USE OF INTELLIGENT SYSTEMS WITHIN SUBSTATIONS

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Abstract

This report was produced by a subgroup formed within WG 34.07. The working group activity was related to the Configuration, Functional Integration and Use of Expert Systems. The subgroup activity was related to the use of Intelligent Systems within Substations.

This report focuses on intelligent system applications to protection and local control within transmission substations. It is devoted to the application of several new techniques in the substations protection and local control including expert systems, knowledge based systems, artificial neural networks and fuzzy logic systems. The aim is to provide references relating practical experience as well as some guidance concerning the use of intelligent systems to improve the technical and economical performance of the substations protection and control function.

After having given a few definitions on intelligent systems, the report depicts the typical example of the fault data analysis which represents an application in existence today. Then, emphasis is put on the potential applications of intelligent systems within substations and on their technical and economic benefits. To make the most of these techniques, intelligent systems have also to be harmoniously combined or integrated to the secondary equipment of the substation. The report gives some requirements which may influence the design of the digital integrated secondary equipement of the transmission substations. It is concluded that applications based on intelligent systems should play a major role in the future in the protection and control of substations.

1. INTRODUCTION

There is great potential for further improvement of the operation of power systems through the use of Intelligent Systems in the secondary equipment within transmission substations. Intelligent Systems offer an opportunity to increase the performances of the traditional existing protective, control and monitoring functions of a substation. They are also powerful techniques which can be used to develop new applications like the automated analysis of all data which are recorded in substations.

Used in conjunction with modern digital integrated secondary equipment, they are expected to improve the reliability of the power system and to significantly reduce the global cost of secondary equipment of substations, i.e. the investment cost, the operation cost and the maintenance cost. Thanks to their capabilities of automatically and quickly performing powerful data analysis, they are also a means to increase productivity and reliability of electricity suppliers and a chance to develop new customer oriented services specially in the actual context of changes in the electricity market.

After having somewhat "demystified" the intelligent system concept by giving a few definitions, this report depicts the typical example of the fault data analysis applications which are in existence today. Then, emphasis is put on the potential applications of intelligent systems within substations and on their technical and economic benefits. To make the most of these techniques, intelligent systems have also to be harmoniously combined or integrated to the secondary equipment of the substation. The report gives some requirements which may influence the design of the digital integrated secondary equipement of transmission substations. Lastly to satisfy a curious reader eager for further information about actual applications, a list of references related to recent developments and experiences is given in the last part of the report.

2. INTELLIGENT SYSTEMS – BACKGROUND

Nowadays a definition of an Intelligent System can be given as: "a set of various hybrid programming techniques which are well suited individually to represent and to solve a specific part of a problem and adjusted to reach the best conclusions."

Intelligent systems is, therefore, a part of the Artificial Intelligence (AI) field where significant progress has been made during the last decade in knowledge representation, language and processing techniques, and hardware developments. AI applications are emerging today in various fields such as medical diagnosis, planning, financial management or speech recognition.

A lot of technical approaches have been investigated to represent the knowledge and to solve the problem. As a technical point of view, we can group the Intelligent Systems into the following three main families:

- expert systems,
- neural networks,
- fuzzy logic systems.

These techniques are briefly presented below.

2.1 EXPERT SYSTEMS

The first expert systems included a few heuristic rules based on the expert's experience. In such systems, the knowledge takes the form of rules written using a "If... Then..." syntax, and also consists of facts which generally describe the domain and the state of the problem to be solved. A generic inference engine uses the facts and the rules to deduce new facts which allow the firing of other rules. This process continues until the base of facts is saturated and a conclusion has been reached. To guide the reasoning and to be more efficient these systems may incorporate some strategies known as metaknowledge. Rules based systems represent still the majority of the existing expert systems. Their limits are their performance, in terms of computation time.

