

A Rule-Based Approach to Voltage Collapse Estimation: A Case Study of the National Electric Power Authority (NEPA) PLC, Egbin Thermal Station

S.O. Ajose¹, Ph.D., I.I. Ezebuio¹, Ph.D., D.Sc., and A.S. Adegoke², M.Sc.

¹Department of Electronic and Computer Engineering, Lagos State University, Epe, Nigeria.

²Department of Electrical Engineering, Yaba College of Technology, Yaba, Lagos, Nigeria.

¹E-mail: ajose@hotmail.com

ABSTRACT

Electrical system collapse has been a problem all over the world, and Nigeria is no exception. In this paper, a rule-based approach for voltage collapse estimation is researched. Our paper describes the development, design, and implementation of a rule-based technique that can be used effectively to support managers and project engineers in performing electricity crisis analysis, and making immediate decisions or recommendations towards solving the problems.

The approach is described as rule-based because it uses a set of rules represented as symbolic expressions to determine the actions to be taken. The set of rules were constructed using a simple 'IF-THEN' structure in a natural language. The project was implemented using the C++ programming language.

The design of rules utilized in this study consisted of two major parts. The first module served as a knowledge base for the second module, which stood as an inference box. The rules were programmed to give a timely indication of probability of failures in a power supply situation.

Such indications were classified as critical, light, or severe and were to be communicated immediately to appropriate authorities for remedial action to avert any system collapse or total failure. The design was simulated and tested by a designed set of rules and the results obtained were found very satisfactory.

(Key words: electric grid, electricity crisis analysis, power supply failures).

INTRODUCTION

For the past twenty years, voltage collapse problems have become a major concern for many individuals, utilities, and manufacturing companies in Nigeria. The situation is due to improper planning, implementation, and a lack of maintenance culture in the natural power system. Moreover, the rising population of Nigeria and increasing demands for electricity supply is far in excess of what is available; therefore, a situation of heavy loading of the interconnected transmission systems, which in turn causes increased voltage drop, is threatening the reliability and efficiency of operations. Worst cases [1] of low voltage and inadequate controls which incidentally lead to blackout have been reported.

One of the methods for solving the problem of voltage collapse is the rule-based technique. This technique proposes certain rules to adopt for the detection and prevention of total power failure. In other words, the approach identifies voltage collapse knee points [2] while manually adjusting available controls such as reactive power, transformer taps, and other system parameters as detected by the rule-base.

OVERVIEW OF RULE-BASED SYSTEM

A rule is simply a conditional test action pair that must be followed. Rule-based Programming began with artificial intelligence rule-based systems in the 1970s [3]. This paradigm is inherent in prolog and has been used in many program-manipulation systems.

Using a set of assertions, which collectively form the working memory, and a set of rules that specify how to act to assertion set, a rule-based system can be created.

Rule-based systems are fairly simple, consisting of a little more than a set of "if-then" statements, but provide the basis for the so-called "expert systems" which are widely used in many fields [4]. The concept of an expert system is this: the knowledge of an expert is encoded into a set of rules. When exposed to the same data, the expert system Artificial Intelligence will perform in a similar manner to the expert.

To create a rule-based system for a given problem, one must have (or create) the following:

1. A set of facts to represent the initial working memory. This should be anything relevant to a particular state of the system.
2. A set of rules. This should encompass any and all actions that should be taken within the scope of a problem. Irrelevant actions are avoided since a number of rules in the system can affect its performance.

So, instead of representing knowledge in a relatively declarative, static way (for example, a series of statements that are true), a rule-based system represents knowledge in terms of a collection of rules that tells one what to do or what to conclude in different situations. A rule-based system consists of a series of "IF-THEN" statements, a base of facts, and an interpreter controlling the application of the rules, given said facts.

There are two broad kinds of rule systems; namely, the forward chaining system, and the backward chaining system [5]. In a forward chaining system, one starts with the initial facts and keeps using the rules to draw new conclusions (or take certain actions) given those facts.

In a backward chaining system one starts with some hypothesis (or goals) one is trying to prove, and keeps looking for rules that would allow one to conclude that hypothesis, perhaps setting new sub goals to prove as one goes. Forward chaining systems are primarily data-driven, while backward chaining systems are goal-driven.

