Intelligent System for Voltage Abnormal Condition Detection

C. R. Cavati and E. P. Pereira

***Abstract*-- The main goal of this work is to present a computational solution, namely ISVAC – Intelligent System for Voltage Abnormal Condition, for under and over voltages protection relay based on fuzzy logic in order to be applied in various parts of the electrical system. The ISVAC was developed by using Delphi programming tool. In order to analyses and assessment this algorithm, it was developed a Graph User Interface with support voltage, temperature, and time variations as well as display the algorithm performance. This kind of protection function of under and over voltages, when used in a microprocessor, becomes an attractive and innovation alternative. The results also highlight the use of fuzzy logic in performance of relay protection functions on microcontrollers.**

***Index Terms*--Voltage, Protection, Fuzzy Logic**

I. Introduction

For the current society the Energy Electrical Systems (EES) are not only necessary, but essential for the maintenance of the standards life quality, by guaranteeing a series of benefits and easiness to these users. These benefits are guaranteed by the reliability of the EES, which mainly depend on the economic factors and quality in the power supply and for the guarantee of the security of the equipment that will be used by consumers [4].

The use of protection equipment on EES mainly aims at the security of the equipment and its users. The security is guaranteed not only with the use of adjusted protection equipment, as well as by the correct procedures adopted in its maintenance and use. The protection devices act in diverse levels inside of an EES, guaranteeing the security, selectivity and coordination of the EES. Amongst the protection devices the relay function will be detached, that is the main object of study of this work.

The micro processed protection relays, due to its great capacity to accumulate functions, have two important characteristics such as flexibility and precision [6]. However, its functions' accumulation can provoke an increase in the time to process all data and information. Hence, this can cause an increase in the reply time and a fall in the trustworthiness of the relay function. Then, in order to get a relay with several functions, it is necessary to carry through the processing with high speed. In such a way, two different solutions may be implemented in order to increase the capacity of its reply time. In principle, it could be to use faster microprocessors, but it would imply in higher costs with research. It also would very expensive because of the use of to many components. As a second alternative, a simplified emulate system logic implementation namely ISVAC – Intelligent System for Abnormal Voltage condition, would require in a lower number of cycles of processor machine for its processing. Despite of it, its trustworthiness is not lost.

Inside this context, this work proposes an algorithm based on an Intelligent Logic supported on Fuzzy Sets. The purpose is to become it less complex, that other conventional solutions, in the attempt to minimize the necessary time for its execution. In this way, the proposed algorithm would be implemented and could be constructed for practical ends.

This work shows applications of the ISVAC and demonstration of the use of the relay protection function of voltage abnormal condition such as sub or over voltages is made for induction engines. The implemented modeling fuzzy allows to adapt the diverse voltage and insulation classes, and, therefore, it is flexible to the dynamic behavior of the load..

II. Variations of the Voltage

The IEEE 1159 standard defines the several phenomena that occur in the voltage of an EES [5]: transient (that they can be: oscillatory or impulses); variations of short duration (of the swell type or the sag type); variations of long duration (over voltage or sub voltage) and severe Interruption.

The Brazilian regulation agency ANEEL resolution 505 (November 26, 2001), establishes, brought up to date and consolidated form, the relative disposals to the conformity of the voltage levels of electric energy in steady state [1]. The 4º and 5º Article of this norm, states that the attendance voltage must be classified in accordance with the measured voltage bands of variation. Some main definitions for operational voltages are:

- ✓ Nominal Voltage (NV): voltage value by which the system is assigned;
- ✓ Adequate Voltage (AV): rms voltage value that is close to the nominal voltage value, inside of the specified limits, and that does not affect the electrical system;
- ✓ Precarious Voltage (PV): rms value of voltage that is below (sub voltage) or above (over voltage) the adequate voltage values, but not in the critical region,

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and that they already start to provoke damages in some electrical systems;

- ✓ Critical Voltage (CV): rms voltage value that is below (sub voltage) or above (over voltage) PV values.

