Development of an intelligent system for power adaptive protection

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Abstract

This paper presents the developments made in the Technologic Development and Research Program from AES-Eletropaulo. This project has set up a methodology and developed a computer package for an Intelligent Adjust System of Protection. This methodology took in consideration the global system state, the load level as used by system, besides other outside factors related to protection systems. For that purpose were developed mathematical routines adequate to protection studies, and summed up the area engineers' knowledge as Intelligent Systems. This system for decision support was introduced using the intelligent multi-agents systems concept, by the use of many advanced techniques of Artificial Intelligence interacting with a master agent, and cooperating between themselves for the solution of problem for protection system adjustment. The objective was to sum up the implementation advantages from each artificial intelligence technique used in the classic problems of electrical systems, and suppressing their disadvantages.

Key-words

Intelligent systems 1, Intelligent agents 2, Digital protection 3, and Multi-agents systems 4.

Introduction

The steady load expansion throughout the distribution network and the strengthening of load feeding regulations, enforcing more rigid penalties for breakdowns in supplying electric power, have increased the improvement of power distribution systems protection.

A new trend of studies for the improvement of equipments and methods used in distribution systems, aiming more selective protection, have generated a new concept of protection systems that be adaptive to the system they are connected to, looking for better dependability and adaptation to the continuous increase of new consumers, giving birth to the system known as adaptive protection.

In developing this system it was realized that to manage this adaptation using intelligent specialist systems, would make it easier the introduction of more strong functions, allowing the integration widening of systems and the adjust versatility for the protected circuit branch (TORRES et al, 1997).

The objective of this project was the development of a new protection structure for the AES-Eletropaulo' substations and particularly for the DTS-Limão. Thus it was bought from ABB the protection relays REX 521-H05 and the supervision system MicroScada, which will operate together with the program that was made with this project.

The structure made is flexible allowing the protection system layout expansion and the inclusion of new type of relays and functions. Both systems MicroScada and SIP (System for Intelligent Parameterization - name of program developed in this work) operate on-line, in accordance with the web topology configuration and the main system changes.

It is possible to say that the objective of this project was duly made. All the items included in the item "Project Objective" were achieved, making possible for Program SIP to work in different operation modes: automatic, by hand and off-line. In the first one, always an important change happen in the system the SPI calculates the new parameter and forwards it for the relay through the MicroScada program. In the second, the SPI program receives the changes, calculate again the parameter and, in accordance with the pre-adjusted alarm rules set up by the user, issue a message. In this type of operation, that will be the most frequent, the user should give an order to the program to forward the new set of adjustments for the relay. In the operation mode off-line the user gives the entries.

The computer package used several languages during its development: Pascal, Turbo-Prolog and Visual-Basic, according the development requirements. In the last version all the routines were written in VISUAL BASIC 6.0® integrating the many tools and computer routines for the protection adjustment.

FUNDAMENTAL CONCEPTS OF INTELLIGENT AGENTS

The concept of Intelligent Agent (IA) happened inside the category of systems that act rationally, being the agent an autonomous software entity in position to feel its environment through sensors, and act inside this environment owing to actuators, for witch it is necessary to make correct inferences and be able to represent knowledge, to express results in natural language, learn and feel the world, etc. (RUSSELL; NORVIG, 1995).

What is rational in a given moment depends on four factors:

The performance evaluation that defines the success degree;

The whole previous agent's perception, named perceptions sequence;

What the agent knows regarding the environment;

The actions the agent may develop.

There is not a definitive and generally accepted concept by the whole scientific community for intelligent agents (IA's), but the above mentioned idea translates the used conception into implementation of all the agents introduced into this work, as shown in Figure 1.