LITERATURE REVIEW

Early researchers into electricity supply crises have demonstrated the possibility of simulating how experts such as electrical engineers solve problems when they occur. Most of the approaches employed are neural networks and artificial intelligence (A.I) techniques such as the knowledge-based systems.

E.F Tsang [6] and E.W.T Ngai [7] came up with an expert system named 'EXSGACM' (Expert system for Gas Crisis Management) in 1996. According to their work, the approach they adopted was an artificial intelligence technique. The system used a knowledge-base and inference engine.

Also, K.A. Oladipupo [8] developed a system name "EXSESMA" (Expert System for Electricity Supply Crisis Management). It was a case study of the Egbin Thermal station. The system used knowledge based acquisition skills and inference engine to solve electricity supply crisis.

METHODOLOGY

The method adopted in this research work is a rule-based technique. This technique uses a set of rules represented as a symbolic expression to determine what actions are to be taken if a given event occurs.

The event occurrence will be programmed using a simple "IF-THEN" structure (i.e. a conditional test action pair: if condition is true, then certain things could be inferred).

One basic advantage of the rule-based technique is that the rules can be easily understood because the control structure is relatively simple as an "IF-THEN" format. Also the rules can be encapsulated as an important part of the knowledge base, in that they can be modeled or tailored to solve complex problems.

A detailed theory of rule-based techniques and their design has been discussed above. Implementation was achieved using the C++ programming language. The results, analysis, and discussions of the results are presented in subsequent sections.

DESIGN VARIABLES OF THE RULE-BASED SYSTEM

The following parameters were used in the design of our rule-based system.

Outage Duration: This is the period for which either plant or transformer is out of operation for the purpose of major repairs or overhauling.

Survival Time: This is a predicted period that elapses between electricity supply interruption and resumption.

Supply Loss: This is percentage of electrical energy loss as a consequence of plant or transformer breakdown.

Plant Affected: This is the plant which breaks down and consequently could not render the needed service to the grid.

Problem Type: This is simply the cause of the electricity supply crisis. It may be transformer or plant-related.

Advise Crisis: This variable indicates the severity of the crisis. It indicates the criticality of the crisis taking into proper consideration some other variables.

Advise Hope: This variable indicates the expectation in view of the present situation (e.g. the expectation may be optimistic or pessimistic depending on whether the duty manpower is high or low).

Duty Manpower: This is the percentage of the manpower expected to be on duty at a particular time to handle the plant repairs, transformer repairs, maintenance, and installation.

Decision Status: This is a variable, which shows the effect of the crisis. (e.g. voltage collapse).

Advice Action: This variable indicates the action to be taken in view of the conditional circumstances.

Set Rule Comments: This is remark or comment on the decisions taken, particularly it reveals why certain actions were taken.

DECISION TABLES

Decision tables are used in defining the sequence of events of a process in a logical manner. They are always used as tools to test for data. In some cases, they could be made more elaborate by implementation with decision trees.

Tables 1 and 2 are constructed for power supply loss severity and survival time.

Table 1: Decision table for survival time.

Survival Time Rule		
Rule Name	Average Time	Survival Time
Survival Time 1	Greater than or equal to 6 hours	Long
Survival Time 2	Between 3 and 6 hours	Medium
Survival Time 3	Less than 3 hours	Short

Table 2: Decision table for determining the severity of power supply losses.

Rule Name	Production Loss	Power Supply Loss
Power Supply Loss 1	Less than 30%	Mild
Power Supply Loss 2	Between 30% and 50%	Moderate
Power Supply Loss 3	Greater than 50%	Serious

SIMULATION AND TESTING

Figure 1 shows a flow chart for simulating and testing the designed set of rules. The research work was simulated and tested on a computer system with C++ version 5.0 compiler. The operation was simple and the design was quite interactive. The rules were tested thoroughly with recommendations and inference checked against the decision table. It was found to perform satisfactory with striking results shown in subsequent sections.