The energy quality is direct related to the variations of the voltage and its corresponding values of sub or over voltages affect suppliers and mainly the consumers of EES. This quality is guaranteed through the monitoring of some pointers and here will be detached the ones that have direct relation with the voltage variations.
One of the most important aspects in the evaluation of the quality of power supply to the units' consumers is this power supply continuity. A trustworthy service is one that is always available. One of the indices that allow evaluating the quality of the power electric energy supply is the amount of interruptions that one consumer or set of consumers is submitted.
The relative disposals to the continuity of the power distribution system, in its aspects of time duration and frequency, to be observed for the utility energy company of the electric energy public service to the units consumers, are established from 24/2000 ANEEL resolution of 27/01/2000, with the alterations foreseen on resolution 075/2003, of 13/02/2003 [2].

III. FUZZY MODELING

The function relay of voltage abnormal condition such as sub or over voltages, as described previously, will use the fuzzy logic as intelligent logical for decision making.
The resolution of problems by using fuzzy logic obeys a sequence of steps that must be followed so that it gets satisfactory resulted. The main steps consist of:

1. Description of the Knowledge and Data;
2. Defining of Border Regions;
3. Modeling of the Parameters;
4. Fuzzyfication Process;
5. Inference System Machine;
6. Defuzzyfication Process.

The advantages of fuzzy logic are:

· Conceptually easy to understand;
· Flexible;
· Tolerant of imprecise data;
· Can model nonlinear functions of arbitrary complexity;
· Can be built on top of the experience of experts;
· Can be blended with conventional control techniques;
· Based on natural language.

The structure of the FIS - Fuzzy Inference System is formed by four main modules: Facts Base, Knowledge Base, Inference Machine and New Knowledge. In the FIS it has three types of entrance, namely: the variable that they need to be analyzed (quantified or qualified) to generate the result; the relative data or information to these variables that go to quantify them or to characterize them, and finally the rules that will relate the data and the variable with the desired output. Fig. 1 shows the types of entrances as well as the main modules of the FIS.

The quality of fuzzy approximation depends on the quality of the rules. The result always approximates some unknown non linear function that can change in time. Fuzzy systems theory or "fuzzy logic" is a linguistic theory that models how we reason with vague rules of thumb and commonsense.

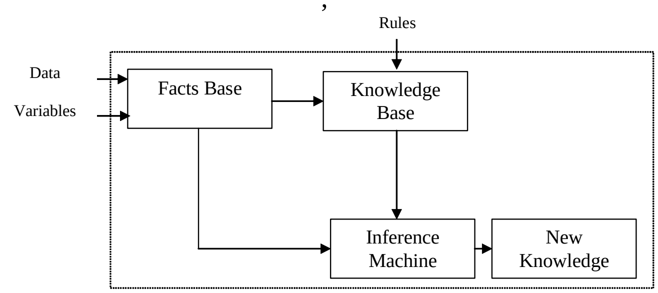

Fig. 1 FIS Structure

Many fuzzy modeling methods have been proposed in the literature [7]. Most are based on collections of fuzzy IF-THEN rules of the following form:

$$\text{IF } x_1 \text{ is } B^1 \text{ AND } x_n \text{ is } B^n \text{ THEN } y \text{ is } C \qquad (1)$$

Where x = $[x_1,\ldots,x_n]$ = and y are the input and output linguistic variables respectively, and B^1 and C are the linguistic values characterizing the membership functions. It is considered that this fuzzy rule representation provides a convenient framework to incorporate human expert's knowledge.
With all parameters and variable described in the previous section and also duly adjusted by themselves for reality of the load, the emulate system ISVAC initiates its main calculations routine and the FIS will have as output the equipment state which will determine the actuator status, that will keep on or disconnect the equipment that is being monitored. The Fig.2 brings the flowchart of this algorithm.

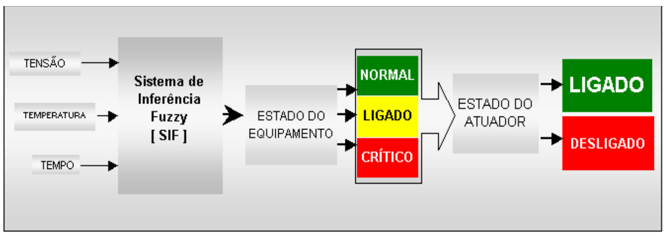

Fig. 2. Logical flowchart

The input parameters are the voltage limits, time and temperature limits. These are defined in agreement as it follows:

