DEVELOPMENT OF AN EXPERT SYSTEM FOR POWER QUALITY ADVISEMENT USING CLIPS 6.0

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ABSTRACT

Proliferation of power electronic devices has brought in its wake both deterioration in and demand for quality power supply from the utilities. The power quality problems become apparent when the users' equipment or systems maloperate or fail. Since power quality concerns arise from a wide variety of sources and the problem fixes are better achieved from the expertise of field engineers, development of an expert system for power quality advisement seems to be a very attractive and cost-effective solution for utility applications. An expert system thus developed gives an understanding of the adverse effects of power quality related problems on the system and could help in finding remedial solutions. The paper reports the design of a power quality advisement expert system being developed using CLIPS 6.0. A brief outline of the power quality concerns is first presented. A description of the knowledge base is next given and details of actual implementation include screen outputs from the program.

INTRODUCTION

The introduction of nonlinear loads and their increasing usage, have led to a point where the system voltage and current are no longer sinusoidal for safe operation of the equipment at both industrial and customer levels. Before the advent of electronic and power electronic devices, the current distortions were due to saturation of the magnetic cores in the transformers and motors, arc furnaces and mercury arc rectifiers. Even though the overall effect on the system was there, it had no serious effect on the performance of comparatively more rugged and insensitive equipment. Today, sensitive electronic and microprocessor based equipment are commonly used and they are susceptible to variations and distortions of the sinusoidal wave. Distorted sinusoidal waveforms of voltage and current are produced due to the nonlinear characteristics of the electronic components which are used in the manufacture of any electronic related equipment. The power quality problems arising in the system basically are impulses, surges, sags, swells, interruptions, harmonics, flicker etc. These power quality problems can be a potential threat to the satisfactory operation of the equipment. Thus there is a need to alleviate or eliminate the effects of poor power quality. Engineers are applying their experience with the causes of power quality impairment to recommend solutions to correct the problems.

Expert systems could be used for domain specific problems, such as power quality. The solutions to power quality may be many and it may not be possible to come to a single conclusion. Expert System approach can be useful to get a very successful approximate solution to problems which do not have an algorithmic solution and to ill-structured problems where reasoning may offer a better solution. The opinions of the experts may vary regarding a particular problem, but the level of expertise combined from several experts may exceed that of a single human expert, and this can be made use in an Expert System. The solutions given by an expert system are unbiased but the solutions from an expert may not always be the same. Databases can be accessed by an

expert system and algorithmic conclusions can be obtained wherever possible.

POWER QUALITY (PQ) IN POWER SYSTEMS

The impulses arising in the system are usually due to lightning and they cause insulator flashover, transformer failures, arrestor failures and damage to other substation equipment. Lightning strokes can pass through the transformer neutrals and cause damage to the customer equipment also. This is especially when the lightning strikes close to the distribution transformers. Oscillatory transients can be classified into three groups as low frequency, medium frequency and high frequency transients. Their range is from below 5 kHz to above 500 kHz. The main causes for these transients are capacitor switching, cable switching, back to back capacitor energization, travelling waves from lightning impulses and circuit switching transients. The impact of these transients are very high voltage levels on the secondary side of the transformers, especially due to capacitive coupling between primary and secondary windings, for medium frequency transients. Thus, these transients can also cause equipment failures and disruption of sensitive electronic equipment.

Sags and Swells can be classified into three groups namely instantaneous, momentary and temporary. They may last from 0.5 cycle to 1 minute. Sags may cause dropout of sensitive electronic equipment, dropout of relays, overheating of motors etc. Swells are usually due to single-line-to-ground faults occurring in the system. The extent of voltage rise varies with the type of grounding scheme adopted. An increase in the voltage of 73.2% is for ungrounded systems. The effect of swells could cause Metal Oxide Varistors to be forced into conduction.

Over-voltages and under-voltages last longer than 1 minute. They are caused by load switching, capacitor switching or due to bad system voltage regulation. The impact of these is dropout of sensitive customer equipment which usually require constant voltage.

Harmonics are caused due to nonlinear characteristic of the loads of which converter circuits, arcing devices etc are some examples. Harmonics are multiples of fundamental frequency and are continuous in nature and distort the sinusoidal waveform. Interharmonics are caused by cycloconvertors and arc furnaces. The impact of harmonics can cause overheating of transformers and rotating machinery, maloperation of sensitive electronic equipment, maloperation of frequency sensitive equipment, metering errors, presence of neutral to ground voltage resulting in possible neutral overloading, capacitor failures or fuse blowing, telephone interference, increased power losses, etc.

Noise is caused by the range of components less than 200 kHz. Improper grounding and operation of power electronic equipment are the main causes of noise production. The impact of noise is on telephone interference. Notching is due to commutation in three phase inverters and converters. The number of notches depend on the converter and invertor configuration. The converters and invertor circuits can be operated in a six pulse, twelve pulse, eighteen pulse or more configurations. Flicker is usually caused by presence of components less than 25 Hz. Arc furnaces and intermittent loads like welding machines are some examples. These low frequency components may cause problems with lighting.