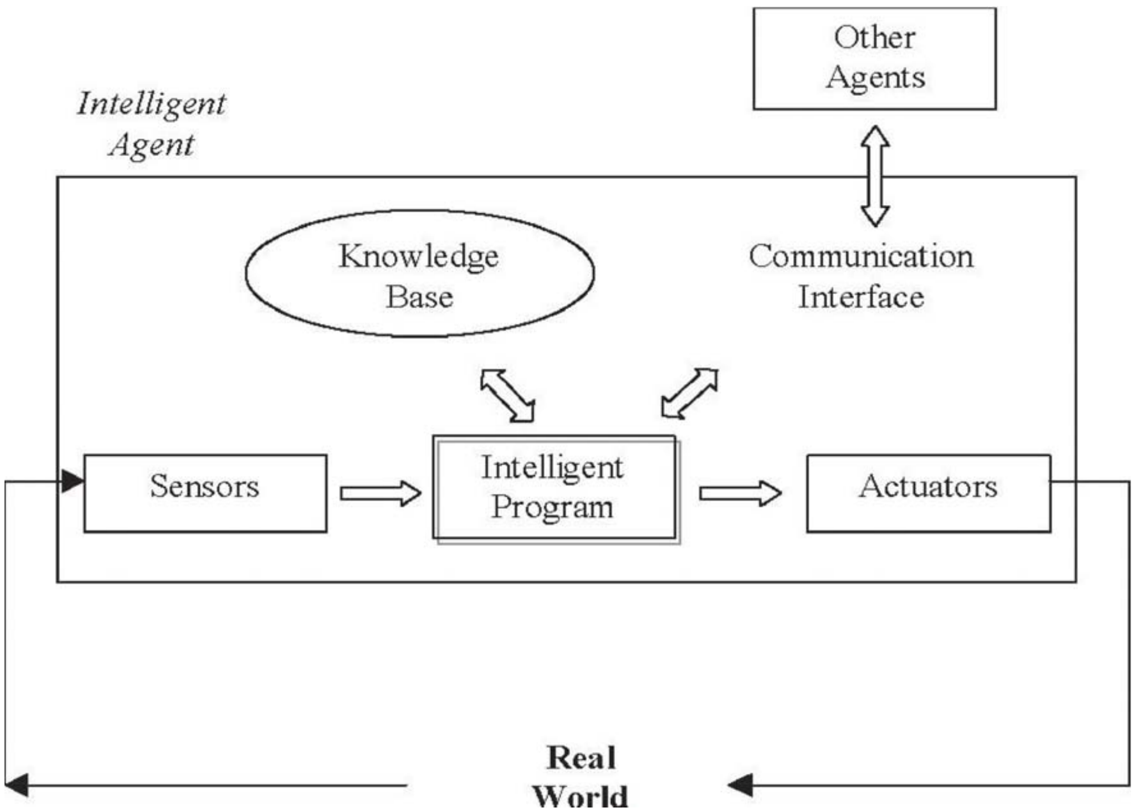


Figure 1 - Used architecture from an IA.

Sensors

Sensors are responsible for entry (acquisition) of environment data for IA. No system reacts with its environment unless there is a way to know what is going on in the environment, so the need for IA to receive information regarding the environment is supported by this modulus, which contains the controlling services of Hardware sensors (data acquisition plates) and Software (database).

Actuators

Actuators are the necessary means for IA may interact with environment after receiving and processing the environment information. The IA may answer to the environment including changing it through its actuators (in/out plates).

Intelligent Program

An IA should know its world and reasoning about the possible action alternatives. In addition may accept new tasks and goals, acquire and up-to-date knowledge based in environment changes and adapt itself to such changes. This agent has to have notion regarding the actual world state, to know how to infer information not visible to its perception of the world, to understand how the world changes as the time goes by, what developments it is going after, and what actions should be taken as conditions changes.

To attend to above requirements the intelligent program has the production rules, is that to say, the method responsible for the storage of an IA knowledge. Any technique from AI for supplying some intelligence to the agent may be used, depending of the application and the autonomy degree given to the agent.

Knowledge Basis

The IA has a core that is the Knowledge Basis (KB), a set of facts representations about the world, where each representation is called a clause. The clauses are expressed in the so-called knowledge representation language and the learning is made in the process of KB up dating.

The KB also has rules for analysis of data that comes from the environment, the objectives that the agent should reach and the agents' community knowledge from the community the agent belongs to.

Communication Interface

Many researches aim the communication between agents and the common languages do not present specific characteristics for this purpose, making difficult the development process for Multi-Agent Systems (MAS). Generally speaking, it is possible to state that two agents may communicate between themselves whenever they own a common language or by the use of languages that may be translated between them.

The communication process is based in protocols that are a set of rules governing the transmission of messages between the units. To interact with a society the IA must know the protocol in use by it.

The communication interface is responsible for providing the means for the IA to communicate with other agents. This mode may be either inherent in the language used for development of the IA or it may be used other standards like Knowledge Query and Manipulation Language – KQML (FIPA, 2001a).

Intelligent Multi-Agent Systems

A MAS has the basic premise of providing mechanisms for generating intelligent systems starting from software autonomous entities, called agents. These agents interact through a common environment used by all the MAS members, acting and changing its state.

Once each agent has a skill and private goals the MAS has to be able in providing mechanisms for interaction and coordination of these entities. This way the MAS is able to solve problems bigger than the knowledge domains of its members (FIPA, 2001c).

The MAS may be classified as reactive and cognitive. The reactive systems are compounded by a great number of very simple agents interacting between them and having no explicit representation of environment state and of other agents, nor of their past actions. The main influence of this MAS type comes from entomology, the science that focuses on insect's behavior. Yet the cognitive systems in general have little agents, once each agent has a rational behavior, and have a symbolic logic conception of the world, planning its action strategy according a strong mechanism of logic inference. This type of agent besides using techniques of deduction and learning, consider also characteristics aspects of human will, like believe, desire and intention.