- NV = Nominal Voltage;
- PSubVmin = Minimum Precarious Sub Voltage;
- AVmax = Maximum Adequate Voltage;
- AVmin = Minimum Adequate Voltage;
- POverVmax = Maximum Precarious Over Voltage;
- HTp = High Temperature;
- ETp = Environment Temperature;
- WTp = Work Temperature;
- ETpM = Edge of Rise of the Temperature;
- T = Time Limit;

The parameters are adjusted automatically in the following way:

- Voltage - As ANEEL Resolution 505 [1];
- Temperature - As NBR 7094 [3];
- Time - As IEEE 1159. The limit of adopted time will determine the short duration and the long duration Variations[5];

A. Membership Functions

The ISVAC has three membership functions for input parameters data and two membership functions for output parameters data. The membership's functions of inputs are defined as follows:

a) Voltage membership function: it possesses five partitions, as follows:

- SubC - Region where the voltage is classified as Critical
- SubP - Region where the voltage is classified as Precarious
- Adequate - Region where the voltage is classified as Adequate
- OverP - Region where the voltage is classified with Precarious
- OverC - Region where the voltage is classified with critical

b) Temperature membership function: it has two partitions, as follows:

- Work - Region where the temperature is inside of the tolerable limits for the equipment
- Raised - Region where the temperature is above of the tolerable limits for the equipment

c) Time membership function: it has two partitions, as follows:

- Short Time - Region where the variations of short duration occur
- Long Time - Region where the variations of long duration occur

The output membership functions are defined in the following way:

a) Equipment state membership function: it possesses three partitions, namely:

- Normal: Region where the equipment is in normal operation
- Warning: Region where the equipment is out of the normal operation, but before the critical operation
- Critical: Region where the equipment is in critical operation

b) Actuator status membership function: it has two partitions:

- On: it is remained feeding voltage
- Off: feeding of voltage is cut off

B. The ISVAC' Behaviors

The input-output knowledge matrix used by ISVAC defines its behavior described by the set of production rules. Each production rule is represented by a sentence such as: {IF … THEN …}. On the short way, this rule is expressed with the general structure of the following way:

{IF
Voltage is (SubC, SubP, OverC, OverP, Adequate)
AND
Time is (VarShort, VarLong)
AND
Temperature is (Work, Raised)
THEN
Equipment State is (Normal, Warning, Critical)
AND
Actuator Status is (On, Off)}.

Initially the input parameters must be introduced or be chosen in the emulate system ISVAC menu.
As standard, the emulate system ISVAC relay defines the level for voltage greater than 230 KV, isolation class B, 1 sec. time limit and 0.1 sec. precision, as shown in the Fig. 3. The user can choose any one of these parameters. After that, the emulate system ISVAC can be initiated and will be presented two graphs: one of Temperature x Time and another one of Voltage x Time, as seen also in the Fig. 3.
Immediately after to its execution, at each cycle the emulate system ISVAC executes the inference routine and presents the result through the output data that means the equipment state and actuator status. Beyond that, it also fills the time and frequency tables with the amount of occurrences in each voltage level.

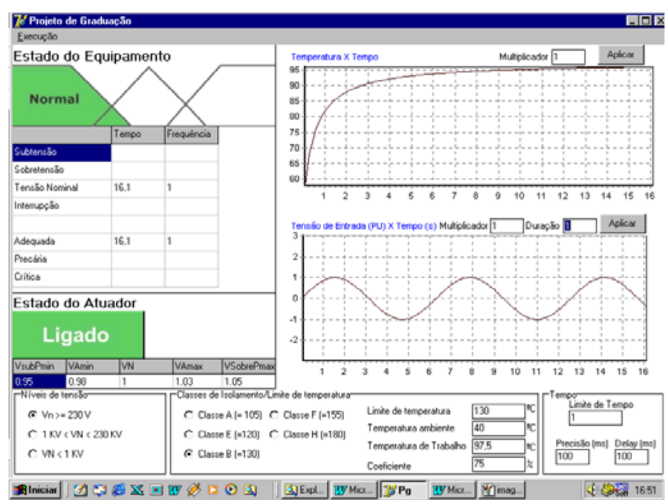

Fig. 3. Relay in Supervisory Simulation

When voltage or temperature variations occurs, that is, when the multipliers for the simulation is applied, the emulate system ISVAC through its monitoring system updates these

values and shows the results by updating the voltage and temperature graphs as well as, through its supervisory system, by filling the time and frequency tables.
The entire calculation routine follows the blocks diagram of Fig. 4.

