the alarm prioritisation technique, two indexes are proposed, as follows:

Test cases Primary factors	1	2	3	4	5	6	7	8	9	10	11	12
Actual output	0.9	0.8	0.9	0.9	1	1	1	1	1	1	1	1
Single Confidence Index	0.1	0.2	0.1	0.1	0	0	0	0	0	0	0	0
Average Confidence Index	0.0083	0.0167	0.0083	0.0083	0	0	0	0	0	0	0	0
Overall Confidence Index	0.003472222											

Table 20 Performance evaluation of alarm prioritisation

Table 20 illustrates that the average performance of experiment was carried out over 12 combinations of SCADA data sets, and 10 days of trials. The formula used in this performance evaluation is, as follows:

Single Confidence Index (SCI): $\text{Expected- Actual/Expected}$ 31

Average Confidence Index (ACI): $\text{Sum of SCI/No of Test cases}$ 32

The total performance indicates that the total confidence index is 0.00347, quite successful trials, but subject to further improved knowledge based design.

7.2.4 Performance of fault diagnosis

This section shows performance of fault diagnosis in the object-oriented expert system is carried out employing different uncertain alarms. The designed expert system consists of three stages, observed disorders, plausible explanations, and observed explanations, which

was tested employing four data sets unseen by the ES before. The details are discussed in the proceeding sections.

7.2.4.1 ES structure

A task to deal with uncertain SCADA messages was carried out, which is based on heuristic rules programmed in the KBS employing confidence values. Table 21 shows the number of outages were diagnosed utilising these three stages as aforementioned in 7.2.4, an abductive reasoning, as below:

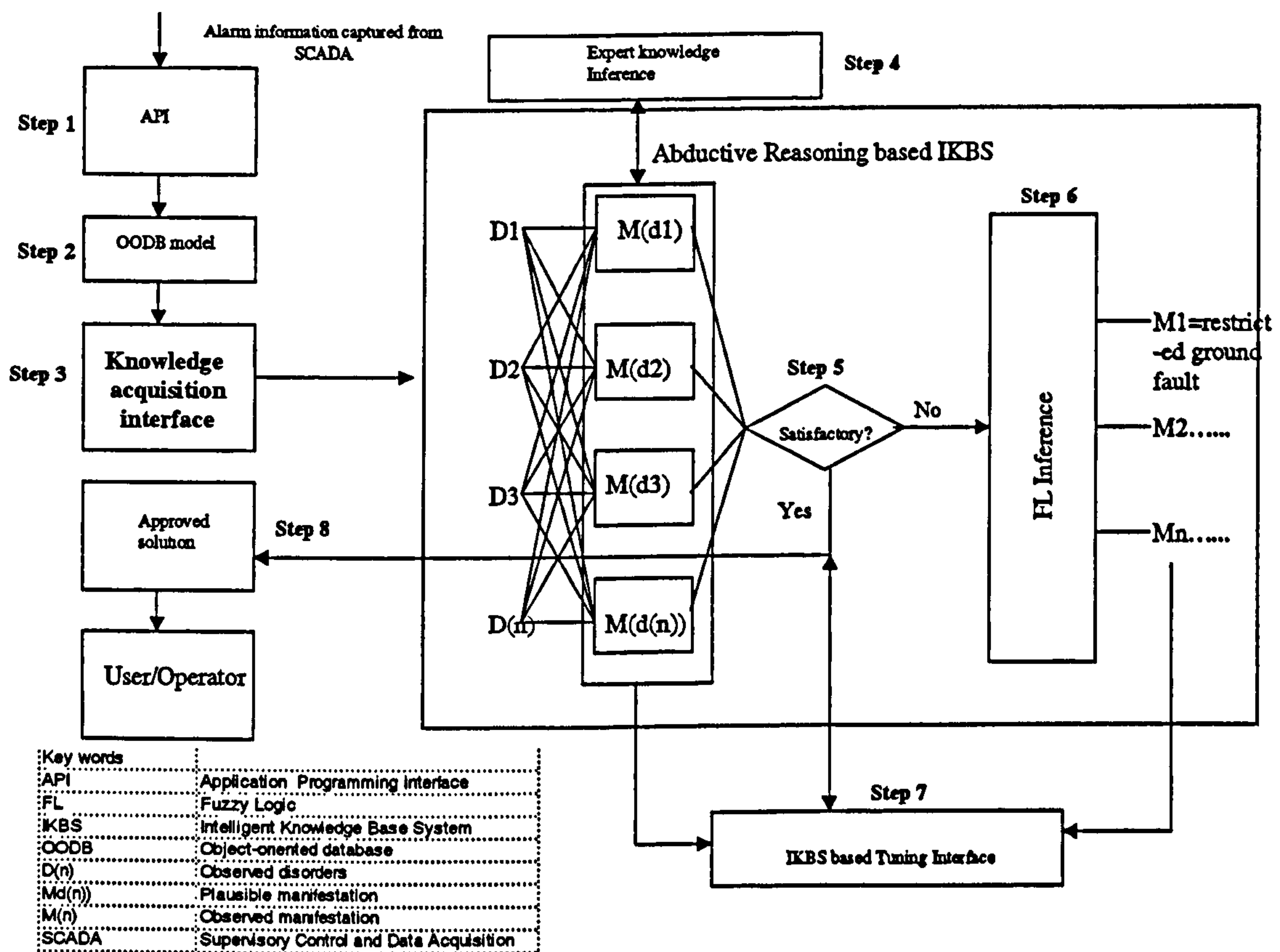


Figure 54 Architecture of ES in FL for fault diagnosis in a power system

Figure 54 illustrates that there are two systems incorporated, which are ES and FL. For the experiment of ES, the system consists of six parts, step1, step 2, step3, step4, step5, and step8. A number of sample tests were carried out, as follows:

Hypothesis steps SCADA data sets	Step1	Step2	Step3	Step4	Step5	Step8	Overall performance
SCADA data set1	1	1	0.9	1	1	1	0.98
SCADA data set2	1	1	0.9	1	1	1	0.98
SCADA data set3	1	1	0.9	1	1	1	0.98
SCADA data set4	1	1	0.9	1	1	1	0.98
Means	1	1	0.9	1	1	1	0.98
Note							
0~1	Successful trials						

Table 21 A performance test on the object-oriented expert system structure

Table 21 illustrates that the experimental procedure consists of a number of trials, and four SCADA data samples. Each step of the hypotheses was applied to 10 days of trials. The following figure 55 shows the performance of ES structure:

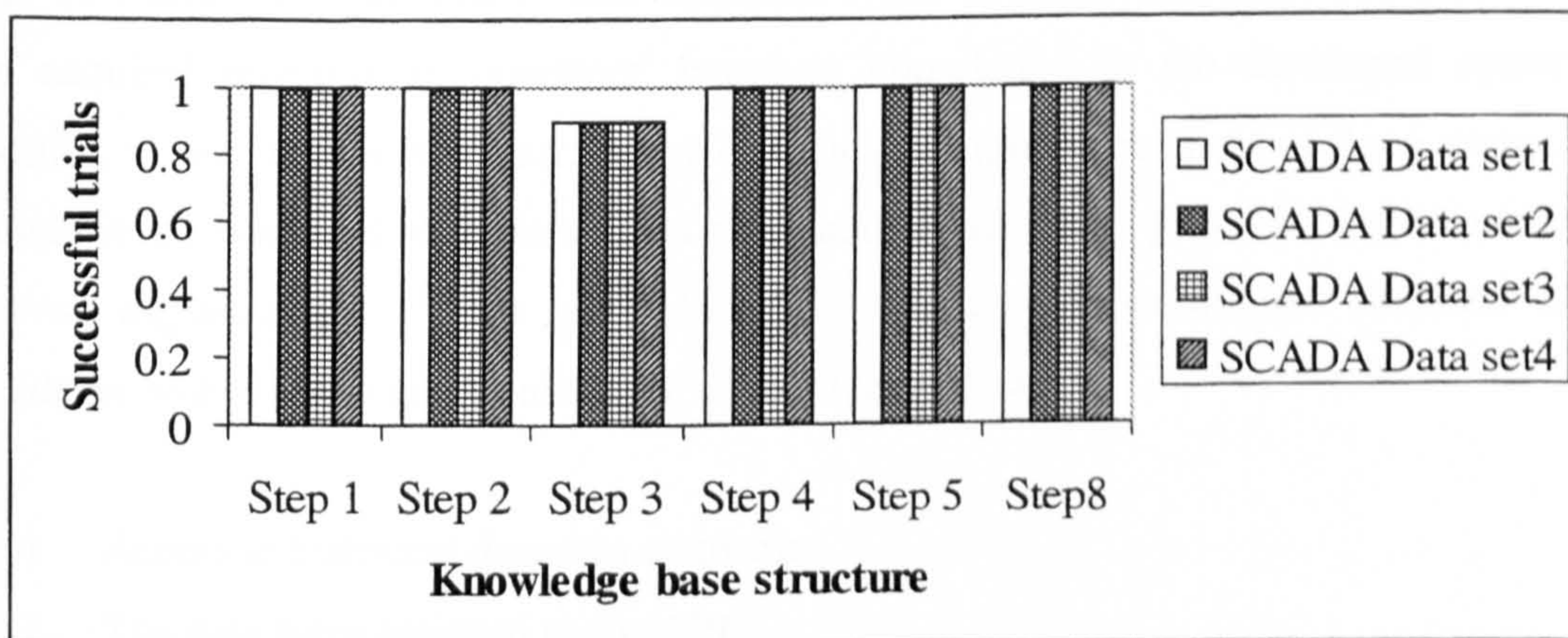


Figure 55 A sample test on the knowledge base structure

Figure 55 indicates that Step 3 was observed less successful than the other hypotheses as the knowledge acquisition interface was observed a minor fault, receiving data from the OODB model. This is because the technical programming of updating current SCADA data on the object-orientation has caused this minor problem. On the other hand, the rest shows that the sample test is satisfactory.

7.2.4.2 ES reasoning in conjunction with parsimony covering set theory

In comparison with any database, a knowledge base system contains the data which is called 'facts' in the fixed properties of the problem of object-orientation. The knowledge base

provides instructions describing how to process these data. In respect of these instructions, ES reasoning was conducted in conjunction with parsimony covering set theory employing an object-oriented power system model. An extensive literature search has shown that parsimony covering set theory is to infer uncertain data, by employing effects-causes explanations[Dabbaghchi 1992;Josephson 1994;Peng 1990].

The technique presented in this section is based on the results of detecting uncertain SCADA data where the KBS have not encountered them before. A task was carried out to test these uncertain SCADA data, as follows:

Criterion 1. Did forward chaining algorithms prove uncertain SCADA data?

Criterion 2. Did the reasoning process provide parsimony notion employing GUI?

These two tasks were applied to four different types of uncertain SCADA data which has been acquired referring to operators' heuristic knowledge in the developed system. ES reasoning in conjunction with parsimony covering set theory consists of three components, acquisition of observed disorders from the fault conditions, plausible explanations, and observed explanations. These were designed utilising object-oriented features. Several procedures were used to carry out the experiment, as follows:

Step 1 Access to historical data was confirmed

Step 2 The data were assigned to the API

Step 3 Knowledge acquisition in the KBS was checked when the new alarm messages arrive and are formed in the class and instance of object-oriented frames

Step 4 GUI was tested when the KBS was connected to the OODB

After identifying the necessary steps, a number of trials were carried out in conjunction with the fault conditions as shown in table 22 and 23:

Reasoning techniques	%Best explanations in conjunction with uncertainty management				Actual performance
	Data set1	Data set2	Data set3	Data set4	
With parsimony notion	1	0.85	0.9	0.95	0.925
Without parsimony notion	1	0.85	0.85	0.9	0.9

Table 22 Four SCADA sample data test employing parsimony covering set theory

Reasoning techniques	%Best explanations in conjunction with uncertainty management				Average
	Expert 1	Expert 2	Expert 3	Expert 4	
With parsimony notion	8	9	9	8	8.5
Without parsimony notion	6	7	8	7	7

Table 23 A survey of best explanations

The results presented above indicate that the outages in this study were identified quite successfully employing parsimony covering set theory.

7.2.4.3 Analysis of test results

Ten sets of test data were supplied whether uncertain SCADA data to each reasoning process is applied in the fault conditions. The method was based on the operation of circuit breakers and relays. Three techniques were adopted as aforementioned in section 7.2.4.2, observed disorders, plausible memberships, and observed parsimony covering set theory. The output of performance is expressed as the best explanations for the approximate faulted feeder. The heuristic knowledge plays a major role in an abductive expert system, which provides the seven inference steps.