In the second half of the eighties a second generation of expert systems was introduced. These combine heuristic and "deep" knowledge based on models of the operation of the system to be diagnosed or the reasoning structure. These systems became powerful tools because, on one hand, the amount and the variety of the knowledge has been increased and, on the other hand, the knowledge itself could be represented using structures more complex than rules (e.g. objects, frames, methods, tasks, agenda and algorithms). The advent of these expert systems has been possible due to the progress made both in the computer software and hardware. Nowadays modern knowledge representation languages often offer several formalisms such as the object and rule oriented programming. They are interfaced to traditional languages, data bases and standard graphic display systems.

The drawbacks of these expert systems have to be found in the availability of wide knowledge and data needed to achieve the diagnosis. Their performance depends on the quality of the knowledge base, i.e. the precision, the granularity, the completeness and exhaustiveness of the models.

The first prototypes of expert systems applied to power systems appeared in the beginning of the eighties. Papers [1], [2], and [3] depict some of those pionner applications for security assessment, fault section estimation and alarm handling.

The rapid expansion of the expert systems technique in the field of power systems has lead to publication of important literature, books [4], surveys, [5-9] and the organization of dedicated courses [10], workshops [11] and conferences [12-18].

The survey [7], made in 1991 by the CIGRE Task Force 38.06.03, counted 26 operational systems in use. In this study, most of the mentioned systems are located at the dispatching level and are used as tools to support the control action: alarm handling, fault section estimation and restoration of the network after an incident. Very few are located in the substation. No application is concerned with protection probably because it is considered as a strategic function which requires real time processing and a very high level of security.

The monitoring and diagnosis of the substation HV gear may constitute another category of expert systems applications within substations [19]. This topic is not considered in this report as it is in the field activity of the CIGRE Committee 23 and has been studied by the CIGRE WG 23.05.

2.2 NEURAL NETWORKS

Neural Networks can be classified as a specific part of Intelligent Systems. They are very different from expert systems in the sense that they do not need a knowledge base to work. They only have to be trained with numerous actual cases. A Neural Network is a set of elementary neurons which are connected together in different architectures organized in layers. An elementary neuron can be seen like a processor which makes a simple non linear operation of its inputs producing its single output. A weight is attached to each neuron and the training enables adjusting of different weights according to the training set. Neural Networks techniques are attractive because they do not require tedious knowledge acquisition, representation and writing stages. The speed of processing, allowing real time applications, is also an advantage. But they were adapted only to some problems like recognition of speech, pictures and waves. The first papers on Neural Networks applications to power systems were published at the beginning of the nineties [20]. These concern mainly security assessment, alarm handling and fault diagnosis applications. Since then, a large number of papers was published related to a variety of substation applications [21].

2.3 FUZZY LOGIC SYSTEMS

In the fuzzy logic systems, the knowledge is represented by facts and rules which are expressed in terms of "vague" words such as uncertain, certain, small, medium, large etc. A fuzzy inference program uses this qualitative knowledge to deduce the conclusion which have the highest possibility to occur. Fuzzy logic seems to be a "sturdy" technique well suited to take into account the imprecise and missing input data. That is the case of "fault section estimation" where the existence of some fuzzy logic systems can be noticed.

3. INTELLIGENT SYSTEMS WITHIN SUBSTATIONS

The survey, made in 1992 by the IEEE Working Group D10, focuses on potential applications to Power System Protection [8]. The applications of increasing interest in the near future are the post mortem fault analysis and monitoring functions related to the substation equipment. Some recent research and development efforts show that expert/intelligent system technique combined with the existing digital technology is applicable to protection, real time control and substation automation [12-18].

Table 1 gives a classification of intelligent system applications to protection, control and monitoring functions within substations according to various characteristics such as the kind of input and output data, knowledge representation, reliability and speed.