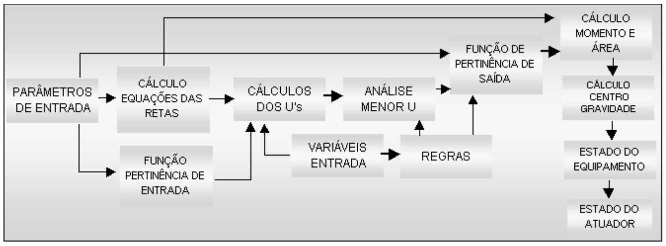

Fig. 4. Blocks Diagram of Calculation Routine

The input parameters give origin to the input membership functions, to the equations of the input-output knowledge matrix and the output membership functions.
By applying the input parameters data to its corresponding input membership functions variable and using its membership function equations, it is possible to get its membership degrees, which mean the satisfaction indices of each one of the membership's functions. It is get all degrees of input membership function variable, in which when the active rules from knowledge matrix is applied. Then, it is possible to infer the desired outputs parameters data.
An appropriate membership degree set, by applying AND and Or fuzzy logic operators, is selected from satisfaction indices found from all input membership functions. With the application of this satisfaction indices on the output membership functions and with the use of its corresponding membership function equations, it is possible to calculate the respective entire areas and also the corresponding moment component to each active rule and finally to determine the center of gravity of the composition of these areas, that will go to indicate, after defuzzyfication process, the equipment state and the actuator status.

IV. TESTS AND RESULTS

Several simulations had been carried out to guarantee the effectiveness of the system ISVAC that emulate the function of protection relay and consequently to allow its evaluation and analysis. Some of these simulations will be presented in the following topics for better comprehension of its behavior.

A. Normal Temperature and Voltage Variations

When a variation of the voltage is applied, with lesser time that the permissible time limit, as correlation of the operation rules from knowledge matrix, the emulate system ISVAC starts to count this variation of the voltage. It will not immediately act changing the equipment state and hence actuator status from On to Off, because it considers this a variation of short duration, then not having harmful effect on the equipment. This situation can be observed in the Fig.5.

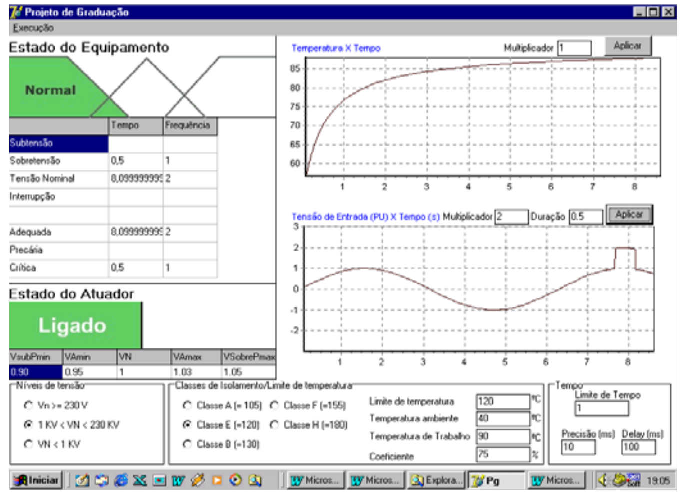

Fig. 5. Over voltage: short variation

The actuator status will change from On to Off only if the duration period of time is longer for this operation situation.

B. Nominal Voltage and Variations of the Temperature

In the Fig. 6, it can be observed that an increase of 20% (twenty percent) in the temperature does not exceed the boundary-value of the isolate class, but in this case the equipment enters in a warning state. It can bee explained because if the temperature continues going up, the limit of the isolation class can exceed and the equipment can be changed to the critical state.