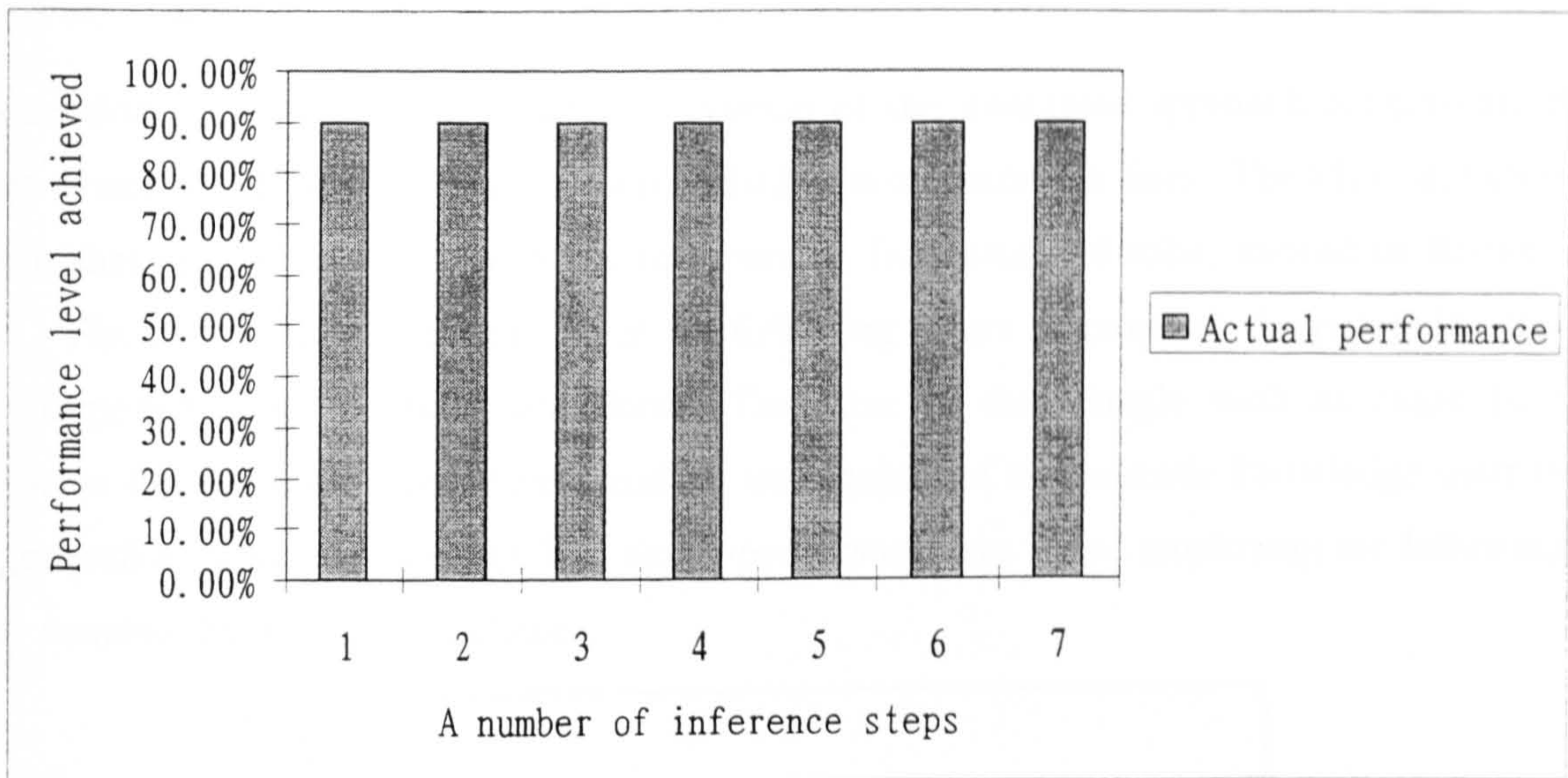


Figure 56 An expert system with parsimony set theory

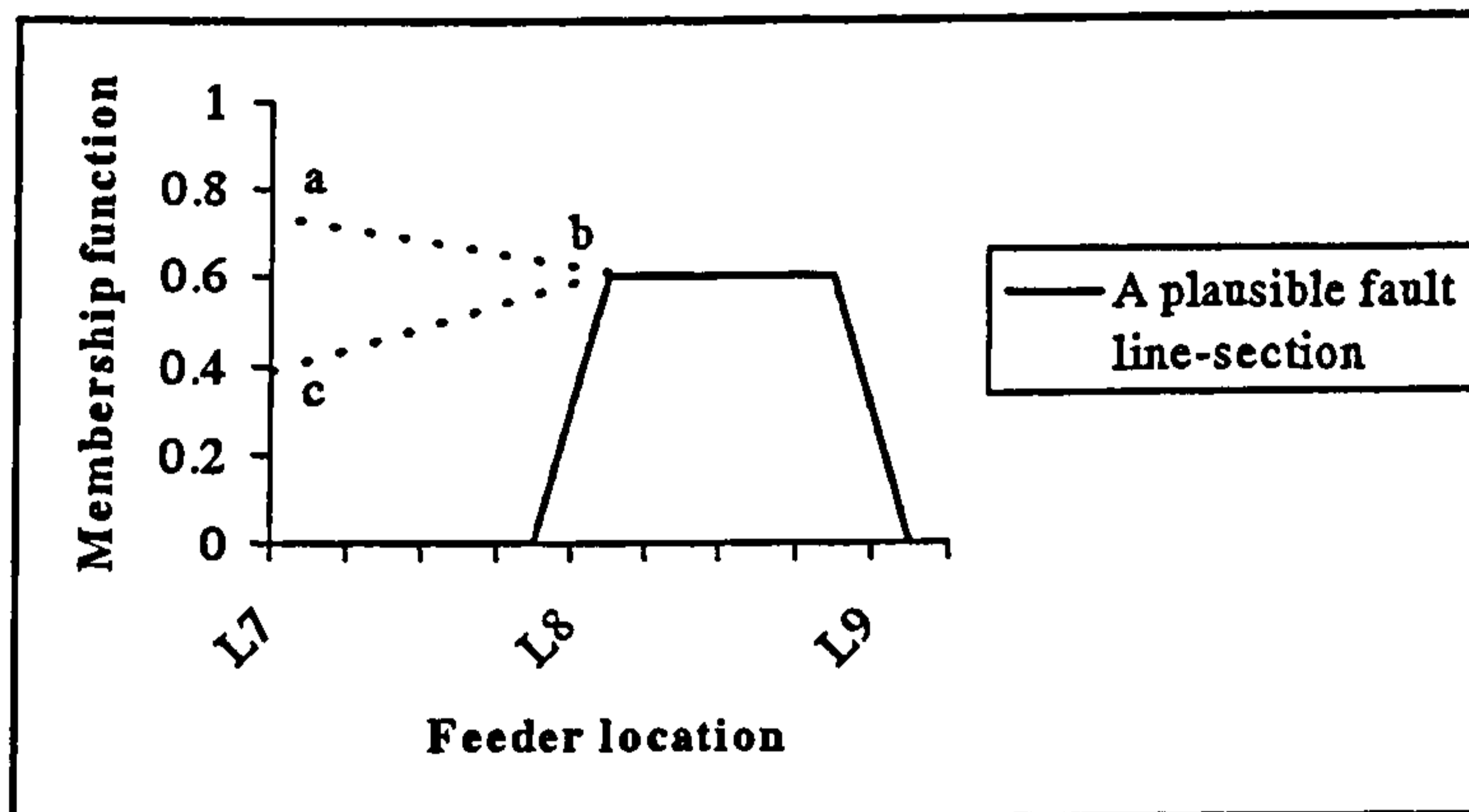
Figure 56 shows uncertain SCADA data were detected and tested on the seven inference steps of the developed system which are, as follows:

- 1) Alarm knowledge acquisition by classes and instances
- 2) Un-encountered alarms by alarm prioritisation algorithms
- 3) Observed disorders by “Hypothesis_layoutB”
- 4) Plausible explanations by “Hypothesis_layoutC”
- 5) Observed explanations by Parsimony notion algorithms
- 6) Fault detectors’ provision by User Request
- 7) MB (Measure of belief) by $((\text{object:slot})+(\text{object1:slot1})/(\text{object:slot})*(\text{object1:slot1})))$.

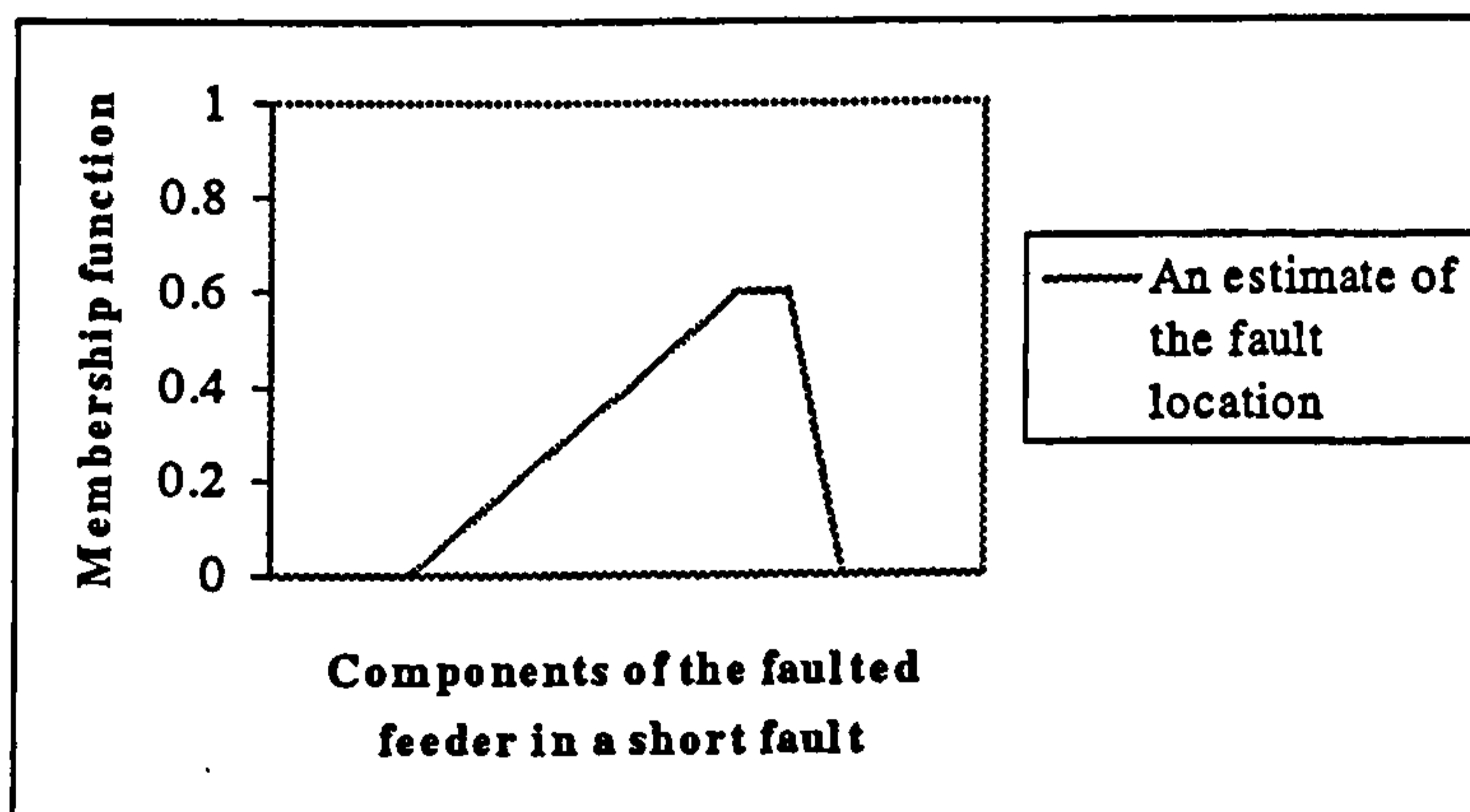
The inference step 1 has caused some inconsistency to the overall performance of parsimony set theory, which is to retrieve the updated SCADA data from the object-oriented database/Visual FoxPro in the first attempt of data acquisition. Although the acquisition was successful in the second attempt, the technical process design error employing an external encapsulation method has occurred. This problem has been unresolved, which is expected to spend more time and subject to further investigation. The results suggest that except the inconsistency of first data acquisition, the seven steps of the inference mechanism is well incorporated with small number of plausible memberships against observed disorder memberships. These steps tested provide best explanation of outages in the transmission lines.

7.3 Performance evaluation of the technique based on FE

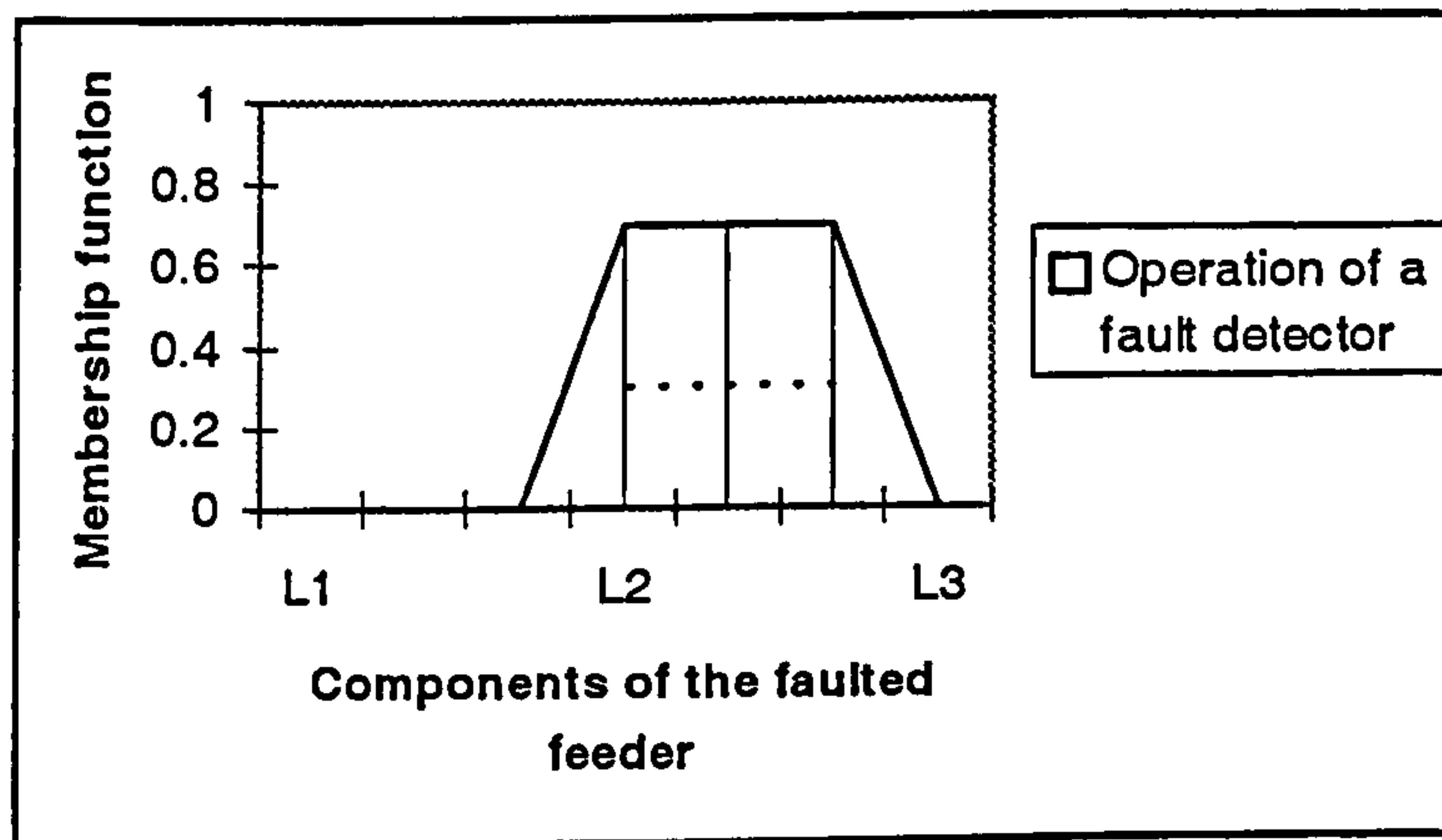
This section presents the performance evaluation of the integrated approach comprising expert systems and fuzzy logic for reasoning faults on transmission lines. The FE is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic. The apex b of the triangle abc in the following figure a) proposes the possibility that the components are the fault considered. The base of the triangle such as range $[a,c]$ represents the amount of inexactness and the uncertainty of the heuristic knowledge itself in the generalised abductive system. The developed system was tested employing the following fuzzy membership functions and rules:



a) The membership function of the fault location knowledge



b) Membership function of the estimated fault location in a short circuit



c) Membership function of a fault detector

Figure 57 Various fuzzy membership functions in the faulted feeders

Figure 57 shows three different membership functions are applied to defuzzify an optimum fault location which is based on the following fuzzy rules, as follows:

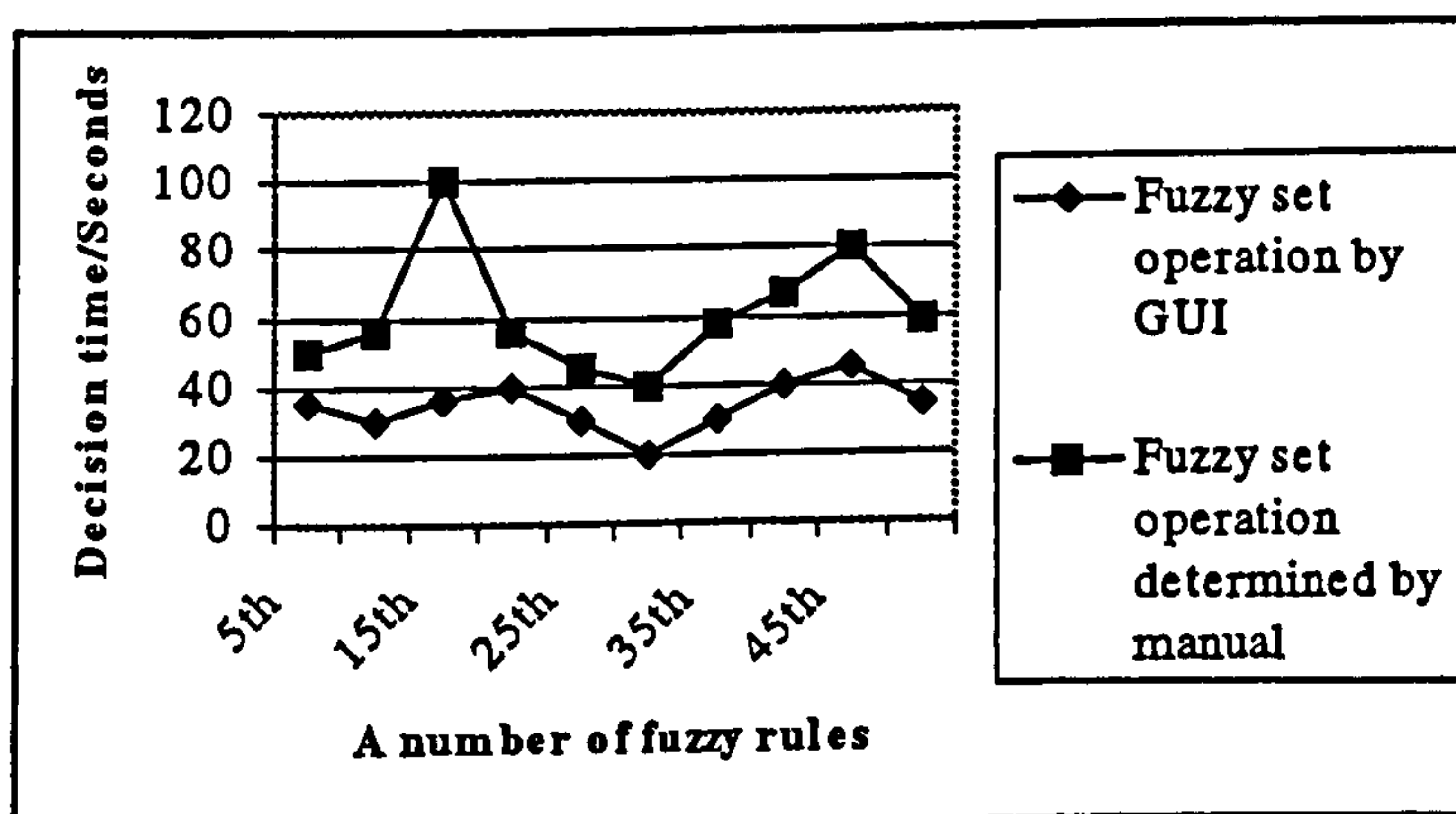


Figure 58 Fuzzy set simulation for faulted feeders

Figure 58 demonstrates that three membership functions as aforementioned in figure 57 of a), b), and c) were defuzzified employing various linguistic variables of faulted feeders, in order for decision time taken. The results indicate that fuzzy set is more effective using a GUI based inference engine when alarm activity is high.

7.4 Fuzzification of the ES based plausible explanation

Among all the techniques developed using expert systems, the ES based plausible explanations are inferred fuzzy input using linguistic variables. The algorithm of fuzzification provides the degree to which the input data match the condition of fuzzy rules in conjunction with the observed configuration. A sample system was tested, as follows:

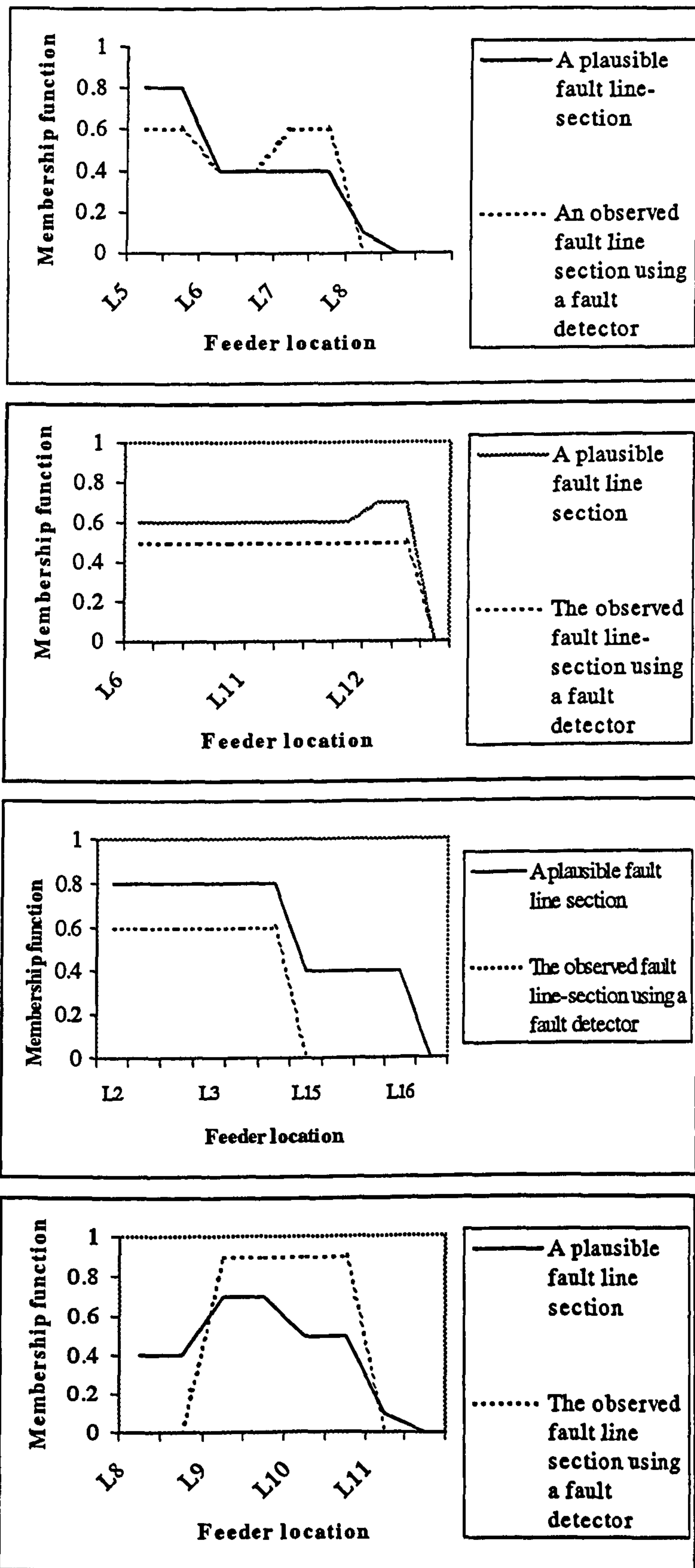


Figure 59 Membership functions for fuzzification of the faulted feeder

Figure 59 shows that the membership functions are used to convert the faulted feeders of line-section and the corresponding fuzzy sets for a line-section at the feeder location. In respect of fuzzification for the ES based plausible explanations, fuzzy rules are employed to infer these fuzzy inputs employing heuristic confidence value and observed fault detector's configuration value. The corresponded membership functions are conducted to the following object-oriented fuzzy rules:

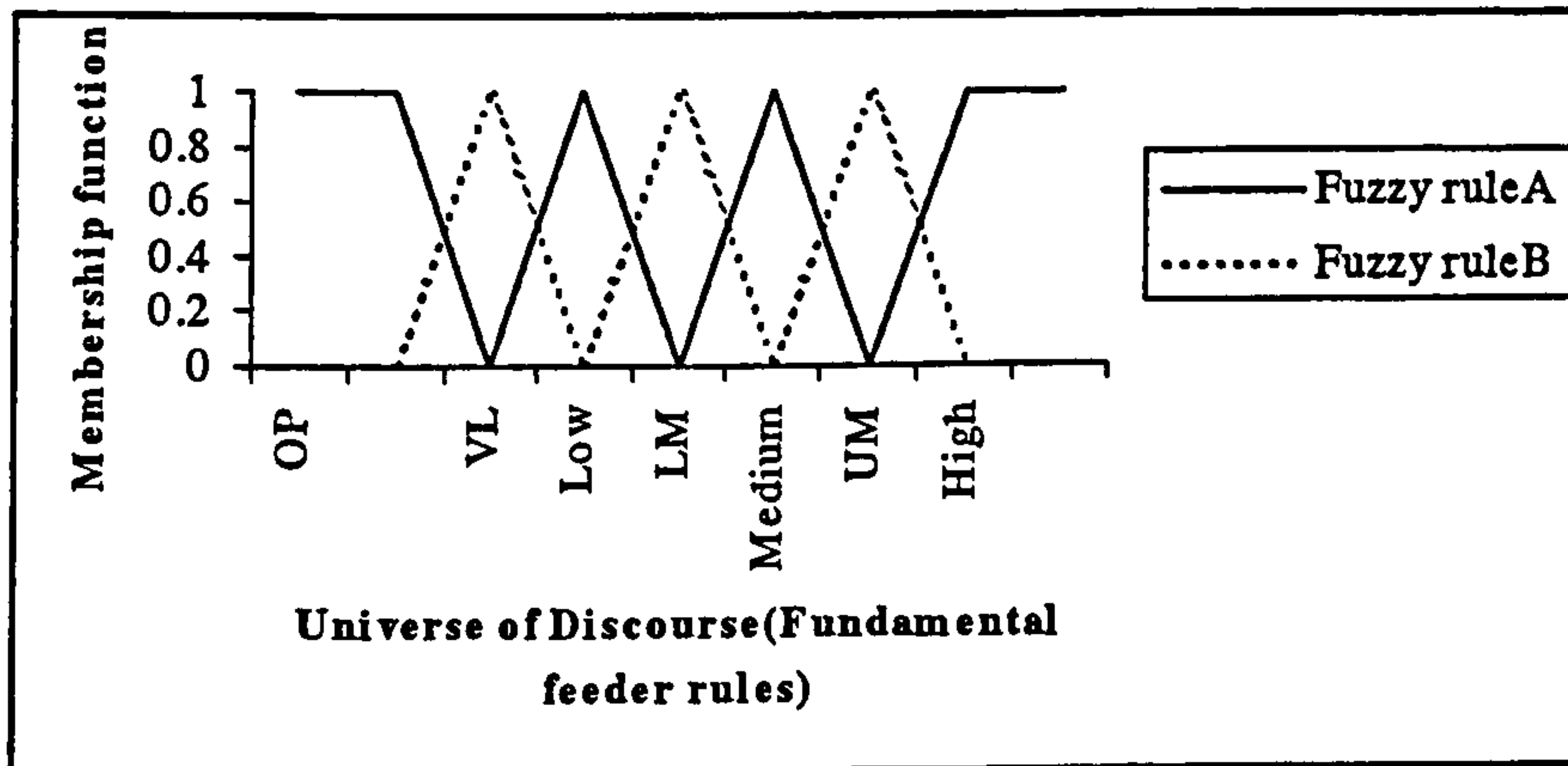


Figure 60 A composition of fuzzy rules in the fault location

Figure 60 shows that two rules of fuzzification were applied to obtain an appropriate defuzzification. The composition of these fuzzy rules on the faulted feeders was tested using the proposed object-oriented tool, as follows:

Trials	Feeder location	Fuzzy rule A	Fuzzy rule B	Adaptable composition performance(A+B)
Data set1	L5	High	Medium	100%
	L6	Medium	Medium	100%
	L7	Low	Medium	100%
	L8	Low	Low	100%
Data set2	L6	Medium	Medium	100%
	L11	Medium	Medium	100%
	L12	Medium	High	100%
Data set3	L2	High	Medium	100%
	L3	High	Medium	100%
	L15	Low	Medium	100%
	L16	Low	Low	100%
Data set4	L8	Medium	Low	100%
	L9	High	High	100%
	L10	Medium	High	100%
	L11	Low	Low	100%
Overall means				100%

Table 24 The sample test of the fuzzy rules from figure 60

Table 24 illustrates that these four sets of the fuzzy rules on the KBS tool respond to the uncertain SCADA messages. This sample test shows that these membership degrees are able to provide optimum truth boundary of the faulted feeder location using the linguistic variables while mathematical formula fails.

7.4.1 FE reasoning

A typical fuzzy expert system has more than one rule. For example, the following form shows a membership function of fuzzy logic expression in the knowledge base:

- If x is low and y is high then z=medium

This rule was computed to obtain an optimum value of the composition, which consists of three types of membership functions, as aforementioned in section 6.2.6, i.e. fuzzy union, fuzzy intersection, fuzzy complement. In power systems, these membership functions were adopted to diagnosis faulted feeders as well as equipment malfunctions, as follows:

A number of faulted feeder membership function	Dominant Rules											
	Antecedent		Consequence									
	P_M(n)	O_M(n)	M is LOW-likely		M is Lower MEDIUM-likely		M is MEDIUM-likely		M is Upper Medium-likely		M is HIGH likely	
			No. of feeder rules	Average probabilistic value	No. of feeder rules	Average probabilistic value	No. of feeder rules	Average probabilistic value	No. of feeder rules	Average probabilistic value	No. of feeder rules	Average probabilistic value
1	Low	High	20		10		10	0.54	10		10	
2	High	High	40		10		10		10		10	0.85
3	Medium	High	60		10		10		10	0.6975	10	
4	Low	Medium	70		10	0.371	10		10		10	

Table 25 An example of generation of fuzzy feeder rules

Table 25 shows the antecedent of these two rules are applied to match the consequence employing four membership functions. The probabilistic value is computed by applying fuzzy union onto the chosen values of all the control variables involved.

7.4.2 Defuzzification

The location of the faulted feeder is obtained using centroid defuzzification as given by the equation. The following table describes defuzzification of the fuzzy outputs for different SCADA messages.

Data sets	Plausible substation faults					Crisp substation faults using fault detectors					Degree of defuzzification		
	Relay operation			Lines	Rank	Relay operation			Lines	Rank/normal weather conditions	Rank/thunder storms	Normal weather conditions	Thunder storms
	z1	z2	z3			z1	z2	z3					
Data set1	OP			Line5	0.8	OP			Line5	0.6	0.5	0.92	0.96
	OP			Line6	0.4	OP			Line6	0.4	0.3	0.64	0.748
	OP			Line7	0.4	OP			Line7	0.6	0.3	0.76	0.832
	OP			Line8	0.1	OP			Line8	0	0.3	0.1	0.37
Data set2		OP		Line6	0.6		OP		Line6	0.5	0.3	0.8	0.86
		OP		Line11	0.6		OP		Line11	0.5	0.3	0.8	0.86
		OP		Line12	0.7		OP		Line12	0.5	0.5	0.85	0.925
Data set3	OP			Line2	0.8	OP			Line2	0.6	0.4	0.92	0.952
	OP			Line3	0.8	OP			Line3	0.6	0.4	0.92	0.952
	OP			Line15	0.4	OP			Line15	0	0.3	0.4	0.58
	OP			Line16	0.4	OP			Line16	0	0	0.4	0.4
Data set4		OP		Line8	0.4		OP		Line8	0	0.3	0.4	0.58
		OP		Line9	0.7		OP		Line9	0.9	0.6	0.97	0.98
		OP		Line10	0.5		OP		Line10	0.9	0.5	0.95	0.975
		OP		Line11	0.1		OP		Line11	0	0	0.1	0.1

OP: operated

Table 26 Defuzzification of fuzzy outputs for faulted feeder examples

Key words: high likely [1-0.8]; upper-medium likely [0.79-0.6]; medium-likely [0.59-0.5]; lower medium likely [0.49-0.3]; low-likely [0.29-0]

Table 26 shows that there are two types of defuzzification observed using formula (4), normal weather conditions, and thunderstorms. The sampling data were subject to the weather conditions, as hypotheses. The plausible substation faults suggest that their probabilistic values are static while heuristic knowledge is highly reliable, but evolving quite slowly by the fuzzy substation faults. The observed configuration using fault detectors such as bus transmission impedances, line reactances, etc are deterministic factors, but its reliability is 70% under normal weather conditions [Partanen 1994]. Thus, combination of these two antecedents suggests that the best interpretation of the fault location is achieved.