4. AN EXISTING APPLICATION: FAULT ANALYSIS

Up to now, all the analyses of network incident were done manually by analyzing a posteriori all the recordings of analog or logic data related to the HV gear or the protection and control systems. Due to the growing complexity of protection systems, more sophisticated algorithms, vast diversity of the number of protection functions, and the emerging need for correct monitoring induced an important workload and an extensive field of knowledge. Therefore, a tool to aid the analysis became indispensable and the expert system technique has been naturally considered as a significant number of prototypes have been developed.

Two categories of expert system can be noticed: those which are fed by the time tagged sequence of contacts created during incidents and those fed by digital samples of the changing analog wave forms of currents and voltages during incidents.

4.1 SEQUENCE OF EVENT ANALYSIS [22, 25]

These systems are fed by the events which are time tagged and recorded at the substation level. The states of breakers and the tripping orders are the minimum information for making a diagnosis. To make the analysis deeper, the detailed sequence of events created by the protective relays, (starting, phase selection, directional, zone, teleprotection, closing signals etc...) fault locators and autoreclosers can be very useful. To improve the diagnosis, data coming from neighboring substations like telecontrol signals may sometimes be helpful. The precision of the time tagging is another important factor for the accuracy of the diagnosis. A value of 10 milliseconds is thus recommended. We can notice a lot of various diagnosis techniques, particularly for the faulty section estimation (pattern recognition, simulation, hypotheses generation etc.).

Monitoring of the behavior of the protection system may include verification of correct operation of the protective equipment inside a substation. The loss of selectivity and the measurement of the clearance time are also essential for performance evaluation and preventive maintenance purposes. The protection system monitoring often needs a model of the system to be able to perform the diagnosis. As a consequence detailed knowledge bases are important.

4.2 ANALYSIS OF DIGITAL FAULT RECORDINGS [26-33]

A common practice in a number of countries is to use Digital Fault Recorders (DFR), quite often also called Disturbance Recorders, Transient Recorders, etc. These devices

TABLE 1. Various Characteristics of Intelligent System Applications

Applications	**Field**	Control, Planning, Line (Bus...) protection, Security, Monitoring, Maintenance, Operation, Restoration, Quality of supply, Metering, Billing, Customers information
	System location	Substation control room, Bay computer, Protection, Protection engineer's office, Control center, Headquarters, Financial Dept.
Data Input	**Type**	Logical, Analog, Time tagged events, Digital currents-voltages, Keyboard answers, ASCII/binary files
	Source	Line (Bus...) protection, Recloser, Circuit-breaker, Event (fault) recorder, CT-VT, Meters, Bay computer, Substation computer, Local Area Network
	Origin	Switchyard, Cubicle, Protection, Bay level, Control room, Neighboring (other) substations
Knowledge Implementation	**Representation**	Rules, Facts, Objects, Frames, Methods, Tasks, Demons, Relational/traditional data base
	Connection with existing Data base	Network electrical components/structure DB, Control real time DB, Fault recordings DB, Customers DB, Billing file
	Solving technique(s)	Inferences, Forward/backward chaining, Procedures, Agenda mechanisms, Neural net, Fuzzy logic, Genetic algorithm, Load flow algorithm, Petri nets, Impedance calculation
Output	**Type**	Operating (tripping) order, Logic event, Explanation ASCII file, Synthesis message, Real time data filtered, Data base, Alphanumeric/graphic display, printing
	Response time	from 50 ms (real time applications) to several hours
User	**Main activity**	Control, Maintenance, Protection engineer, Financial, Network planning
	Location	Substation, Control center, Maintenance / Repair office, Headquarters

are an advanced version of the "old" design of the analog devices called Strip Chart Recorders or Oscillopertur-bographs. The role of these devices is to record analog waveforms and contact (status) information in substations. This data is then used by the operators in analyzing events that have caused the disturbances.

One of the main practical problems with the use of the recorders is handling of the large amount of data being recorded. Most of these instruments have as many as 64 analog and 125 contact inputs. All the input data is recorded each time the recorder is triggered. This results in the recordings of some data that may not be relevant for the analysis since, in many cases, only a limited number of inputs are affected by a given disturbance.