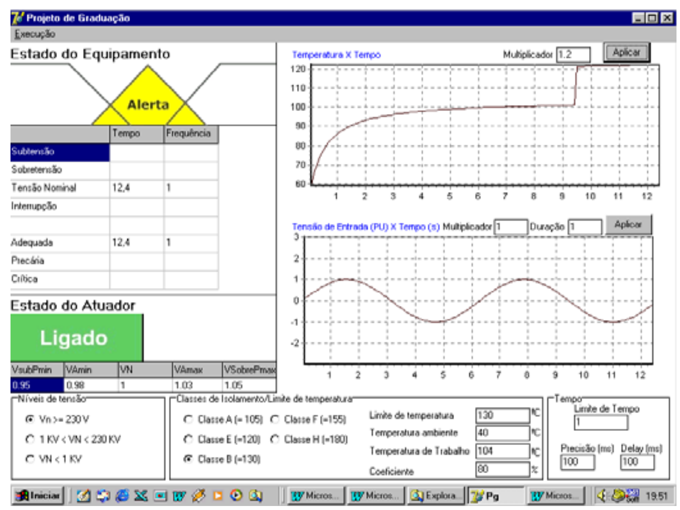

Fig. 6. Temperature with 20% increase

For a bigger increase of temperature, the equipment state becomes critical and the actuator assumes status Off, as shown in Fig. 7.

As we can see, this work presents an interesting application of logic fuzzy for performance of protection relays for voltage and temperature conditions. In future works, the authors intend to continue by dealing with this ISVAC monitoring system of abnormal voltage conditions in order to stand out all phase of this audacious project. As other interesting way, the authors also intend to insert some economic evaluation of the implantation of this ISVAC system in a company.

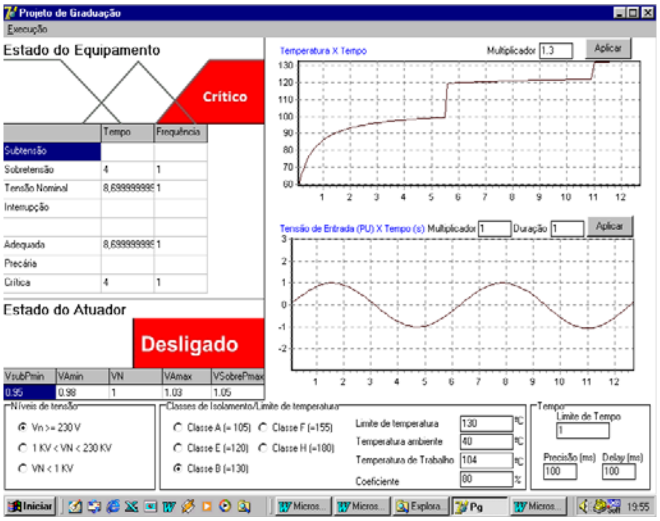

Fig. 7. Temperature with 30% increase

It is possible to notice at the ISVAC main interface, on its left side shown on Figs. 3, 4, 5 and 7, that this system makes and stores statisticians of all events. Moreover, on its below side of these same Figures, it can be established conditions limits to prevent or to minimize occurrences as well as this system has the possibility to establish standards of sub and over voltages for each type of isolating class of electric engines.

V. CONCLUSIONS

It is important to stand out that nowadays real innumerable solutions for protection against voltage abnormal conditions such as sub and over voltages exist, however the algorithm presented in this work aims at to be a protection tool, with the differential of being based on an intelligent logic and also to be a low cost one.

The development and implementation of this project contributes for the building more modern protection equipment and for the beginning of the study of new alternatives for electrical power systems protection against condition of sub and over voltages.

The results show that this intelligent logic in a real protection situation on power distribution system can be implemented and also adapted for other functions beyond the implemented ones in this paper.

Finally, the emulate system ISVAC can be considered as a auxiliary tool in order to simulate and analysis voltage abnormal conditions in any part of electrical system and it acts as a modern monitoring, supervisory and protection analysis decision support tool.

VI. REFERENCES

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VII. BIOGRAPHIES

Cicero R. Cavati (M'1979) was born in Victoria, Brazil, on January 27, 1955. He graduated in Electrical Engineering at the Federal University of Espirito Santo (UFES). His special fields of interest included automation.

He is specialist in Power Distribution from EPUSP on 1982. He got the Master degree on Electric Engineering from São Paulo University on 1984, and the Dr on Electric Engineering - Automation from the UFES on 2004. He is a professor from Electrical Engineering Department of the UFES since 1979. The recent works are concentrated in control of industrial processes. However, the majority of his work concentrates in the areas of planning, operation and automation of power distribution configuration, having been developed some micro processed software and hardware, mainly for ends of voltage regulation and protection equipments. His interests in these areas are related to the applications of computational intelligence with multiples goal and uncertainties. More recently he comes carrying through inquiries in the Environment area directed to the maintenance function.