The various disturbances leading to power quality deterioration can stem from a wide variety of reasons that are often interdependant and quite complicated. A thorough analysis may be time consuming and inefficient. The solutions also depend upon experience of the system.

EXPERT SYSTEM APPROACH TO PQ

Expert systems came into existence as an outcome of the need for better problem solving methods where a closed form solution is unavailable. Since knowledge of power quality

problems is obtained more through study and experience, development of an Expert System is a viable approach.

An Expert system comprises of user interface, working memory, inference engine, agenda, and knowledge acquisition facility. The user interface is a mechanism by which the user and the expert system communicate. Working memory consists of a global database of facts used by the rules. An agenda is a list of rules with priority created by the inference engine, whose patterns are satisfied by facts or objects in the working memory. The knowledge acquisition facility is an automatic way for the user to enter knowledge in the system rather than by having the knowledge engineer explicitly code the knowledge.

Rule-based, object-oriented and procedural programming paradigms are supported by CLIPS 6.0. The basic components of CLIPS 6.0 are facts list, knowledge base and inference engine. The fact list contains the data on which inferences are derived, knowledge base contains all the rules and the inference engine controls the overall execution. Thus the knowledge base contains the knowledge and inference engine draws conclusions from the knowledge available. The user has to supply the expert system with facts and the expert system responds to the users' queries for expertise.

Knowledge can be represented by rules, semantic networks,parse trees, object-attribute-value triples, frames, logic etc. Each have their own limitation and a suitable field of usage [1]. Trees and lattices are useful for classifying objects because of hierarchical nature.

Decision trees can be used effectively in the development of power quality expert system due to hierarchical nature of power quality problems as usually one problem leads to several problems. A decision structure is both a knowledge representation scheme and a method of reasoning about it's knowledge. Larger sets of alternatives are examined first and then the decision process starts narrowing till the best solution is obtained. The decision trees should

provide the solution to a problem from a predetermined set of possible answers. The decision trees derive a solution by reducing the set of possible outcomes and thus getting closer to the best possible answer. Since the problems pertaining to power quality have different effects the solutions and remedial actions may be approximated by successive pruning of the search space of the decision tree.

A decision tree is composed of nodes and branches. The node at the top of the tree is called root node and there is no flow of information to the root node. The branches represent connection between the nodes. The other nodes, apart from the root node, represent locations in the tree and they can be answer nodes or decision nodes. An answer node may have flow of information to·and from the other nodes and are referred as child nodes. The decision node is referred as leaf node and represents all possible solutions that can be derived from the tree. Thus the decision node terminates the program with solutions.

Broadly classifying a system, the power quality problems are felt at the distribution system level or a customer level. Thus this can be taken as the root node. At the distribution level the problem may be with the equipment at the substation or with the equipment in the distribution lines. Similarly the problem at the customer level could be with an industrial customer, a commercial customer or a residential customer. Thus these can be referred to as the child nodes. The problems faced at each of these levels may be understood better with each successive answer node, and thus probable answers could be arrived at, at the decision nodes. This approach could be useful if any numeric or monitored data pertaining to the system is not available. Also a probable answer can be concluded, depending on the answers given by the user only by observable impacts on the equipment, say the equipment maloperating or equipment failing or fuse failing, motor getting overheated etc. The efficiency or the level of certainty of solutions given will depend on the information provided by the user regarding the problem.

When monitoring equipment are connected at various points at the customer facility, data pertaining to the various disturbances due to surges, impulses, interruptions, variations in voltage, current etc can be collected or stored. Many such monitors are available and used by the utilities. PQ node program of Electric Power Research Institute (EPRI) uses a number of monitors for collecting disturbance data. The output from these analyzers can be used by the expert system for diagnosis. This approach could be very effective as the user may not be able to provide enough information from his knowledge. This will increase the efficiency of the expert system, as the user may give an incorrect answer or may not be able to answer some questions. The data files can be accessed into the expert systems, which is CLIPS 6.0, in our study and the data can be internally manipulated to come to a certain decision. If necessary, further information can be elicited from the user before arriving at a final solution.

Standard reports of the outputs with graphs of disturbances, possible solutions etc can be generated by the program by opening text files within the program.

IMPLEMENTATION OF THE EXPERT SYSTEM

EPRI is sponsoring a research project for the development of software modules for addressing power quality problems in the utilities. The center for Electric Power of the Tennessee Technological University is co-sponsoring the project. The major objectives of the project are the following :

● Design and test a prototype expert system for power quality advising.
● Develop dedicated, interactive analysis and design software for power electronic systems.
● Develop a concept of neural network processor for the power system disturbance data.

For developing the expert system, CLIPS software designed at NASA/Johnson Space Center with the specific purposes of providing high portability, low cost and easy integration with other systems has been selected. The latest version CLIPS 6.0 for Windows provides greater flexibility and incorporates object-oriented techniques.

Figure 1 shows the configuration of the expert system blocks being analyzed for the power quality advisement. The rules are framed by the experts opinion and the number of rules can be increased and added to the program whenever possible. The monitored data from PQ nodes, user or both can supply the facts, which can be utilized to come to a probable solution. The inference engine and agenda fire the rules on the basis of priority. There is an explanation facility which gives reports and suggests the possible reasons for coming to a conclusion depending on the inputs given.