7.4.3 Analysis of the test results

The designed FE involved in the stage of the chapter 6 was tested with a number of SCADA data which is not encountered by the ES before. The stage consists of a number of FE being determined uncertain SCADA data by the symbolic alarm prioritisation from the ES in the first stage. The following table presents some examples of the test results:

Fault location techniques	Outage 1	Outage 2	Outage 3	Outage 4
ES	[L5,0.28]	[L12,0.36]	[L2,0.28];[L3,0.28]	[L9,0.48]
FE	[L5,0.92]	[L12,0.85]	[L2,0.92];[L3,0.92]	[L9,0.97]
Maximum selection	[L5,0.92]	[L12,0.85]		[L9,0.97]
Alpha level selection			[L2,0.92];[L3,0.92]	

Table 27 Fault location results obtained between ES and FE under different feeder condition

Table 27 shows that the approximate fault location achieved in FE is higher than the brittle expert system. An extensive series of studies have shown that the fault location technique demonstrated herein provides the best interpretation of alarms under different fault conditions. The improvement over the ES technique based system is significant when compared with fuzzy logic, which will enable operators to take more confident action.

7.4.3.1 Improvement on the accuracy of fault identification

The improvement in the appropriate reasoning is attained over the fault location technique based on ES. The fuzzy-expert systems are tested with same sets of testing SCADA data as such in the previous technique on abductive expert system architectures. The results are compared in terms of Maximum selection and alpha level selection as aforementioned in section 7.4.3.

Trials	Expert system				Fuzzy-expert system			
	Faulted feeders	Plausible output	Observed output	MB(Measure of belief)	Faulted feeders	Plausible output	Observed output	Defuzzification of Algebraic sum
Data set1	Line5	0.8	0.6	0.28	Line5	0.8	0.6	0.92
	Line6	0.4	0.4	0.48	Line6	0.4	0.4	0.64
	Line7	0.4	0.6	0.6	Line7	0.4	0.6	0.76
	Line8	0.1	0	0.09	Line8	0.1	0	0.1
Data set2	Line6	0.6	0.5	0.44	Line6	0.6	0.5	0.8
	Line11	0.6	0.5	0.44	Line11	0.6	0.5	0.8
	Line12	0.7	0.5	0.36	Line12	0.7	0.5	0.85
Data set3	Line2	0.8	0.6	0.28	Line2	0.8	0.6	0.92
	Line3	0.8	0.6	0.28	Line3	0.8	0.6	0.92
	Line15	0.4	0	0.24	Line15	0.4	0	0.4
	Line16	0.4	0	0.24	Line16	0.4	0	0.4
Data set4	Line8	0.4	0	0.24	Line8	0.4	0	0.4
	Line9	0.7	0.9	0.48	Line9	0.7	0.9	0.97
	Line10	0.5	0.9	0.7	Line10	0.5	0.9	0.95
	Line11	0.1	0	0.09	Line11	0.1	0	0.1

Table 28 Improvement tests on the accuracy of fault identification

Table 28 shows two different methods are employed to test an accuracy of fault identification, MB, and defuzzification of Algebraic sum, which indicates that the SCADA data in this experiment were performed well in the defuzzification of Algebraic sum. This is because membership functions in fuzzy sets allow uncertainty of faulted feeders to be more approximate in conjunction with their linguistic variables.

7.4.3.2 Evaluation of parallel capability in the process

The previous study of an AI based alarm processing in Scottish Hydro & Southern Energy group was realised using the KAL language environment, developed in C++, old version of Kappa-PC [Ramsay 1994]. Its purpose was to design a prototype of parallel alarm management employing the existing SCADA messages, which consists of alarm prioritisation systems, including transformer faults, temporary faults, and permanent faults. Further development to the prototype system, an extensive study has resulted in improving more effective parallel object-oriented power system model, as follows:

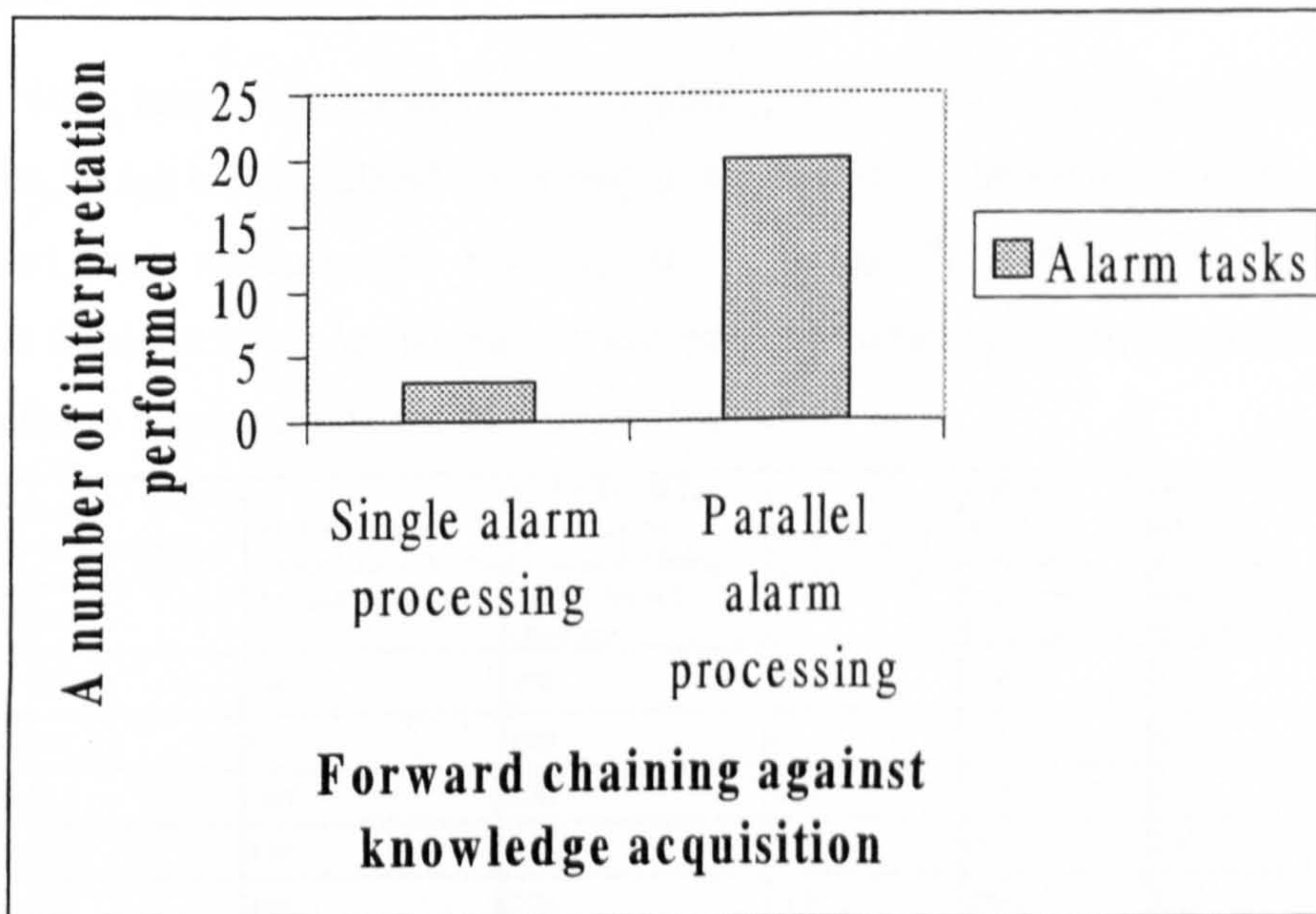


Figure 61 A survey of alarm processing capability

Figure 61 shows that the developed system was tested using 30 rules. The designed four symbolic alarm processing was adopted for the capability between single alarm processing and parallel alarm processing. The forward chaining provided the knowledge acquisition performance when new alarms are input. The results indicate that parallel alarm processing has resulted in reducing operators' workload by contrast to single alarm processing.

7.4.3.3 Evaluation of reusability

The development tool employed in this work is the version of Kappa-PC, 2.3. The power system model, 12Buses-16Lines, was simulated employing Kappa-PC. The reusability of the object-oriented alarm management is concerned with better, cheaper in software engineering technology. The benefits of an AI based alarm management to be derived from object-orientation are that of knowledge modification which was tested, as follows.

Object-oriented KBS techniques	% Performance of the reusable power system components								Overall performance
	Ground fault	Short fault in relay	Unknown alarms	Fault detectors	Frequency deviation	Bus_bar fault	Circuit breaker trip failure	Transformer fault	
Heuristic rule match(pre-programmed)	100.00%	100.00%	75.00%	100.00%	100.00%	75.00%	100.00%	100.00%	93.75%
Fuzzy rule match(manual process)	100.00%	100.00%	100.00%	100.00%	87.50%	100.00%	100.00%	75.00%	95.31%

Table 29 An experiment of power system model reusability

7.4.3.4 Evaluation of adaptability

The rules controlling fuzzy systems and their weightings are based on the model based power system networks, which was modified according to experience. The system can be tuned two ways, supervised, and unsupervised training, by updating the fuzzy rules. The work presented in this thesis is based on the supervised learning technique from the defuzzification of an abductive fuzzy knowledge based system, as follows:

A number of un-encountered alarms by the KBS	Alarm prioritisation update by the KBS	Heuristic alarm interpretation by the forward chaining	Abductive fuzzy reasoning by forward chaining and backward chaining	Detection of existing rules	Estimate adaptive knowledge base update by KALView	Actual adaptive knowledge base update by KALView	STD
Data set1	100	100	100	100	100	100	0
Data set2	100	0	100	0	100	50	57.735
Data set3	100	100	100	100	100	100	0
Data set4	100	100	100	100	100	100	0
Data set5	100	100	100	100	100	100	0
Data set6	100	100	100	100	100	100	0
Data set7	100	100	100	100	100	100	0
Data set8	100	0	100	100	100	75	50
Data set9	100	100	100	100	100	100	0
Data set10	100	100	100	100	100	100	0
Means	100	80	100	90	100	92.5	10.774

Table 30 adaptive knowledge base rules by un-encountered alarms

7.4.3.5 Evaluation of maintainability

Maintainability is concerned with implementation details that are isolated from the interface of the developed OO diagnostic tool in a power system. Implementation code can be changed without any fear of breaking other objects that access it. Because of inheritance, changes made to an ancestor spread to all its descendants automatically. Also, related code and data is held together, it is easier for the maintenance users to find what they are looking for in one place. A sample test was attempted, as follows:

Trials/knowledge modification	Alarm prioritisation	Rule relations of MB(Measure of Belief)	Defuzzification of Algebraic sum	Rule Trace	KBS update	Overall performance
1	80.00%	80.00%	100.00%	100.00%	100.00%	92.00%
2	100.00%	60.00%	100.00%	80.00%	100.00%	88.00%
3	90.00%	70.00%	100.00%	90.00%	100.00%	90.00%
4	80.00%	80.00%	100.00%	100.00%	100.00%	92.00%
5	80.00%	80.00%	100.00%	100.00%	60.00%	84.00%
6	80.00%	80.00%	100.00%	100.00%	100.00%	92.00%
7	80.00%	60.00%	100.00%	100.00%	80.00%	84.00%
8	80.00%	80.00%	100.00%	100.00%	100.00%	92.00%
9	80.00%	80.00%	100.00%	80.00%	100.00%	88.00%
10	80.00%	80.00%	100.00%	100.00%	80.00%	88.00%
Successful trials	83.00%	75.00%	100.00%	95.00%	92.00%	89.00%
Trial 1	Line configuration					
Trial 2	Bus configuration					
Trial 3	Plausible membership					
Trial 4	Observed membership					
Trial 5	Circuit breakers					
Trial 6	Composition rules					
Trial 7	Fuzzification rules					
Trial 8	Relays					
Trial 9	Backward chaining					
Trial 10	Forward chaining					

Table 31 An experimentation of maintainability in the developed system

Table 31 illustrates an experimentation was carried out using the OOP development toolkit. The methods employed in this implementation are based on five OO characteristic features, i.e. classes, instances, methods, functions, and graphical assimilation. These five elements were applied against a number of trials when 5 factors of different interfaces were designed. The results suggest that some minor failures were occurred during the experiment for several

problems, for example, an inheritance code module by classes of Circuit breakers, and methods constrained by inappropriate forward chaining and backward chaining for line configuration. However, they were resolved at the late stage, by using the advantage of code re-use, in terms of maintainability.

7.4.3.6 Evaluation of GIS applicability

GIS (Geographic Information System) provides a display geographically, referring to relevant data, which is being promoted as a technology. This technology can be used to improve the efficiency of various operations within an organisation. In this respect, a pinpointing system on the outage areas was tested employing object-orientation based GIS, as follows:

Alarm processing techniques	% Display of outage areas presented by the object of protection components						Estimate performance	Actual performance
	Lines(Line_No:Deenergised_region)	Buses(Bus_No:Busbar_failure)	CBs(CBNo:Trip_failure)	Transformers(Tran_No:Fault?)	Loads(Load_No:Overloaded)	Generators(Gen_no:Low_frequency)		
Minor alarms	100.00%	75.00%	100.00%	100.00%	100.00%	100.00%	100.00%	95.83%
Non-urgent alarms	100.00%	75.00%	75.00%	50.00%	100.00%	75.00%	100.00%	79.17%
Urgent alarms	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Unknown alarms	75.00%	75.00%	100.00%	75.00%	100.00%	75.00%	100.00%	83.33%
Means	93.75%	81.25%	93.75%	81.25%	100.00%	87.50%	100.00%	89.58%

Table 32 GIS applicability on the object-oriented protection components

Table 32 shows outage areas are summarised using the object of graphical assimilation. Operators are able to see the possible fault locations, by pinpointing the event areas. The results indicate that this primary evaluation of GIS based alarm processing can be further developed using an efficient mapping storage tool.

7.4.3.7 Evaluation of recognised abductive algorithms

Fuzzy-expert systems were tested employing various fault conditions, in conjunction with abductive algorithms. The results presented in table 33 show participants prefer FE with linguistic variables, and five fault conditions were applied against these 5 factors as shown in the table. The latter system provides them more human-alike and readability. This is a significant achievement over the former technique. The approximate reasoning error such as Estimate performance-Actual performance is based on the same test cases applied to both techniques.