4.3 COMBINED SOLUTIONS

An accurate diagnosis of an incident needs detailed analysis of data related to the protective relays and circuit breakers which have worked to eliminate the fault. As this equipment is not located in the same substation, and as an overall view of the power system is necessary, a hierarchical fault analysis and diagnosis system can be imagined. In a context of a digital substation, it is expected that the future protection and control equipment will give more data. In these conditions, expert systems could help avoid the bottleneck of the data transmission links. A combination of the analysis of the digital fault recordings and of the sequential events recordings could be well suited for a top down reasoning approach.

5. POTENTIAL APPLICATION AREAS

In considering the use of intelligent systems for substations monitoring, control and protection, one may divide the applications into:

- individual device level,
- substation level.

5.1 INDIVIDUAL DEVICE LEVEL

Most of the intelligent system applications in relaying are aimed at improving the conventional relaying functions. However, some new approaches were also introduced. The main contributions are provided for the following applications:

• adaptive relaying and reclosing,
• new transmission line relaying principles,
• improved fault location,
• high impedance fault detection,
• improved power transformer protection.

Table 2 summarizes some examples of the most recent applications.

5.2 SUBSTATION LEVEL

At the substation level, most of the applications available today refer to the fault analysis. A summary of the possible approaches is given in Table 3.

Some of the intelligent system applications are aimed at improving fault monitoring and analysis. Several studies indicate that the fault analysis improvements can be made in the following areas:

• new approaches to disturbance waveform classifications,
• improved automated fault analysis approaches,
• new fault location principles,
• new techniques for power transformer monitoring [51-52].

Neural networks may be used to improve bus-bar protection [53]. In this case the neural network is utilized for pre-processing the data for the purposes of restoring the distorted signals occurring due to the saturation effects of current transformers.

6. OPPORTUNITIES AND BENEFITS

6.1 IMPROVING THE CONTROL AND PROTECTION SYSTEM

Intelligent systems may improve the performance, reliability and avaibility of the control and protection system. It is particularly the case in complex situations where different disturbances are combined and drastically distort the wave form of currents and voltages which feed protective relays (for example harmonics due to the saturation effect of transformers). Implementing an algorithm in a digital relay is difficult

TABLE 2. Individual Device Level Applications

Application Area	Improvements	Intelligent Technique Used	References
Distance Relaying and Related Functions	Fault type identification	Fuzzy Sets	[34]
	Fault detection and directional discrimination	Neural Nets	[35-37]
	Adaptive protection of double-circuit lines	Neural Nets	[38,39]
	Adaptive selection of the operating characteristic	Pattern Recognition	[40-42]
	Adaptive reclosing	Neural Nets	[43]
Transmission Line Relaying	V-I vs. R-X plane for fault detection and classification	Neural Nets	[44]
Fault Location	Analysis of the disturbance pattern	Neural Nets	[45]
High Impedance Fault Detection	Detection of the faults	Neural Nets	[46-48]
Power Transformer Protection	Selectivity between faults and operating conditions	Fuzzy Sets Neural Nets	[49-50]

TABLE 3. Substation Level Solutions

Application Area	Improvement	Intelligent Techniques Used
Sequence of Events (SOE) Recorders	• Automated analysis • Consistency check through redundancy	Rule Based Expert Systems
Digital Protection Relays (DPR)	• Analysis of relay operation • Analysis of faults	Expert Systems (not yet reported)
Digital Fault Recorders (DFRs)	• Automated analysis • Combining of analog and contact information for redundancy check	Hybrid Solution, Signal Processing and Rule Based Expert System
Bus Bar Protection	• Detection of the current transformers saturation	Neural Network

since the electrical equation to solve may be very complex and difficult to implement in real time. Moreover the numerous parameters which intervene may also be difficult to set. Neural networks and specially their training capabilities offer interesting possibilities: to set the relay only by training the neural network with a set of numerous cases. These cases can be obtained by actual recordings of waveforms or by using powerful simulation programs like EMTP or MORGAT. The advantages of the simulation is to cover a lot of situations and specially those that rarely occur and are difficult to record as actual cases. As a consequence, the training set is more robust.