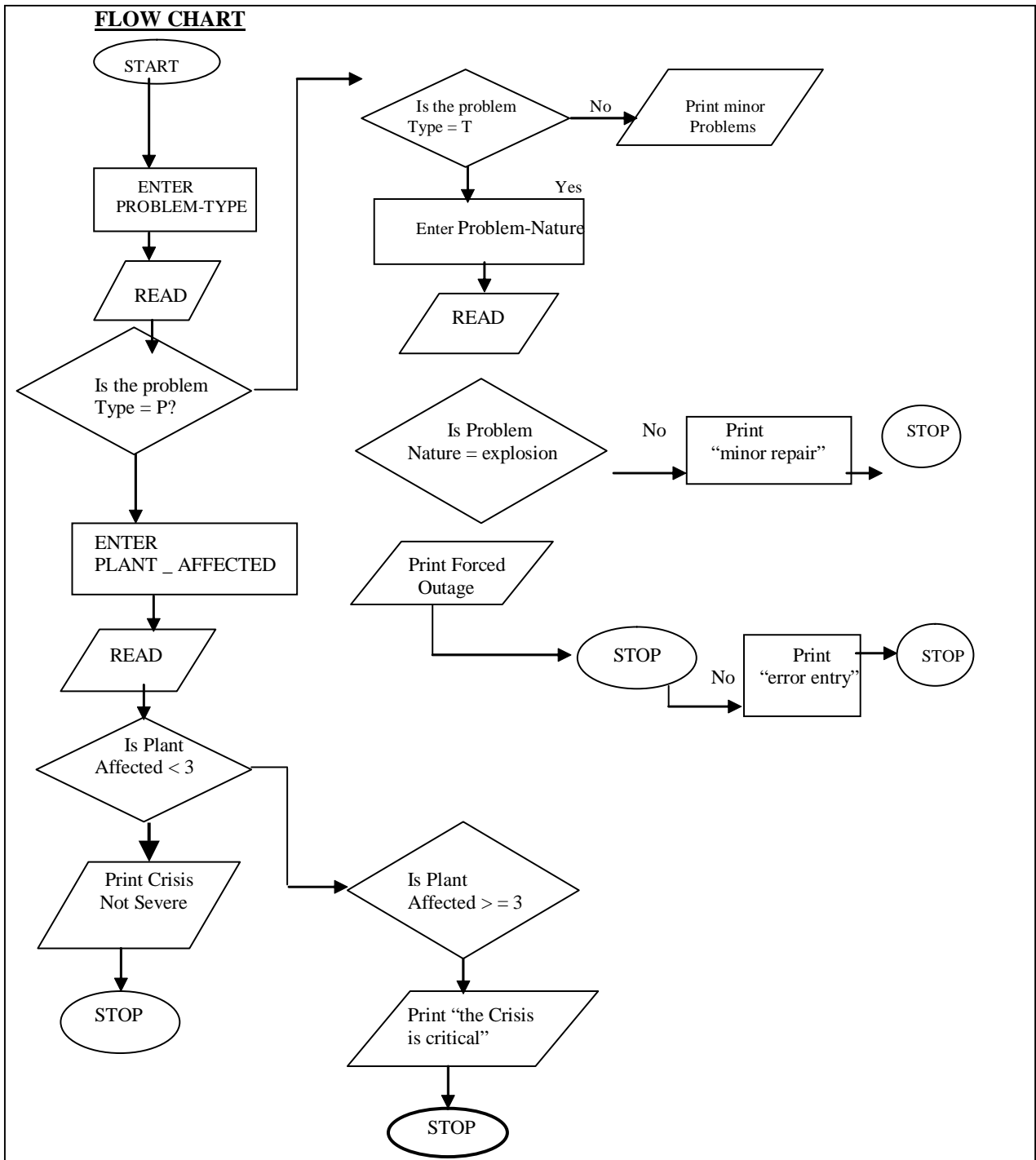


Figure 1: Flowchart for simulating and testing design of the set rules.

RESULTS

Break;
Default;// end of outermost switch statement.
Comparing each of the unit plants one by one
Y(es) or N(o)?
(P = Plants, T = Transformer, A = Explosion, B = failure)

..... New Run
Problem type → P.

..... USER INPUTS
Plant affected is Plant 1
Outage duration in hours is 7.20
Duty manpower in percent is 50.00

..... INFERENCE
Advise Crisis: = critical
Survival time: = long
Advise Hope: = pessimistic

..... COMMENT
The seriousness of the crisis
Is critical and urgent repair to be carried out?