Fault identification techniques	% Approximate reasoning error					Estimate performance	Actual performance
	Observed Disorder	Plausible explanation	Observed explanantion	Configuration value	Composition methods		
ES with confidence value	89.17%	90.00%	90.83%	90.83%	81.67%	100.00%	88.50%
FE with linguistic variables	89.17%	92.50%	90.83%	92.50%	90.00%	100.00%	91.00%

Table 33 A sample test supported by participants in abductive algorithms

In respect of table 33, an improvement of abductive reasoning over current fuzzy rule based system was attempted to determine qualitative fuzzy rules, as follows:

Primary source used	Plausible memberships										A number of fuzzification with parsimony notions	A number of fuzzification without parsimony notions
	M_d1	M_d2	M_d3	M_d4	M_d5	M_d6	M_d7	M_d8	M_d9	M_d10		
[CB8_CB10]	D1,D2	D1	D2	D3	D1	D2	D3	D2,D3	D3		7	9
[CB6_CB3]	D1	D2	D2,D1	D3,D2	D3	D3,D4	D1	D4	D1	D3	7	10
[CB4_CB35]	D3	D1,D3	D1	D2	D5	D3,D5					4	6
[CB1_CB32]	D1	D4	D1,D2	D2	D3	D1,D4	D1				5	7
[CB5_CB36]	D4	D4,D2	D4	D2	D3	D4					5	6
[CB38_CB11]	D2	D1,D3	D3	D2,D4	D1	D4	D2,D3	D3	D4	D3	7	10
[CB12_CB13]	D1	D2	D3,D4	D1	D1	D1,D4					4	6
[CB14_CB16]	D2,D4	D3	D5	D6,D3	D1,D2	D2	D4,D5	D5	D4	D5	6	10
[CB19_CB20]	D2	D1,D2	D2	D1	D4	D3,D4					4	6
[CB21_CB22]	D1	D3	D1	D2	D2,D4	D2	D4				6	7
[CB23_CB24]	D3	D1	D2	D3	D1,D2						4	5
[CB31_CB25]	D5	D2	D1	D3	D5,D1	D4					5	6
[CB28_CB39]	D1	D3,D1	D3	D4	D2	D4	D2,D3				5	7
[CB33_CB30]	D2	D1,D2	D4	D2,D3	D3	D1,D4	D4				4	7
[CB9_CB34]	D2	D1,D3	D2	D3	D2	D2	D3	D3,D2	D5		7	9
[CB42_CB2]	D1	D3,D4	D3	D2	D3	D3	D4				6	7
[CB41_CB7]	D1	D2	D1,D3	D4	D3	D2,D4	D3,D4	D1	D2		6	9
[CB40_CB39]	D1	D2,D4	D2	D3	D2,D3	D1	D4,D1				4	7
[CB13_CB15]	D2	D3	D4,D1	D3	D2	D2	D1				6	7
Overall											102	141

Table 34 An improvement of abductive reasoning over current fuzzification

Table 34 shows that the testing elements consist of three, 19 feeders, 10 different memberships, and maximum 5 observed disorders from unknown alarms. These were employed to test the object-oriented fault diagnosis in the power system. A sample test is shown in the following figure 62. The theorem of employing parsimony notions suggests that the use of heuristic knowledge often makes mistake during the alarm analysis, specially during a heavy alarm period. On the other hand, the utilisation of parsimony notions attempts to produce more qualitative fuzzy rules.

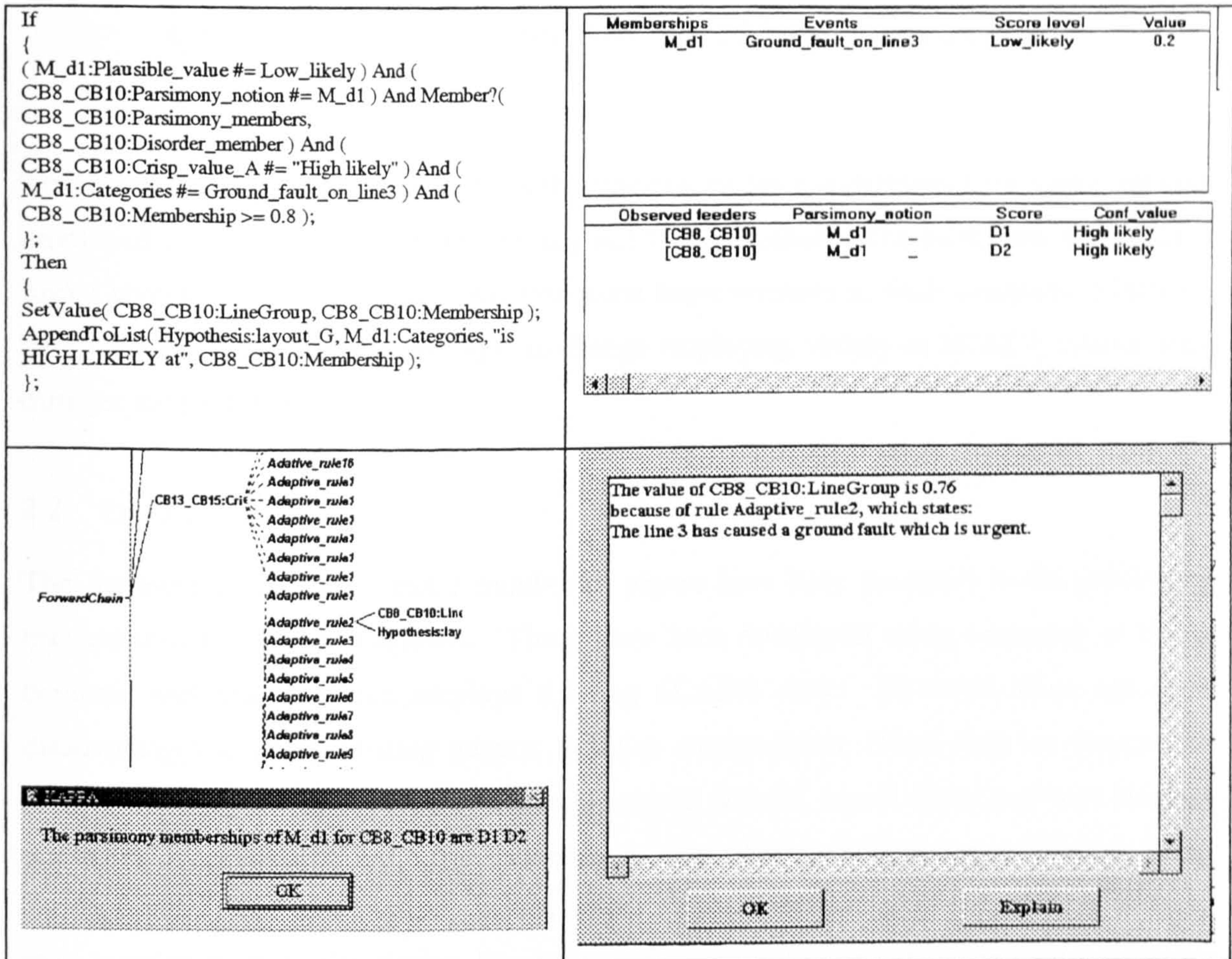


Figure 62 A sample test from the developed system for the feeder "[CB8_CB10]"

7.5 Summary

The performance evaluation of the two AI based fault identification techniques is discussed employing series of tests and knowledge modification. These experiments suggest that an abductive expert system can classify the fault conditions on the 132Kv transmission lines, in association with all practically encountered alarms. In respect of the ES alarm processing and fault diagnosis, the SCADA based expert system was tested with a separate set of unseen data for alarm prioritisation and uncertainty management.

The results presented herein, clearly suggest that an abductive fuzzy knowledge based system provides a high approximate reasoning in fault identification in conjunction with various fault conditions, which improves on the knowledge base maintenance based solely on ES architecture.

Chapter 8: Conclusions and recommendations

8.1 Introduction

This final chapter of the thesis restates the research problem and reviews the major methods employed in the study of alarm processing and fault diagnosis. The technique, an abductive fuzzy knowledge based system addresses some improvements in fault diagnosis, which can be applied to a non-linear power system change employing variety of SCADA system when outages are persistent.

8.2 Previous work

The literature study shows that a number of papers have been proposed to the problem of transmission lines fault diagnosis. These have been developed using operation of circuit breakers and relays, which employs existing SCADA data. However, there are some disadvantages to apply existing generic SCADA configuration. First, they are designed to cope with comprehensive range of alarm messages. Second, heavy alarm activities increase operators' workload. Third, large heuristic rules are required to design a SCADA based expert system. At the same time, various types of fault detectors have been installed to find a fault location in protection device, but these sources are not taken into account in association of fuzzy logic.

The work presented in previous chapters is taken into account in conjunction with these problems.

8.3 Expert systems

Application of expert systems to alarm processing and fault diagnosis has attracted many researchers. Power system components have physical and operational limit, which are usually described as hard inequality constraints in mathematical formulations. In respect of these, expert systems have shown an effective solution using heuristic knowledge, but maintenance of a rule base and brittle rule based systems by uncertainty are major problems [Elkan 1994]. In the case of the existing SCADA data, expert systems provide an encouraging interpretation to approximate fault location on transmission lines. Since a hybrid system has emerged in early 1990s, integration with fuzzy logic is a method to improve common problems in fault diagnosis.

8.4 Fuzzy logic expert system

Fuzzy logic and expert systems share heuristic knowledge in trouble shooting or fault analysis. With respect to uncertainty handling in fault diagnosis, many researchers look for a calculus handling by MYCIN theory which has the following features, claims Chandrasekaran (1994), as follows:

- The semantics of its uncertainty terms capture the intuitive meaning of uncertainty terms that people use in their common-sense behaviour.
- The operations of combination in the calculus capture human behaviour when their uncertainties are combined.

These two features suggest that a calculus method underlies the combining of uncertainties through human common sense, on the other hand, what if this can not be captured by the calculus method? The real explanation of human behaviour is not given by a calculus, but by the collection of complex. In respect of the critiques, the experiment presented in previous chapters implies that incorporating the complex data into fuzzy systems provide the uncertainty degrees. At the same time, the degrees show of which one of true or false are the best explanation between the most plausible truth-value and crisp configuration value, supported by an abductive inference.

8.5 Fault identification techniques

Two fault identification techniques are discussed in this thesis, plausible memberships, and crisp configuration memberships utilising fault detectors. The method is based on utilising operation of circuit breakers and relays when the alarms are not resolved and persistent. In addition, the transmission line impedances employed is based on parallel source to the buses.

The first technique, plausible memberships are designed to extract operation of protection device, as follows:

- Circuit breakers
- Relays
- Transformers
- Buses

- Generators
- Lines
- Loads

These protective systems are inferred using parsimony theory set in the object-oriented power system model, which consists of degree of the plausible memberships. The parsimony theory set is conducted employing “user request” dialogue in the tool.

The second technique, crisp configuration memberships utilising fault detectors are fused to attempt further improvements, referring to the plausible memberships of heuristic knowledge based values, which can be adopted using fuzzy rules. In respect of fault detectors, the exact subset of the faulted feeder should be included that based on the operation of fault detectors. According to the survey by operators’ practical experience to HE, the fault detectors provide quite reliable information in normal weather conditions and short fault on the protection device, approximately 70%[Partanen 1994]. However, during heavy alarm period and thunderstorms, the information by the appropriate detectors is not particularly dependable, such as line fault detectors and earth fault detectors.

The techniques simulated are based the modified power system labels using a PC based system, which, however, will take into account the practical problems in association with these severe outages.

8.6 Performance in respect of original interpretation

The overall performance of the FE for fault diagnosis under outage conditions is critical to restore the power system and take an appropriate action, in order to minimise the disturbance and alarm management cost. The work presented in this thesis is reviewed, as follows:

- The choice of feature extraction to section 5.4, is crucial to design a model based alarm processing system for the expert system, which provides an important role of alarm prioritisation. An extensive series of studies have shown that the one based on alarm prioritisation is suited for the application discussed hereof and determining the uncertain SCADA information detected by the prioritisation scheme is adopted using an abductive inference.

- The performance of the ES for alarm processing and fault diagnosis under outage conditions, has indicated successful trials employing three dependant variables. This shows that the object-oriented expert system employing the power system model is quite effective in interpreting all types of fault on the transmission systems.
- The work has been observed that for the comprehensive alarm management, the fault arrangement design test is attained employing encapsulation of object-orientation. This suggests that the information on power protection components is acquainted in the KBS.
- The technique retains its high reliability of explanations under different outages, which demonstrates the flexibility of model based algorithm in the object-oriented features and these plausible memberships can be updated into the KBS. This is so that the KBS recognises the updated alarms when new arrival of alarms matches the alarms.
- The work shows that the SCADA system provides alarm information of fault position which is dependent on persistent alarms of weather conditions. This SCADA based ES system is a significant advantage over conventional AI techniques
- The fault diagnosis described in chapter 5 produces an external fault which contains the direction of strong wind, and circuit breaker maintenance records. This is an important feature of uncertainty.
- The technique presents a trial of minimum rules while large rules in expert systems are necessary.

8.6.1 Improvement on the uncertainty interpretation

The second part of the tests described in chapter 6 is focused on the evaluation of the FE fault diagnosis, which shows a novel diagnosis for 132kv transmission lines. The methodology approached in the experiment is based on an integrated approach, in conjunction with the method of fault detectors. The diagnosis technique demonstrates an improved performance when compared with fuzzy logic, which has resulted in determining the best alarm interpretation. This is a considerable improvement over other artificial intelligence techniques when such weather conditions and persistent alarms cause a major workload for operators.

8.7 Limitations of Work

Some elements of the work delineated in this thesis were theoretical in nature and the techniques have not been previously applied to the object-oriented tool. Thus, it is essential

to recognise the limitations of the work reported. The identified limitations fall into three, an AI based methodology approach, the tool, and the analysis procedure.

8.7.1 Limitations of Approach

- User interface data sets presented in chapter 5 contained some subjective features. This shows the performance level for the survey is not consistent as individual interest and their heuristic knowledge of power system operation affect the survey. In defence of this approach, it attempts to improve the design process of object-orientation by this analogy. The survey was to maximise usability of such user interface for those people from novice to senior operators when alarm knowledge acquisition is formed in the object-oriented tool.
- Much information on SCADA is possibly the most widely used and reported alarm-processing indicator. For this reason, the SCADA information was employed as original messages in the developed system. A major task was that of attempting simplified power transmission elements in conjunction with the ordinal messages. The status of power transmission elements was designed simulating a standalone SCADA configuration. This is so that minimum rules and shorter descriptions in the knowledge base would determine more effective alarm interpretation.
- A developed system is desirable of automatic knowledge base update for uncertain alarms in which the knowledge base will adapt the alarms, by programming themselves. This thesis presents an optimum solution of inferring uncertain single outage, using an abductive fuzzy knowledge system, which enables operators to drive the specified steps of inference techniques. This feasibility has been overlooked.

8.7.2 Tool limitations

- The functions in Kappa-PC have proved to be effective for inferring a fault location, which is to optimise the best explanation of features. The mechanism of object-oriented programming against each other is required to evaluate every combination of power system changes, in order to facilitate the best explanation. Unfortunately, there is a limit to the numbers of features such as DLL application and external interface to graphical

assimilation. These two systems could have provided more interactive transmission network sources to tool developers.

- Kappa-PC is being used or evaluated by a number of major software developers. The tool has not been systematically tested in conjunction with dynamic quantitative sources, and the value of faulted feeder was referred to field engineer's report and auxiliary parameter systems.

8.7.3 Analysis Limitations

- The level of performance that the overall developed system was almost consistently able to maintain over the deployed data sets. This was encouraging, especially, in the relative performance of the object-oriented expert system structure when the different SCADA data sets were applied to the system. However, some hypothesis steps in the fuzzy-expert system structure were not responded to the level of expected performance as some features of the object-oriented tool was poorly designed, including external data acquisition.
- Another limitation of the analysis procedure was that evaluation of abductive algorithms, which was tested employing maximum 5 observed disorders as aforementioned in 7.4.3.7. The performance level is satisfactory, however, there is a need for employing excessive numbers of observed disorders in the tool where mapping facility will ease operators to determine best explanations from outages.