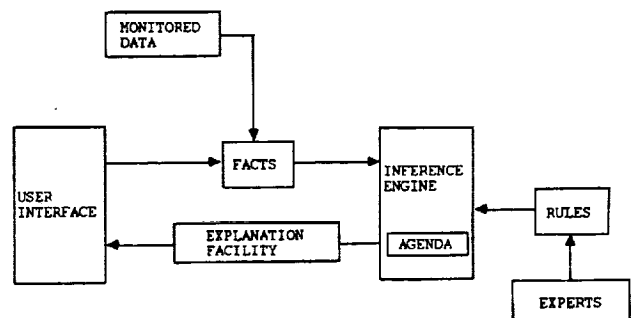FIG 1 : BLOCK DIAGRAM OF EXPERT SYSTEM

The following is the pattern in which the questions are asked by the Expert System for the responses of the user. Here a batch file is run and CLIPS 6.0. response is given below.

```
CLIPS> (open "s.dat" s "w")
TRUE


CLIPS> (open "r.dat" r "w")
TRUE


CLIPS> (load "sept1.clp")
!!***********************************************************
*********
TRUE
```

CLIPS > (reset)

CLIPS > (run)

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                           *
*        Expert System  For Power Quality Advisement        *
*                                                           *
*                      Developed By                         *
*                                                           *
*          Dr. A. Chandrasekaran  and   P.R.R. Sarma        *
*                                                           *
*               Center For Electric Power                   *
*                                                           *
*            Tennessee Technological University             *
*                                                           *
*                  Cookeville, Tennessee.                   *
*                                                           *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Where is the complaint from?

1. Distribution-system
2. Customer

1

Where is the problem occurring ?

1. Circuits
2. Sub-Station

2

What is the complaint ?

1. Service-Interruption
2. Device-Maloperation
3. Equipment-Failure

2

Which of these has the problem ?

1. Transformer
2. Circuit-Breaker
3. Control-Circuitry

1

Is the system voltage normal ?

1. Yes
2. No

1

Is the hum of the transformer excessive ?

1. Yes
2. No

1

Is the transformer getting overheated ?

1. Yes
2. No

1

Is the transformer getting overheated even
under normal load conditions ?

1. Yes
2. No

1

Is the transformer supplying power to
heavy lighting and power electronic loads ?

1. Yes
2. No

1

Are there capacitor banks in the substation ?

1. Yes
2. No

1

Is the substation provided with harmonic
filters to filter harmonics ?

1. Yes
2. No

2

Probable cause:

Place filters to prevent saturation
and overheating of the transformers
when it supplies power to power
electronic loads.

CLIPS > (exit)

The following is the symptoms file "s.dat", which was storing the symptoms pertaining to the problem is given below.

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                   *
*              THIS EXPERT SYSTEM IS BEING                          *
*                                                                   *
*                     DEVELOPED BY                                  *
*                                                                   *
*          Dr. A.CHANDRASEKARAN & P.R.R. SARMA                      *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SUMMARY OF SYMPTOMS OBSERVED:

** The complaint is from the distribution system.

** The trouble is in the substation.

** Complaint is device maloperation.

** The problem pertains to the transformer.

** The hum of the transformer is excessive.

** The transformer is getting overheated.

** The transformer is supplying power to lighting and
power electronic loads.

** The transformer is getting heated under normal load conditions.

The following is the possible reasons file "r.dat", which was storing the possible reasons pertaining to the problem is given below.

** The transformer hum could be more due to loose core bolts, presence of
harmonics etc.

** Transformer may get overheated due to overloading, saturation,
insignificant faults in winding etc.

** Transformer can get overheated under normal load conditions due to
harmonics, insignificant faults in transformer etc.

** Harmonics may be in the system when the power is being supplied to
lighting and power electronic loads.

** Harmonics may be present if harmonics are not filtered out.

The text files generated can be imported into Word perfect, Winword etc for making the final reports. At present, efforts are being made to integrate the data obtained from the PQ analyzer into the CLIPS program as a part of the EPRI project. The monitored data reports from the PQ analyzer can be used to arrive at conclusions about the power quality problems especially with regard to the origin of the disturbances from the users' queries. Also the reports could incorporate disturbance graphs obtained from the data specified in the input files of the monitored data.

The concepts of the theories of uncertainty and Fuzzy Logic can be utilized using FuzzyCLIPS in the development of the power quality expert system, especially in cases where the questions like " Is the hum of transformer excessive?" have to be answered. The possibilities for 'excessive' may be more than normal, high, very high etc. FuzzyCLIPS may be used for answers of this sort and the efficiency of the solutions thus can be increased.

CONCLUSION

The development of the power quality expert system shows that expert system usage is definitely a viable alternative. Analysis of monitored data can be used to identify the sources causing power quality deterioration. Suitable conclusions can be drawn to recommend mitigating the power quality problem sources to the customers on one hand and the equipment manufactures on the other. An expert system approach can also be useful to educate customers on actions that can be taken to correct or prevent power quality problems.

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