..... DECISION - ADVISOR
Status: partial Interruption
Advise Action: urgent repair of plant 1.

..... New Run
Problem type → T.

.....USER INPUTS
Problem nature is A
Outage duration in hours is 28
Reliability value is 0.45

Advise Action: carry out replacement
Crisis resolution: send signals to
Network Controlling Center (N.C.C)
Oshogbo for augmentation

Set rule comment: The main reason is that since
the transformer is on forced outage; it is more
reliable to carry out full replacement.

..... New Run
Problem type → T.

..... USER INPUTS
Problem nature is B
Outage duration in hours is 17
reliability value is 0.60.

Advise Action: carry out repair

Set-rule comment: Since the fault is just a failure, repair is recommended. But for better reliability, a full replacement could be undertaken.

The above results are analyzed and discussed below.

ANALYSIS AND DISCUSSION

The result obtained from the implementation is in the form of comprehensive preventive measure guidelines that detect problems and provide protection measures to adopt to solve voltage collapse. It also helps to make timely and better decisions of how to avert electricity crisis. These serve as tools for inexperienced operators or staff to deal effectively with electricity crisis problems as and when they occur.

Comparing these results with those of existing methods used in performing electricity crisis resolution, the rule-based method has shown some improvement. For instance, using a mathematical modeling method as performed by James Mommoh [9], his method could only bring about stability in the system. It does not proffer solutions to crisis situations when they occur.

Moreover, no amount of stability measures can prevent plants from breaking down. His method could only reduce the frequency of break downs. So, when there is a break down, what is the next thing to do? This is where the importance and implication of this research gains prominence.

CONCLUSION

As we have seen in this research, the use of rule-based techniques has demonstrated a flexible approach in the solution of crisis management problems. This also provides the knowledge needed as a pre-requisite to the solution of crises.

Just as in an expert system, knowledge can be more easily implemented in a rule-based system and can be constructed with the application of a simple reasoning structure incorporating natural language. Because of its flexibility, this designed work could be employed in any other related system with little modifications to the existing rules.

The design of the rules consisted of two main parts. The first module served as a knowledge base for the second module, which stands as an inference box. The rules were programmed using a simple "IF-THEN" structure.

The implication of these findings are as follows: First, the rules can be easily understood by programmers or experts because the control structure is relatively simple and understood as "IF-THEN" format. Secondly, the rules can be encapsulated in an important part of knowledge-base to model a complex problem. Also, knowledge can be captured through application of the rules. Moreover, the control structure of a rule system seems to mimic some problem-solving strategies and hence can be used by human beings for solving problems. Most importantly, natural languages are used to formulate the rules and hence it will be more convenient for non-experts to use the rule-based techniques for solving problems in expert systems, especially as it relates to a power system collapse. Finally, the rule-based techniques can be applied in artificial intelligence systems.

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ABOUT THE AUTHORS

S. O. Ajose, Ph.D., FNSE serves as Professor and Dean of Engineering at Lagos State University. He earned his Ph.D. and M.Sc. from the University of London, King's College in 1976 and 1974, respectively. Professor Ajose also holds a B.Sc. in Electrical Engineering (Hons.) from the University of Lagos (1971). He was nominated as a Fellow of the Nigerian Society of Engineers and was featured in the first issue of International Who's Who in Engineering. His research interests are in the areas of electrical engineering, electronics, and communications technology.

I.I. Ezebuio, Ph.D. (Eng), D.Sc. (Eng), FNSE., is a scholar in the field of telecommunications, electronics, computer engineering, and information technology. He holds degrees from the University of Technology Giessen-Fredberg, Germany; Aston University, UK; the Union Institute and University, US; and Greenwich University, Australia. His Bachelors degree and Masters degrees are in Telecommunications/Electronics and Electronic Physics; his Ph.D. is in Electronics and Computer Engineering, and his Doctor of Science degree is in Engineering Science and Information Technology. Professor Ezebuio has taught telecommunications, electronics, and computer engineering at several overseas universities before returning to teach in Nigeria in 2000.

A.S. Adegoke, M.Sc. is a post-graduate researcher in the Department of Electrical Engineering, Yaba College of Technology, Yaba, Lagos, Nigeria.

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