8.8 Future work

The thesis has emphasised a hybrid system which is to interpret the appropriate fault conditions using alarm prioritisation and fault diagnosis. This AI based power system has been conducted employing an object-oriented AI application tool, Kappa-PC. The most effort has been drawn into several subjects; automated learning by neural networks, adaptive system by genetic algorithms, and the FE techniques using extensive model based reasoning by an abductive inference and the existing outage data. They cover the majority of uncertain SCADA data. A further step to the proposed system falls into two, automated knowledge learning from the abductive inference, and automated optimum reasoning by the FE for the

two different configuration values. This algorithm should be tested with the real labelled data.

8.9 Testing the proposed system with the derived data in conjunction with GIS application

As emphasised in this research, the proposed technique is based on an off-line application which utilises the derived SCADA data from the main stream of SCADA system for the fault diagnosis. In this respect, the derived SCADA data can be subsequently processed in the field of GIS where plausible blackout areas are high likely, pinpointing the fault location for field engineers.

8.10 Application of the technique to the prioritisation management for major customers

The power utilities are under obligation to minimise interruption in their supply to important customers, which is usually regulated by acts of law, code of practice, or special contract between customers and utilities. Such customers include hospitals, traffic signal plants, communication centres and plants, telephone plants, public centres, embassies, and industrial plants. The work presented in previous chapters could be extended to the nature of important customers, by including this scheme in the alarm prioritisation algorithm. Ideally, the algorithm should attempt to reconnect all out of service customers when an urgent alarm is informed by the KBS. If this is not possible, the restoration solution should be based on the hierarchy of important customers.

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Appendixes

Appendix A: Data driven/forward chaining

```

{
If ( x #= 1)
    Then SetTimer( 1, 0, 2 )
PostBusy( ON, "SCADA message1 comes in 2 seconds!..." );
    Wait(1.5);
    PostBusy(OFF, "");
SendMessage( DBTable, Self_Change );
SendMessage(Local,control_message);
ForwardChain();
Busy_ON();
Searching();
ForAll [ Q|ALARMS ]
    SendMessage( Q, PrioritisationA );
ForAll[p|ALARMS]
SendMessage(p,Relay_StatusT);

If (x#=2)
Then
SetTimer(2,0,2);
PostBusy( ON, "SCADA message2 comes in 2 seconds!..." );
    Wait(1.5);
    PostBusy(OFF, "");
SendMessage(DBTable,Self_Change1);
SendMessage(Local,control_message1);
ForwardChain();
Busy_ON();
Searching();
ForAll [ C|ALARMS ]
SendMessage( C, PrioritisationB );
ForAll[p|ALARMS]

```

SendMessage(p,Relay_StatusT);

If (x \neq 3)

Then

SetTimer(3, 0, 2);

PostBusy(ON, "SCADA message3 comes in 2 seconds!... ");

Wait(1.5);

PostBusy(OFF, "");

SendMessage(DBTable,Self_Change2);

SendMessage(Local,control_message2);

ForwardChain();

Busy_ON();

Searching();

ForAll [D|ALARMS]

SendMessage(D, PrioritisationC);

ForAll[p|ALARMS]

SendMessage(p,Relay_StatusT);

If (x \neq 4)

Then

SendMessage(DBTable,Self_Change3);

SendMessage(Local,control_message3);

ForwardChain();

Busy_ON();

Searching();

SetTimer(4, 0, 2);

PostBusy(ON, "SCADA message4 comes in 2 seconds!... ");

Wait(1.5);

PostBusy(OFF, "");

ForAll[E|ALARMS]

SendMessage(E, PrioritisationD);

ForAll[p|ALARMS]

SendMessage(p,Relay_StatusT); };

Appendix B: Performance evaluation of the technique based solely on the expert system

A number of SCADA data	Knowledge base search			Estimate performance	Actual performance
	Unstreamed alarms	Confirmed alarms	Stand by alarms		
1	0	1	0	100%	100%
2	1	0	0	100%	100%
3	0	0	0	100%	0%
4	0	0	1	100%	100%
5	0	1	0	100%	100%
6	1	0	0	100%	100%
7	0	0	1	100%	100%
8	0	1	0	100%	100%
9	0	1	0	100%	100%
10	0	1	0	100%	100%
11	0	0	1	100%	100%
12	1	0	0	100%	100%
13	0	0	1	100%	100%
14	0	1	0	100%	100%
15	0	1	0	100%	100%
16	0	1	0	100%	100%
17	0	0	0	100%	0%
18	1	0	0	100%	100%
19	0	0	1	100%	100%
20	0	0	0	100%	0%
Overall KBS usability	4	8	5	100%	85%

API design		A number of participants					Overall score
Primary source used	Step1	P1	P2	P3	P4	P5	
Encapsulation	SA	8	9	9	9	8	8.6
Fault arrangement design	SA	9	9	9	9	9	9
Consistent data acquisition from the derived SCADA data	SA	6	8	7	8	8	7.4
Compatibility of existing SCADA	SA	9	9	9	9	9	9
Consistent data format	SA	8	8	8	8	8	8
Recycling the data using timer function	SA	9	9	9	9	9	9
Means	Strongly agreed	8.167	8.667	8.5	8.67	8.5	8.5

OODB storage		A number of participants					Overall score
Primary source used	Step2	P1	P2	P3	P4	P5	
Encapsulation	SA	9	9	9	9	9	9
Automatic downloading algorithm	SA	9	8	8	8	7	8
Consistent data acquisition	SA	9	9	9	9	9	9
Systematic fault arrangement design for the feeders	QA	8	7	8	8	8	7.8
Means	Strongly agreed	8.75	8.25	8.5	8.5	8.25	8.45

Knowledge acquisition interface		A number of participants					
Primary source used	Step3	P1	P2	P3	P4	P5	
Encapsulation	SA	9	9	9	8	8	8.6
Consistent knowledge capture	SA	9	9	9	9	9	9
Static object-oriented SCADA data update	SA	9	9	9	9	9	9
Code re-use	SA	8	9	9	8	8	8.4
Means	Strongly agreed	8.75	9	9	8.5	8.5	8.75

Expert knowledge inference engine		A number of participants					
Primary source used	Step4	P1	P2	P3	P4	P5	Overall score
Identification of existing SCADA data	SA	9	9	9	8	8	8.6
Knowledge structure for the power	SA	9	9	8	8	8	8.4
Knowledge update	SA	8	8	8	8	8	8
Knowledge modification	QA	6	7	8	8	9	7.6
GUI for an abductive reasoning explanation systems	QA	6	8	7	8	7	7.2
Automated knowledge acquisition	A	6	7	7	7	7	6.8
Low-level reasoning	SA	9	9	9	9	8	8.8
Static alarm retrievals	SA	9	9	9	9	9	9
Means	QA	7.556	8.111	8.11	8	7.89	7.933333333

Decision presented		A number of participants					Overall score
Primary source used	Step5	P1	P2	P3	P4	P5	
Training module using an abductive reasoning	SA	9	9	9	9	9	9
Scenario alarm processing	SA	8	8	7	8	7	7.6
Symbolic process	SA	9	9	9	9	9	9
Means	SA	8.667	8.667	8.33	8.67	8.33	8.533333333
Key words	Score range						
SA(Strongly agreed)	8~10						
QA(Quite agreed)	7~7.9						
FA(Fairly agreed)	6~6.9						
A(Agreed)	5~5.9						
D(Dis agreed)	~4.9						

Appendix C: Simplifying complex alarm management

Knowledge modification:

- Did the knowledge base system collect a disturbance data after the knowledge modification?
- Did the system process all the collected disturbance data after updating heuristic rules in the rule base?
- Did extensibility in OOP allow the power system model modifiable?
- Was the knowledge modification non-influential to the alarm prioritisation process regardless of any number of attempt?
- Did the knowledge modification result in updating alarm summaries?
- Did the alarm processing become automatic after the modification

Inference speed applied:

- Did the timer function conform to the four alarm classifications?

- Did the four alarm classifications become automatic in a given time?
- Did the forward chaining process the disturbance data in a given time?
- Was the disturbance data displayed in the given intervals using GUI in which those operators could see the power system changes?
- Did the GUI incorporate the inference speed?

Disturbance data collection:

- Was the disturbance data collected consistently from the OODB to the system?
- Was the operated relays shown to the frame of OOP?
- Was the information of such tripped circuit breakers processed in the proposed system?
- Did the time-tagged SCADA data distinguish different outages?
- Did the disturbance data include the substations' location?
- Were faulted feeders shown in the data collection?

Solution presented:

- Was a solution presented in textual format?
- Did the explanation system demonstrate why such an event happens?
- Did the prioritisation scheme help operators during a heavy alarm activity?
- Did the uncertainty detection help operators where the data have not been encountered before?

Multiple faults applied:

- Were two outages from different substations processed employing the scenario rules?
- Did the prioritisation scheme function automatically?
- Were multiple events processed during the four recycling intervals?
- Did the GUI show a change of the power system?
- Did the GIS pinpoint the plausible event areas?
- Did the chronological time-tagged data function in the four recycling intervals?
- Did the alarm processor using graphical assimilation mark the unknown multiple data?

Reliance:

- Is the alarm processing updateable?
- Were the substation levels shown in the data acquisition process?
- Did the human operators understand the contents of the SCADA data?
- Did the data from the power system changes show in time-tagged order?
- Did the alarms arrive in adequate speed of operation?
- Were uncertain alarm messages symbolised as unknown more effective than a number of data?
- Were a number of switching operations interpreted?
- Was the power system knowledge maintainable?
- Was the uncertain alarm information readable?

Inference capability:

- Was the amount of SCADA information adequate for an effective alarm processing?
- Were the routing messages fixed at the installation of the SCADA system?
- Were the operators able to carry out their duties when the message prioritisation shows high priority messages?
- How many outages do the operators during variable alarm traffic conditions solve?
- Did alarm interpretation take long?
- Were the operators able to take prompt action during multiple outages?
- Were operators able to quantify alarms effectively?
- Were the alarm interpretations by the operators consistently proved optimum solutions from their wide base of knowledge and experience?

Consolidation of control function:

- Was the alarm summarisation by the topology data more helpful than temporal operators' determination?
- Did the alarm prioritisation result in reductions of alarm volume while the operators identify patterns and connections from the power system changes?

- Did high-speed execution of the KBS help the operators much whilst they were relying on their heuristic knowledge, provided that persistent alarms are outstanding?
- Did the KBS detect uncertain SCADA data where it has not been encountered before in the KBS?
- Was unreliable time ordering of alarms detected as uncertain information?
- Did the KBS capture multiple faults for a conclusion?

Volume of alarms by operators:

- Did the KBS cope with more alarms on faulted equipment than the operators' arithmetic capability when the alarm traffic is high?
- Did the KBS help the potential users for uncertain SCADA data inference, by combining routine alarm messages and reconfigured power system network on existing SCADA?
- Did large heuristic rules for routine alarm management constrain high-speed execution of the object-oriented expert system?
- How many alarm interpretations were determined to reduce operators' workload from 12 different outages for limited period on faulted equipment? Which one was better than the other?

Knowledge capture

- Did domain expertise agree to the form of knowledge representation in the system?
- Would the heuristic knowledge rules in the system be semi-permanent when such people leave their jobs?
- Were the serial labels of substations reusable in the developed system?
- Did the rules of circuit breaker trip respond to the derived SCADA data?
- Did the backward chaining detect unknown fault arrangement data where the KBS has not been encountered before?
- Did GUI (Graphical User Interface) comply with the form of message prioritisation?
- Were the rule labels extendable to the object-oriented power model from the rule editor?

Appendix D: Expert system topology for real-time interpretation

The purpose of carrying out the following questionnaires is to form better benefits of alarm management, employing an AI based power system, which will asses the topology of proposed alarm processing, in conjunction with object-oriented transmission networks. Scottish Hydro and Southern Electric Energy Group has responded to the questionnaires of the proposed alarm processing, which consists of 23, as below:

1) What is the most difficult task in alarm processing?

a) Routine alarms	b) Heavy alarms due to weather conditions	c) Persistent alarms

2) What is the role of heuristic rules in alarm management when comparing to rigours mathematical form?

Very important	Important	Not required

3) The proposed fault arrangement design consists of 7 electrical components, PHASE, EL_LIST, CB_INDEX, TYPE, SORT, CBNO, and STATUS. Will this system function as existing alarm processing?

High likely	Medium likely	Low likely

4) Does the integration with existing SCADA provide characteristics of alarm management?

Yes	No	Not sure

5) A PC-based system will be plugged into the existing SCADA, will it be beneficial when alarm activity is high?

Yes	No	Not sure

6) Inference engine is an interface from the SCADA, which monitors and reasons incoming alarms employing the diagnostic tool of OOP. Is this inference engine effective when comparing with conventional alarm configuration?

Yes	No	Not sure

7) The principles of operation of protective devices over HE transmission networks are that of understanding and determining whether or not correct operation is obtained during system disturbances. Does this topology cover the operation of such faulted feeders?

Yes	No	Not sure

8) A differential relay installation is necessary to cut out the differential protection to prevent incorrect relay operations? Does this topology provide the information more effectively than conventional alarm processing format?

Yes	No	Not sure

9) Fault location techniques fall into two resources, heuristic configuration value, and electronic configuration value/a fault detector, in order to assess fault location. This inference engine is designed to cover the requirements of utilising the two resources. Is this process representation more effective and speedy in terms of workload while operators are dependent on manual action?

Yes	No	Not sure

- 10) Process representation of the tool consists of object-orientation, which provides some common improvement, such as reusability, maintainability, and extensibility. GUI utilisation is seen very effective. Is the process representation acceptable in cost reduction of alarm management?

Yes	No	Not sure

- 11) The operator is essentially only interested in events which could affect the future state of the system. Thus, the operator would like to be informed when a critical power line is lost. Does this system cover the information of such events?

Yes	No	Not sure

- 12) The inference engine is the knowledge process which is modelled after the expert's reasoning. The engine is designed to obtain available information on a given problem, and triggered with the knowledge stored in the knowledge base. This process will draw conclusions and make recommendations. Is the inference engine more maintainable than reliance of operators' heuristic knowledge?

Yes	No	Not sure

- 13) Maintenance is often raised a difficult task by the dynamic nature of most databases which reflect the changing aspects of power systems. Large rule bases imply long inference times which may not be acceptable. For this reason, an object-oriented rule base, a model based reasoning, has been designed to attempt some improvement. The method is based on certainty factor which measures and maximises a degree of operators' confidence. Is this method feasible to attempt further improvement from existing problems of large rules?

Yes	No	Not sure

- 14) Temporal representation is to assist operators in various task environments, which covers several areas, periodic alarm processing, alarm prioritisation, GIS(Geographic Information System), and Recommendations. How much does this scheme help operators?

Very much	Fairly	Not much

- 15) GUI utilisation eases users in consulting the ES, i.e. displaying the appropriate information of conclusions and explaining the reasoning. Does the GUI provide the capability where a human expert interacts with these interfaces?

Yes	No	Not sure

- 16) The behaviour of a power system in object-orientation is relayed to the users through a single mechanism rather than a diverse set of attributes. Does the object-orientation provide more simple user interface design?

Yes	No	Not sure

- 17) Encapsulation of explicit object behaviour in one class is to share State Machines/protection systems which contains a set of internal states, i.e. a set of external triggers, and a set of transitions. Does the behaviour of object-orientation show a dynamic power system change?