6.2 DETECTING HIGH IMPEDANCE FAULT

In the case of the high impedance fault detection, it may be argued that these applications are not indeed new since they have been discussed for the last 20 years. On the other hand, it is well known that there were no standard solutions introduced in the past to successfully deal with these problems. Only the recent implementation attempts have demonstrated that working solutions can be developed using intelligent systems. These are utilized to recognize patterns of waveforms for different types of conditions (level of loading, type of soil, type of fault). In most of these cases, the fundamental frequency signal does not indicate a major change, while most of the information needed to distinguish these events from some other normal operations is contained in the higher harmonics. The need to use signal processing techniques demonstrates the processing complexity to be the major disadvantage. This, in turn, requires more powerful microprocessors and more complex software. Recently, it has been demonstrated that the application of neural networks may be an appropriate approach to this problem since it can be defined as a pattern recognition problem. The neural network processing applied to this problem eliminates a need to define complex thresholds for various signal parameters obtained using known signal processing techniques.

6.3 AVOIDING THE BOTTLENECK OF DATA TRANSMISSION

In a context of all-digital secondary equipment available in substation, it is expected that the integrated/coordinated protection and control equipment will give more data. In these conditions, intelligent systems could avoid the bottleneck of the data transmission by combining the analysis of the digital fault and sequential event recordings as well as recordings available from digital relays.

Analysis of the new, all digital, solutions for the substation equipment shows that the main trend is to provide a large amount of data related to the substation quantities. The analysis of data available from typical modern digital relays shows that the quantity of data generated by a relay after a fault may reach 16 K bytes. It can be noticed that an increase of the sampling rate is also expected in the next few years. If all this data is stored after it is used for the main application, it becomes available for any subsequent processing. The fact that this data is available opens a question of what to do with it. Furthermore, the question may be extended to the use of intelligent systems to compress the data or to make some additional conclusions based on this data.

Intelligent systems offer the possibility to utilize the excess data to make more comprehensive conclusions about the overall substation equipment operation possible today through the SCADA systems. On the other hand, if the data is collected directly from the substation monitoring, control and protection equipment, rather than through remote terminal units, new possibilities may exist for application of the intelligent systems to perform local assessment of the substation equipment operation.

6.4 FAULT DATA ANALYSIS

In the case of the automated fault diagnosis, it is important to combine information derived from both analog measurements and contact indications to be able to make a conclusion about a fault event and an operation of the related equipment. The use of expert systems have been quite useful when a large number of comparisons had to be performed based on a number of different parameters. Implementing the same application using an algorithmic approach may be inconvenient, if not impossible, due to the heuristic nature of the diagnostic search procedures.

Opportunities exist to improve the synthesis and reliability of the data to be transmitted to the control center. A hierarchical fault diagnostic system can be imagined. An accurate fault recognition and location are possible at the substation for all the faults which are located inside the substation or on the lines fed by the substation. A full integrated protection and control system makes easier implementation of such a system. This hierarchical solution is illustrated in figure 1.

At the bay level, information generated by the protections (main and backup), the fault locators and the reclosers are considered. Comparing the behavior of these devices, a mini synthesis can be performed at this first level. The substation is the second level of synthesis. Taking into account all the feeders of the substation, the diagnosis can be reinforced and sent to the district or regional control center. At this last level, an overall synthesis is necessary.

7. IMPACT OF INTELLIGENT SYSTEMS ON THE DESIGN OF THE SECONDARY

7.1 DATA BASE REQUIREMENTS

The use of digital equipment in substations has provided for software implementation of various standard monitoring, control and protection functions. As a result, intelligent system application became of interest since they can also be implemented using appropriate software. These possibilities opened a question if there are any special substation equipment requirements that need to be satisfied in order to utilize the intelligent system solutions using this equipment.