Yes	No	Not sure

- 18) Each transition of power system objects is associated with a number of instances of the class such as SendMessage, which is embedded in the transition. Does this function enable a wide range of pre-requisites to be defined?

Yes	No	Not sure

19) Object-oriented relational data access is designed to retrieve SCADA data to the behaviour of the diagnostic tool. This is essential to run updated outages of the power systems. Does the OODB provide updated SCADA data to the diagnostic tool/Kappa-PC?

Yes	No	Not sure

20) Knowledge acquisition to the behaviour of OODB acts to acquire new facts or rules in the KBS. The tool employs three hybrid knowledge acquisitions, a rule editor, functions, and methods. Do these factors contribute to the flexibility of alarm processing and increased speed of retrieval of outage data?

Yes	No	Not sure

21) Subsidiary problems are raised in the design of the most suitable database, which has been developed of an object-oriented relational data, employing Visual FoxPro. This system enables the existing SCADA data to be stored in the behaviour of object-orientation. Is this database design maintainable?

Yes	No	Not sure

22) An experiment to generalise an abductive knowledge based system for fault location was conducted. The application of abductive reasoning has resulted in improving large rule base system, employing confidence factor. Does the expert system development tool adapt the proposed technique?

Yes	No	Not sure

23) The expert system topology is focused on three fundamental factors, User Interactions, Processing Capability of Uncertain SCADA data, and Consistent Knowledge Acquisition. Does this system demonstrate and satisfy operators' requirements?

Yes	No	Not sure

Appendix E: GIS applicability

These questionnaires will be used as part of an AI based power system research dealing with GIS applicability, which will be very helpful to assess usability of GIS in the developed system.

Section 1/Blackout area

1 How do you classify Blackout area?

a) Intertipping circuits	b) Voltage and Currents on the line feeder	c) Configuration of fault detectors on the transmission lines

2 How do you classify the interface of Blackout area?

a) Interactive symbol	b) textual information on the knowledge acquisition

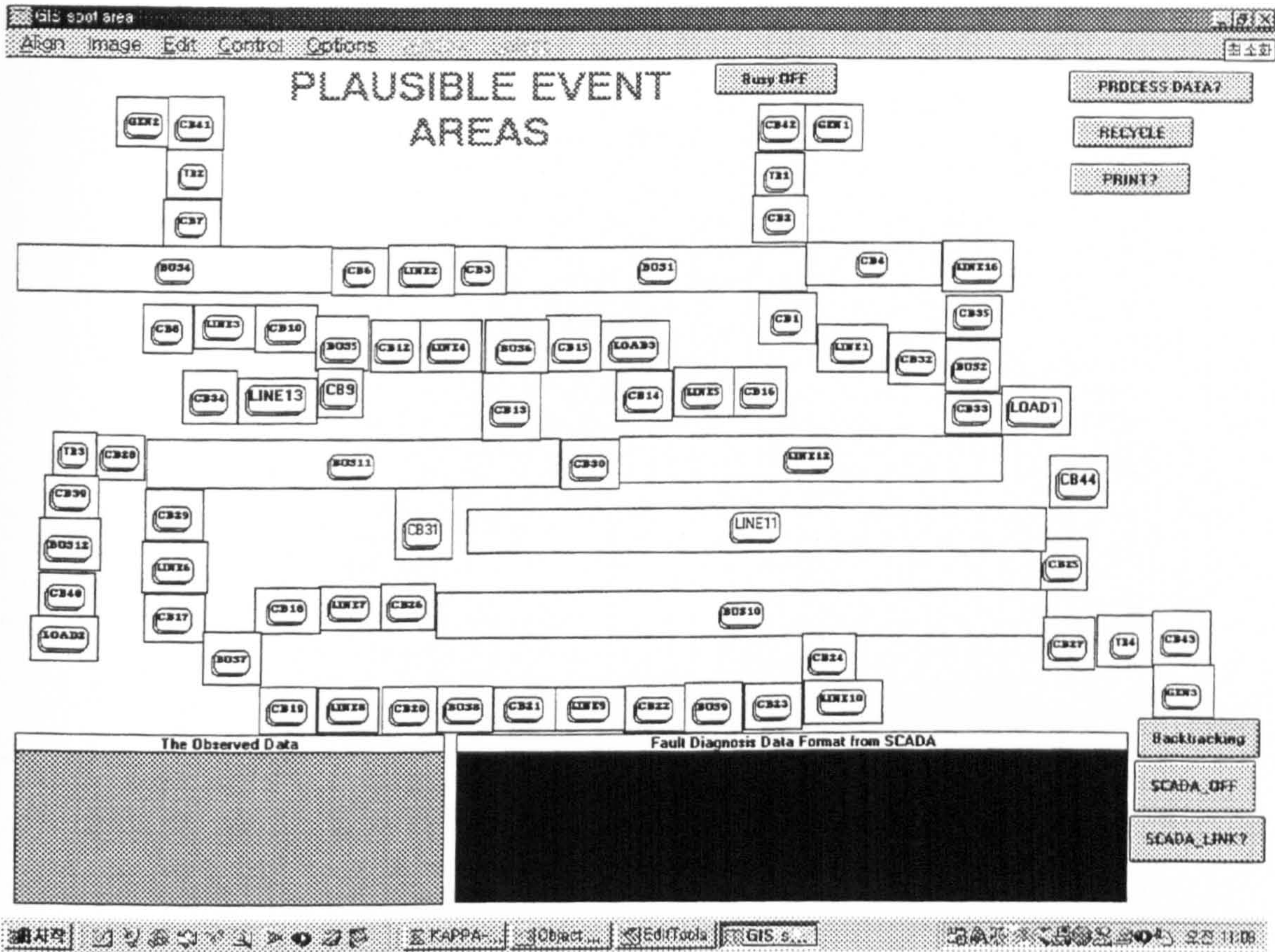
3 Does the Blackout area system support operators?

a) Yes	b) No

4 How would you rate the usability of the Blackout area system?

a) High	b) Medium	c) Low

A sample system demonstrated:



Section 2/Recycling period

5 Do operators need to review the appropriate blackout area in regular intervals?

a) Yes	b) No

6 Does the blackout area system allow the operators to control over the alarm processing?

a) Yes	b) No

Appendix F: Analysis of test results

An expert system with parsimony theory set theory:

A number of SCADA data sets	Alarm Knowledge Acquisition by Classes and Instances	Un-encountered alarms by alarm prioritization algorithms(Function+Method+SendMessage, Timer+Forward Chaining)	Observed disorders by (Hypothesis:Layout.B)	Plausible explanations by (Hypothesis:Layout.C)	Observed explanations by parsimony notion	Fault detectors' provision by User Request(Backward chaining)	MB(Measure of belief by ((object.slot)+(object.slot)/(object.slot)*(object.slot))))	Estimate performance	Actual performance
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%
2	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
3	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
4	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
5	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
6	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
7	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
8	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
9	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
10	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Means	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	100.00%	90.00%

Fault location results obtained between ES and FE under different feeder conditions:

Primary source used	Feeder location	Plausible faulted feeders	Observed disorders(D(n);a number of disorders)	Plausible membership								Overall plausible explanations	Plausible confidence factor	Observed parsimony against feeders	Expert system	
				CB trip failure	Ground fault	Short fault	Primary relay failure	Backup relay Z1	Backup relay Z2	Bus_bar failure	Tr failure				MB(Measure of Belief)	Defuzzification of Algebraic sum
Outage set1	Line5	CB14_CB16	Backup relay Z1 operated at CB16(D1);	1	1		1	1					0.8	0.6	0.28	0.92
	Line6	CB17_CB29	Ground fault occurred at line5(D2);CB19 tripped(D3);CB14 tripped(D4);CB17 tripped(D5);CB20 tripped(D6)				1						0.4	0.4	0.48	0.64
	Line12	CB33_CB30											0.4	0.6	0.6	0.76
Outage set2	Line8	CB19_CB20			1								0.1	0	0.09	0.1
	Line6	CB17_CB29	Backup relay Z2 operated (D1);Bus11 relay operated(D2);CB28 tripped(D3);CB31 tripped(D4);CB29 tripped(D5);Circuit trip failure at CB30(D6)		1								0.6	0.5	0.44	0.8
	Line11	CB28_CB39									1		0.6	0.5	0.44	0.8
Outage set3	Line12	CB30_CB33					1			1			0.7	0.5	0.36	0.85
	Line2	CB3_CB6		1	1								0.8	0.6	0.28	0.92
	Line3	CB8_CB10	CB6 tripped(D1);CB8 tripped(D2);Backup relay z1 operated(D3)	1	1	1							0.8	0.6	0.28	0.92
	Line13	CB7_CB41				1							0.4	0	0.24	0.4
Outage set4	Line14	CB11_CB38											0.4	0	0.24	0.4
	Line8	CB19_CB20											0.4	0	0.24	0.4
	Line9	CB21_CB22	CB21 tripped(D1);CB24 tripped(D2);Backup relay z2 operated(D3)		1					1	1		0.7	0.9	0.48	0.97
	Line10	CB23_CB24		1			1			1	1		0.5	0.9	0.7	0.95
	Line11	CB25_CB31											0.1	0	0.09	0.1

Appendix G: Two API (Application Programming Interface) programming sources

OODB interface implemented in Visual FoxPro 5.0

```

**
** xCusFileHandler
**

** File handler and download base class
** Min Y Park
** 28 May 1997

** Properties
** =====
**
** Public interface properties:
**
**         pcDBF      Name of destination DBF
**     pcTextFile  Name of source data file
**         plDeleted  Has file been deleted?
**
** Public pass-back properties:
**
**         gcTextFile      Name of download text file
**         gnFileHandle  File handle of text file
**     gcDBF      Destination DBF

** Methods
** =====
**
** Constructor:
**         bool INIT()
** Destructor:
**         bool DESTROY()
** Public methods:
**         bool FDownload      Main download algorithm
** Private methods:
**         char fCreateFieldList() Creates field list string of
**                                     destination database
**         bool fTextOpen()
** Protected methods:
**         void pLoadDBF() Loads DBF if necessary
**
** Calling method:
**     1. Instantiate class
**         (ie. x = CreateObject("xCusFileHandler")
**     2. Provide value for property pcDBF (x.pcDBF = "MyDbf")

```

- ** 3. Provide value for property pcTextFile (x.pcTextFile = "Temp1.Txt")
 ** 3. Call the FDownload public method (= x.FDownload())

DEFINE CLASS xCusFileHandler as Custom OLEPUBLIC

**

** Public exposed properties

**

pcDBF = "" && Destination Database

pcTextFile = "" && Source text file

plDeleted = .F. && Is database being emptied?

*-- MessageBox parameters

#DEFINE MB_OK 0 && OK button only

#DEFINE MB_OKCANCEL 1 && OK and Cancel buttons

#DEFINE MB_ABORTRETRYIGNORE 2 && Abort, Retry, and

Ignore buttons

#DEFINE MB_YESNOCANCEL 3 && Yes, No, and Cancel

buttons

#DEFINE MB_YESNO 4 && Yes and No buttons

#DEFINE MB_RETRYCANCEL 5 && Retry and Cancel

buttons

#DEFINE MB_ICONSTOP 16 && Critical message

#DEFINE MB_ICONQUESTION 32 && Warning query

#DEFINE MB_ICONEXCLAMATION 48 && Warning message

#DEFINE MB_ICONINFORMATION 64 && Information message

#DEFINE MB_APPLMODAL 0 && Application modal message

box

#DEFINE MB_DEFBUTTON1 0 && First button is default

#DEFINE MB_DEFBUTTON2 256 && Second button is default

#DEFINE MB_DEFBUTTON3 512 && Third button is default

#DEFINE MB_SYSTEMMODAL 4096 && System Modal

*-- MsgBox return values

#DEFINE IDOK 1 && OK button pressed

#DEFINE IDCANCEL 2 && Cancel button pressed

#DEFINE IDABORT 3 && Abort button pressed

#DEFINE IDRETRY 4 && Retry button pressed

#DEFINE IDIGNORE 5 && Ignore button pressed

#DEFINE IDYES 6 && Yes button pressed

#DEFINE IDNO 7 && No button pressed

**

** INIT

**

FUNCTION INIT

```

    public gnFileHandle, gcTextFile, gcDBF
RETURN .T.

```

```

**

```

```

** DESTROY

```

```

**

```

FUNCTION DESTROY

```

    This.pCloseText
    This.pCloseDBF

```

```

    release gnFileHandle
    release gcTextFile
    release gcDBF

```

```

RETURN .T.

```

```

**

```

```

** ERROR

```

```

**

```

PROCEDURE ERROR

```

    parameters tnError, tcMethod, tnLine, toObject, tcMessage

```

```

    do case

```

```

        case (tnError = 45) AND ( upper(tcMethod) == "FDOWNLOAD" )

```

```

            if type('glRetry') == 'U'

```

```

                gcTextFile = This.pcTextFile

```

```

                public glRetry
                glRetry = .T.

```

```

                retry

```

```

            else

```

```

                mlReturn = .F.

```

```

            endif

```

```

        case tnError = 3

```



```
        This.plDeleted = .F.
```

```
    case tnError = 110
```

```
        This.plDeleted = .F.
```

```
    otherwise
```

```
        Error tnError
```

```
    endcase
```

```
ENDPROC
```

```
**
```

```
** FDownload
```

```
**
```

```
FUNCTION FDownload
```

```
    && Leave response to implementation layer
```

```
    && If fails, then message in calling system
```

```
    && Min Y Park
```

```
    && 11 July 1997
```

```
    if This.plDeleted
```

```
        return .F.
```

```
    endif
```

```
    if This.fTextOpen() AND This.fLoadDBF() && Test to see if files open/open
```

```
files.
```

```
        private mlReturn && Return flag
```

```
        mlReturn = .T.
```

```
        select Download
```

```
        local lcFields
```

```
        lcFields = This.fCreateFieldList()
```

```
        if fclose(gnFileHandle)
```

```
            append from (gcTextFile) fields &lcFields type sdf
```

```
gnFileHandle = .F.
```

```
endif
```

```
if type('glRetry') == 'L'
  release glRetry
endif
```

```
RETURN mlReturn
```

```
endif
```

```
RETURN .F.
```

```
**
```

```
** FDelete
```

```
**
```

```
FUNCTION FDelete
```

```
&& Deletes all data from destination database
&& Warns and checks with user
&& Responds to shared/exclusive rights
&& Min Y Park
&& 10 August 1997
```

```
This.plDeleted = .T.
```

```
private mlReturn
mlReturn = .F.
```

```
if ( recount('Download') # 0 ) AND ( MessageBox([Are you sure?],
MB_YESNO, [Deleting All Records]) = IDYES )
```

```
  local lcExclusive
```

```
  lcExclusive = set('Exclusive')
```

```
  if This.fLoadDBF()
```

```
    select "Download"
```

```
    set exclusive ON
```

```
    use (gcDBF) alias Download exclusive
```

```
    set exclusive &lcExclusive
```

```

        if This.plDeleted
            set safety OFF
            delete all in "Download"
            pack dbf
            mlReturn = .T.
        endif
        use (gcDBF) alias Download again shared
    endif
endif

This.plDeleted = .F.

RETURN mlReturn

```

```

**

```

```

** fCreateFieldList

```

```

**

```

```

PROTECTED FUNCTION fCreateFieldList

```

```

    local lnField, mcString

```

```

    mcString = space(0)

```

```

    for lnField = 1 to fcount()

```

```

        mcString = mcString + field(lnField) + [, ]

```

```

    next

```

```

    mcString = alltrim(mcString)

```

```

Return stuff(mcString, len(mcString), 1, ")

```

```

**

```

```

** fTextOpen

```

```

**

```

PROTECTED FUNCTION fTextOpen

&& This function performs two mutual tasks:
 && 1. Tests for existence of public "properties"
 && 2. Initialises them if necessary
 && Returns success
 && Min Y Park
 && 11 July 1997

local lcString, llSuccess

if NOT (type('This.pcTextFile') == 'C') OR (This.pcTextFile == space(0))

 This.pCloseText

else

 if (type('gcTextFile') == 'C') AND NOT (This.pcTextFile ==
gcTextFile)

 This.pCloseText
 endif

 if (type('gnFileHandle') == 'N') AND fclose(gnFileHandle)
 && Assumes fclose() before fopen()
 endif

 local lnFileHandle
 lnFileHandle = fopen(iif(type('gcTextFile') == 'C', gcTextFile,
This.pcTextFile))

 if lnFileHandle # -1

 && Both of these public variables effectively
 && represent public pass-back properties.
 && Due to the limitations of VFP, this is as
 && good as this gets! Come back VB! All is
 && forgiven!

 gnFileHandle = lnFileHandle
 gcTextFile = This.pcTextFile

 Return .T.

 endif

endif

RETURN .F.