In order to pursue the above mentioned concept, the following issues

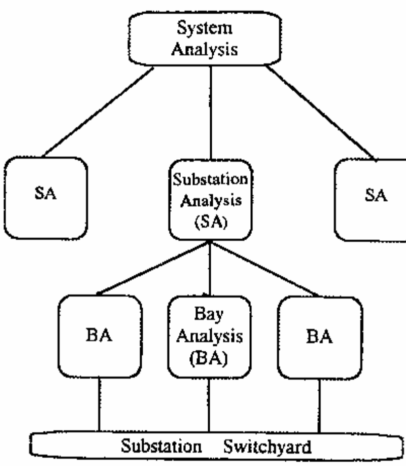

Figure 1. Analyse hiérarchique automatique des défauts.

Figure 1. Hierarchical Automated Fault Analysis

related to data acquisition need to be considered:

- types of the collected data,
- synchronization of data sampling
- accuracy of data acquisition.

The data types usually include samples of voltages and currents from the lines and buses as well as contact status from the switching equipment. The analysis shows that this data is redundant since there is a relationship between the analog quantities in a given substation and the switching equipment contacts. This property can be utilized only if the data from various equipment in the substation is brought to a common database so that the redundancy can be explored. In this case, various intelligent system approaches can be used for a specific type of processing that will directly explore the properties of such a database.

Another important issue for the intelligent system applications in the substation is the temporal element. This consideration relates any data sample to any other one using a well defined time scale. The advantage of the substation data is that it can be used to determine sequence of events using the fundamental frequency sinusoidal waveform as a time reference. In order to preserve this as a reference, all the data needs to be sampled synchronously. This introduces an additional requirement that some sort of sampling synchronization exits between all the equipment in a substation. The use of the standard absolute time signal as a reference may be the most beneficial approach known. In any case, the use of synchronized data may benefit the intelligent system applications since these applications may be used to explore the time relationship between various quantities.

Finally, if the substation data is to be combined and/or consolidated for the purpose of implementing some intelligent processing techniques, it is also important to provide consistent accuracy for all the measurements. This requirement may mean that all the substation equipment uses the same accuracy for the front end electronic aimed at signal sampling and conversion into a data base. This requirement may be difficult to implement since the original application will need to be analyzed to determine if some additional equipment requirements may have to be imposed to provide for the required data accuracy of the intelligent methods.

7.2 KNOWLEDGE ACQUISITION [54-55]

In a digital substation, special care is needed for the description of the substation configuration. Most of the time the manufacturers use a special tool dedicated for this purpose: acquisition of the names of the bays, devices, and description of the behavior of some automatic devices using a special language based on block diagrams, Grafcet or Petri Nets. The knowledge base of the expert system can be partly deduced from the whole data base of the digital substation. Translation software could be used for this.

There is a need for a structured method and a tool for building, organizing, modeling and integrating knowledge into complex knowledge bases. In this respect, the use of such methodologies and tools can also bring a better reliability in the tedious process of building large evolving knowledge bases.

7.3 VALIDATION AND TESTING

The process of evaluating software to ensure that it fulfills all the requirements related to the intelligent system performance may be quite difficult and special care is needed. A large amount of time for testing the software of the system may be spent.

In general, developers tend to try to test software exhaustively, checking all possible combinations. In practice, this is impossible to carry out, even in the cases with a very specific and narrow domain.

In validating an expert system software, another important factor has to be considered. This factor comes from the development method commonly followed, based on the use of a prototype. This implies that part of the knowledge is acquired in an iterative process in which the results of the test are fed back to the expert system functional specification. This, in turn, implies that a complete, consistent and accurate specification of the software is not available at the beginning of the process, in contrast with most of the conventional software developments.

Many expert systems application in the field of power system have been developed by power systems engineers. This is generally considered an advantage that may speed up the knowledge acquisition process. On the other hand, a power system engineer could be less familiarized than a specialist in expert system programming techniques, which can lead to the absence of a systematic application of the methods, procedures and rules of the software design and subsequent difficulty in validating expert system software.

In addition, like in the conventional software developments, errors can be found in the model chosen to represent the devices or the system, in the specification of the system performance, in the program design and coding, and in the documentation.

It is very important to chose a good strategy of testing. Testing is a task that requires a great creativity. Test should be carried out by persons not involved in the development of the system. To include some end-user in the testing team could help in pointing out problems and weaknesses of the software not noticed by developers.

The most common and probably the most effective approach is to combine modular and global testing. After exhaustive testing of each module, tests of combinations of modules, of complete subsystems and the interfaces among them have to be done, and if it is possible of the whole system itself.

Another possibility is the use of the simulators that in many cases cannot be easily developed. An accurate simulation would permit establishing the functional requirements more consistently. Programs have to be tested under valid and invalid conditions and a complete documentation of test cases and results has to be kept.

7.4 MAINTENANCE AND UPGRADING

It should be noted that if the expert system has been properly designed it should not require more maintenance than a conventional program. Once the knowledge-based system has been tested and installed, the software will need maintenance for several reasons :

- Modifications in the configuration of the power system for which the expert system was designed.
- Addition of new features not foreseen in the development of the expert system.
- Correction of errors detected after testing, especially those that appear only under unusual circumstances, which in expert systems are extremely hard to find.

As with any software, a good design may provide for easier maintenance. If developers have paid attention while writing rules by looking for simplicity, modularity, clarity and consistency the maintenance efforts may be reduced. The main difference between conventional software maintenance and expert system software maintenance is that in expert systems the main task of the maintenance is to check the knowledge base and to verify that the correct rules are fired under any given circumstance.

Data base maintenance at substation level has to be considered carefully. The updating must be easy, automatic or computer assisted. But in a context of the digital substation, this is also the case for the data necessary for other applications. The expert system(s) in the substation must be fully integrated like the other functions of the substation. This means a close link with the whole data base of the substation which describe the domain. The knowledge base of the expert system itself must have a reasonable size. Expert system must not add a lot of maintenance work.

It should be noted that the knowledge base is not the only part of the system which can cause errors. In the context of digital substations, errors contained in the databases of different devices can go undetected when used with the conventional application and appear when used in the expert system.

In upgrading the system, before releasing a new version of the knowledge base or installing a new version of the database, the expert system should go through a whole set of test cases to verify that the modifications have not introduced new problems. Software tools can be developed to compare the results obtained in the test cases with the correct-ones.

Expert systems can accumulate knowledge easier than the conventional software, but this incremental improvement can easily be made only within limits. Beyond these limits, significant restructuring may be needed before knowledge can be easily added.

8. CONCLUSION

An Intelligent System can be defined as: "a set of various hybrid programming techniques which are well suited individually to represent and to solve a specific part of a problem and adjusted to reach the best conclusions." Up to now, significant progress has been made in developing intelligent system techniques. A lot of knowledge representation approaches have been investigated: expert systems, neural networks, fuzzy logic and any combination.

Today the most common operational applications within subtations concern fault analysis. One may consider on one hand the fault analysis based on the sequence of events recordings. On the other hand, fault anaysis based on digital fault recordings may also be considered. In this case, the avantage of the use of intelligent techniques is evident: automatic producing of the result, speed of response, accurate diagnosis of the power system and related equipment, etc.

Existing and potential intelligent system applications within substations include both individual device and substation implementations. At the device level, the most promising applications are in the area of new solutions such as high impedance fault detection. At the substation level, opportunities exist to improve the operation of the bus bar protection. In the context of a coordinated-integrated digital substation, intelligent hierarchical automated fault analysis could easily be implemented.

A number of implementation issues such as data requirement, knowledge acquisition, validation and testing, as well as maintaining and upgrading are indeed critical and need careful consideration.

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