**

** fLoadDBF

**

PROTECTED FUNCTION fLoadDBF

&& Loads DBF

&& Initialises public variables

if NOT (type('This.pcDBF') == 'C') OR (This.pcDBF == space(0))

 This.pCloseDBF

else

 if (type('gcDBF') == 'C') AND NOT (gcDBF == This.pcDBF)

 This.pCloseDBF

 endif

 if NOT used('Download')

 lcExclusive = set('EXCLUSIVE')

 gcDBF = This.pcDBF

 set exclusive OFF

 use (gcDBF) in 0 alias Download again shared

 set exclusive &lcExclusive

 endif

 select Download

 return .T.

endif

RETURN .F.

**

** pCloseDBF

**

PROTECTED PROCEDURE pCloseDBF

 if used('Download')

 use in Download

 endif

```
gcDBF = .F.
```

```
RETURN
```

```
**
** pCloseText
**
```

```
PROTECTED PROCEDURE pCloseText
```

```
if ( type('gnFileHandle') == 'N' ) .AND. fclose(gnFileHandle)
endif
```

```
gnFileHandle = .F.
gcTextFile = .F.
```

```
RETURN
```

```
PROTECTED PROCEDURE pDebug
```

```
parameters tcMessage

= MessageBox(tcMessage, 0, "Debugging")
```

```
RETURN
```

```
ENDDEFINE
```

API implemented in Visual Basic 5

```
Dim moDownload As Object
```

```
Public Property Set Interval(tnValue As Variant)
```

```
'Setting download interval
```

```
If tnValue <> 0 Then
    tmrDownload.Interval = tnValue
End If
```

```
End Property
```

```
Public Property Get Interval() As Integer
```

```
Interval = tmrDownload.Interval
End Property
```

```
Property Set ToDBF(tcDBF As Variant)
```

```
'Setting download destination DBF
```

```
If VarType(tcDBF) = vbString Then
    moDownload.pcDBF = tcDBF
Else
    moDownload.pcDBF = ""
End If
```

```
End Property
```

```
Property Get ToDBF() As String
    ToDBF = moDownload.pcDBF
End Property
```

```
Property Set FromText(tcText As Variant)
```

```
'Setting download source text file
```

```
If VarType(tcText) = vbString Then
    moDownload.pcTextFile = tcText
Else
    moDownload.pcTextFile = ""
End If
```

```
End Property
```

```
Property Get FromText() As String
    FromText = moDownload.pcTextFile
End Property
```

```
Public Sub main()
```

```
End Sub
```

```
Option Explicit
```

```
Private moDownload As Object 'Download object
Private mlEnabled As Boolean
Private mcFromText As String
Private mcToDBF As String
```

```
'Downloading events
```

```
Public Event Success() 'Success event
Public Event Fail() 'Failure event
```

'Other events

Public Event Deleted() 'Delete dbf contents event (Responsive)

Public Property Let prpDelete(tlFlag As Boolean)

'Sets and activates DBF clear

If tlFlag = True And Not prpToDBF = Empty Then

'Dim lnInterval%: lnInterval = tmrDownload.Interval

'tmrDownload.Interval = 0

tmrDownload.Enabled = False

Dim x%: x = moDownLoad.FDelete()

RaiseEvent Deleted

'tmrDownload.Interval = lnInterval

tmrDownload.Enabled = True

End If

End Property

Public Property Get prpDelete() As Boolean

prpDelete = moDownLoad.prpDeleted

End Property

Public Property Let prpInterval(tnValue As Integer)

'Setting download interval

If tnValue <> 0 Then

tmrDownload.Interval = tnValue

End If

End Property

Public Property Get prpInterval() As Integer

prpInterval = tmrDownload.Interval

End Property

Public Property Let prpToDBF(tcDBF As String)

'Setting download destination DBF


```

If VarType(tcDBF) = vbString Then
    moDownload.pcDBF = tcDBF
Else
    moDownload.pcDBF = ""
End If

```

```

mcToDBF = moDownload.pcDBF

```

```

End Property

```

```

Public Property Get prpToDBF() As String
    prpToDBF = moDownload.pcDBF
End Property

```

```

Public Property Let prpFromText(tcText As String)

```

```

    'Setting download source text file

```

```

If VarType(tcText) = vbString Then
    moDownload.pcTextFile = tcText
Else
    moDownload.pcTextFile = ""
End If

```

```

End Property

```

```

Public Property Get prpFromText() As String
    prpFromText = moDownload.pcTextFile
End Property

```

```

Private Sub tmrDownload_Timer()

```

```

    With moDownload

```

```

        If .pcDBF = "" Or .pcTextFile = "" Then Exit Sub

```

```

        If moDownload.FDownload() Then
            RaiseEvent Success
        Else
            RaiseEvent Fail
        End If

```

```

    End With

```

```

End Sub

```

```

Private Sub UserControl_Initialize()

```

```

    On Error GoTo ErrHandler

```

```
'Instantiating download Fox object
Set moDownload = CreateObject("ExpertSystemDownload.xCusFileHandler")
```

```
'Setting object 's exposed properties
moDownload.pcDBF = ""
moDownload.pcTextFile = ""
```

```
Exit Sub
```

```
ErrorHandler:
```

```
Select Case Err.Number
```

```
Case 429 'Can't instantiate object
```

```
Err.Raise _
vbObjectError + 1000, _
"Download.udcDownload", _
"Can't load native download object"
```

```
End Select
```

```
End Sub
```

```
Private Sub UserControl_Terminate()
```

```
'Releasing download Fox object
Set moDownload = Nothing
```

```
End Sub
```

```
'Test form
```

```
Option Explicit
```

```
Private Sub cmdDelete_Click()
```

```
Dim lnCount%
```

```
With datDownload.Recordset
```

```
If Not .EOF And Not .BOF Then .MoveFirst
```

```
Do While True
```

```
.MoveFirst
```

```
If Not .EOF And Not .BOF Then
```

```
.Delete
```

```
Else
```

```
Exit Do
```

End If

Loop

```
' For lnCount = 1 To .RecordCount - 1  
'   .MoveFirst: .Delete  
' Next
```

End With

End Sub

Private Sub cmdDownload_Click()

With cmdDownload

.Caption = IIf(.Caption = "Download &On", "Download &Off", "Download &On")
End With

If cmdDownload.Caption = "Download &On" Then

With udcDownload1

.prpFromText = ""
.prpToDBF = ""

End With

cmdReset.Enabled = False
sldInterval.Enabled = False
Text1(1).Enabled = False
Text1(2).Enabled = False

Else

cmdReset.Enabled = True
sldInterval.Enabled = True
Text1(1).Enabled = True
Text1(2).Enabled = True

Text1_Change 1
Text1_Change 2

End If

End Sub

Private Sub cmdReset_Click()

```
Dim lcRecordSource$, lcDatabaseName$, lcDataSource$
```

```
With dbgScada
```

```
    .Enabled = False
```

```
End With
```

```
With datDownload
```

```
    lcRecordSource = .RecordSource  
    lcDatabaseName = .DatabaseName
```

```
    .RecordSource = Empty  
    .DatabaseName = Empty  
    .Refresh  
    .Enabled = False
```

```
    udcDownload1.prpDelete = True
```

```
    .Enabled = True  
    .DatabaseName = lcDatabaseName  
    .RecordSource = lcRecordSource  
    .Refresh
```

```
End With
```

```
With dbgScada
```

```
    .Enabled = True
```

```
End With
```

```
End Sub
```

```
Private Sub Command1_Click(Index As Integer)
```

```
    Dim lcFilter$, lcTitle$
```

```
    On Error Resume Next
```

```
    With cdgBrowse
```

```

If Text1(Index + 1) <> Empty Then

    Dim lnLen As Integer: lnLen = Len(Trim(.Text))

    'Stripping down file name
    Do While Mid$(Text1(Index + 1), lnLen, 1) <> "\" And lnLen > 0: lnLen = lnLen - 1:
Loop

    'Stripping down directory
    .InitDir = Left(Text1(Index + 1), lnLen - 1)

End If

.CancelError = True

If Index = 0 Then

    lcFilter = "Text Files|*.TXT|Data Files|*.DAT|Ascii Files|*.ASC|Word
Documents|*.DOC|Comma Separated Variables|*.CSV|All Files|*.*"
    lcTitle = "Choose source file"

Else

    lcFilter = "FoxPro database files|*.dbf"
    lcTitle = "Choose destination file"

End If

.Filter = lcFilter
.DialogTitle = lcTitle
.ShowOpen

If Err = cd!Cancel Then Exit Sub

Text1(Index + 1) = .filename

End With

End Sub

Private Sub Command2_Click()
    End
End Sub

Private Sub lblCount_Change(Index As Integer)
    lblCount(Index).Visible = (lblCount(Index) <> "0")
End Sub

Private Sub sldInterval_Change()

```

```

    udcDownload1.prpInterval = sldInterval.Value
End Sub

```

```

Private Sub Text1_Change(Index As Integer)

```

```

    With udcDownload1

```

```

        If Index = 1 Then
            .prpFromText = Text1(Index)
        Else
            .prpToDBF = Text1(Index)
        End If

```

```

    End With

```

```

End Sub

```

```

Private Sub Text1_KeyPress(Index As Integer, KeyAscii As Integer)

```

```

    Select Case Asc(KeyAscii)

```

```

        Case 0 To 9

```

```

        Case Else: KeyAscii = 0

```

```

    End Select

```

```

End Sub

```

```

Private Sub StatusCount(Optional ByVal tlSuccess%)

```

```

    If IsMissing(tlSuccess) Then tlSuccess = False

```

```

    If staSuccess.Panels(3).Text = Empty Then staSuccess.Panels(3).Text = "Succ: 0  Fail: 0"

```

```

    Dim lnPosn%, lnCount As Double, lcString$

```

```

    lnPosn = InStr(1, staSuccess.Panels(3).Text, IIf(tlSuccess, "Succ:", "Fail:"),
vbTextCompare) + 6

```

```

    lnCount = Val(Mid$(staSuccess.Panels(3).Text, lnPosn, 4)) + 1

```

```

    lcString = staSuccess.Panels(3).Text

```

```

    Mid(lcString, lnPosn, Len(Trim(Str(lnCount)))) = Trim(Str(lnCount))

```

```

    staSuccess.Panels(3).Text = lcString

```

```

End Sub

```

```
Private Sub udcDownload1_Deleted()
    MsgBox "I've just been deleted!", vbOKOnly, "Message from the Blue Beyond"
End Sub
```

```
Private Sub udcDownload1_Fail()
    StatusCount
End Sub
```

```
Private Sub udcDownload1_Success()
    StatusCount True
    datDownload.Refresh
End Sub
```

```
Private Sub Command1_Click(Index As Integer)

    With File1
        If Index = 1 Then Form1!Text1(gnIndex + 1) = .Path & "\" & .filename
    End With

    Unload Me 'Unloads form

End Sub
```

```
Private Sub Dir1_Change()
    File1.Path = Dir1.Path
End Sub
```

```
Private Sub File1_DblClick()
    Command1_Click 1
End Sub
```

```
Private Sub Form_Load()

    'Isolating file path and name if appropriate

    With Form1!Text1(gnIndex + 1)

        If .Text <> "" Then

            Dim lnLen As Integer: lnLen = Len(Trim(.Text))

            'Stripping down file name
```

```
Do While Mid$(.Text, lnLen, 1) <> "\": lnLen = lnLen - 1: Loop
```

```
'Stripping down directory
```

```
Dir1.Path = Left(.Text, lnLen - 1)
```

```
End If
```

```
End With
```

```
End Sub
```


Appendix H: Referred HE SCADA messages/132Kv and 275Kv

B	08:53:47 BEAU BFS 205 DBI 00	
B	08:53:47 BEAU BFS 205 OPEN	
B	09:12:35 PERSL BRIDGE OF DON 2 TRIP ON FAULT	
B	09:12:56 MILC SAS2000 REMOTE DIAGNO INITIALISED	CLEAR
B	09:12:56 MILC SAS2000 REMOTE DIAGNO CONNECTED	
B	09:45:32 BEAU BK 705 DBI 11	
B	09:45:32 BEAU BK 705 CLOSE	
B	09:45:56 PERSL BRIDGE OF DON 2 TRIP ON FAULT	CLEAR
B	09:47:23 KEITH 705 SELECTED	
B	09:47:24 KEITH 705 SWITCH CONTROL	SELECT SENT
B	09:47:28 KEITH 705 SWITCH CONTROL	CLOSE SENT
B	09:47:27 KEITH 705 CLOSE	
B	09:47:31 KEITH GK 705 CLOSE	
B	09:47:32 KEITH 705 SELECTED	CLEAR
B	09:51:02 MILC SAS2000 REMOTE DIAGNO INITIALISED	CLEAR
B	09:51:02 MILC SAS2000 REMOTE DIAGNO CONNECTED	
B	09:54:07 HECATE SYSTEM B MAIN COMPUTER FAILED	
B	09:54:07 HECATE SYSTEM A FEP FAILED	
B	09:54:07 HECATE SYSTEM B FEP FAILED	
B	09:54:08 HECATE SYSTEM A MAIN COMPUTER FAILED	
B	09:54:08 HECATE SYSTEM B MAIN COMPUTER FAILED	
B	09:54:08 REQUEST-SYSTEM INITIALISED TO LIVE	
B	09:54:08 HECATE SYSTEM A FEP FAILED	CLEAR
B	09:54:08 HECATE SYSTEM B FEP FAILED	CLEAR
B	09:54:16 TEAL1 FLEETING AL OPERATED	
B	09:54:21 TEAL1 FLEETING AL OPERATED	CLEAR
B	09:54:31 TEAL1 FLEETING AL OPERATED	
B	09:54:36 TEAL1 FLEETING AL OPERATED	CLEAR
B	09:55:11 TEAL1 FLEETING AL OPERATED	
B	09:55:16 TEAL1 FLEETING AL OPERATED	CLEAR
B	09:57:39 TEAL1 FLEETING AL OPERATED	
B	09:57:49 FOYP2 TRANSMISSION INTERTRIP OUT	