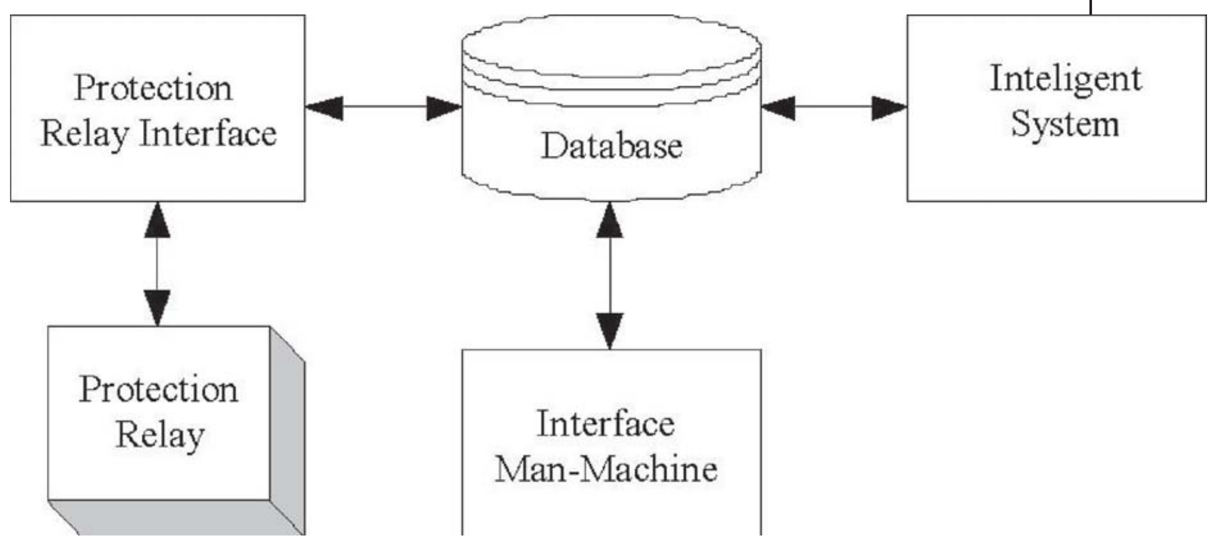
Overall view of SIP program - system for inteliigent parameterization

The main function of protection systems is to protect a system block without other interconnected parts be damaged or stop their functions, when the block is disconnected, which indicates a good selectivity from the protection system introduced. By including into this context the adaptive protection, there is the quest of changing the system configuration parameters without reduction of its initial selectivity. This concept proves that conventional analytical methods would not be usually introduced, making difficult its initial adjustment for the system continuous adaptation.

So, not using these methods, a more advantageous options are the intelligent specialist systems, having as own characteristic the self adaptation to other analysis environments after a previous addition of knowledge from a specialist user in the analyzed system, making easier the method initial adjustment.

After the adoption of a specialist system, were defined the basic blocks of system functions for adaptive protection. The blocks may be described as follows: relay communication interface, data bank, man-machine interface, and intelligent system. Figure 2 shows the connections between the blocks.

In a short description of the blocks that are part of the system it is possible to say that the communication interface from relay has the function of interconnecting measurements of voltage, current and other values from the field, together with the sending of new adjustment parameters for the storage system relay that is part of data bank. Into the data bank besides the storage of values and relays adjustments, also are stored the rules given by the system operator, which are used by the intelligent system that interpret, analyze, classify and execute the rules allowing the yield of new adjustment parameters for the protection relay.



Data Bank

From the data bank come the data acquired from the system and rules related into the process, to be processed. Having a large number of tables regarding since the type of relay communication up to the form of data attached to the specialist system, it is possible to classify the main tables in three groups: the entries, the relay adjustments, and the rules supplied by system.

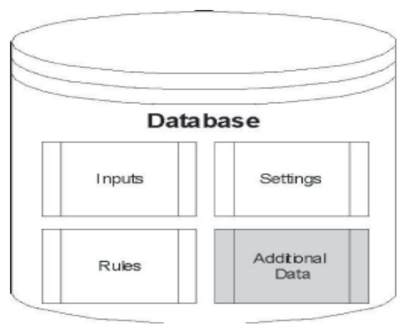


Figure 3 - Data Bank Structure.

The entries comprise measurements made by relay along time, providing one short range story structure of the system magnitudes, and handmade information supplied by user, not shown as samples supplied by system for acquisition of existing data, like information of transformers operation conditions, or attendance to circuits by switches not operated by the system.

This table structure allows monitoring variations along a period regarding any value, increasing the versatility of decisions over the system by knowing its behavior by the curves of values for specific magnitudes.

For the relay parameters the adjustments table has a function for listing the main values to be parameterized in the relay, with the respective addresses for a fast access to the component memory.

The knowledge introduced by the operator is stored in the rules table, which has the function to represent the specialist actions taken over the system considering an analysis of its magnitudes on a given moment. Thus, the rules are formed by two components that add their record to the data bank.

The first of them is the expression that satisfies one impression near of the state of the protected system that is formed by the associations of entries with specific values forming a Boolean expression.

The second part of the rule comprises the actions taken by it, these actions are taken over the relay adjustments for the specific state present into the system described in the expression, and is possible yet to determine such adjustments through instant values from the entries associated to them.

Interface with Relay

The information interchange between the data bank and the adjustment and measurement variables from relay is made by the integrated functions to the communication interface of the protection relay. Besides this communication function between the systems, it also informs the changes in real time for the intelligent system, allowing a better answering time to new adaptations in the adjustment parameters. This way, the interface function also is interconnecting the whole system functions, allowing the development of a communication agent in the program, optimizing the data exchange between its functional blocks, the relay and the user.

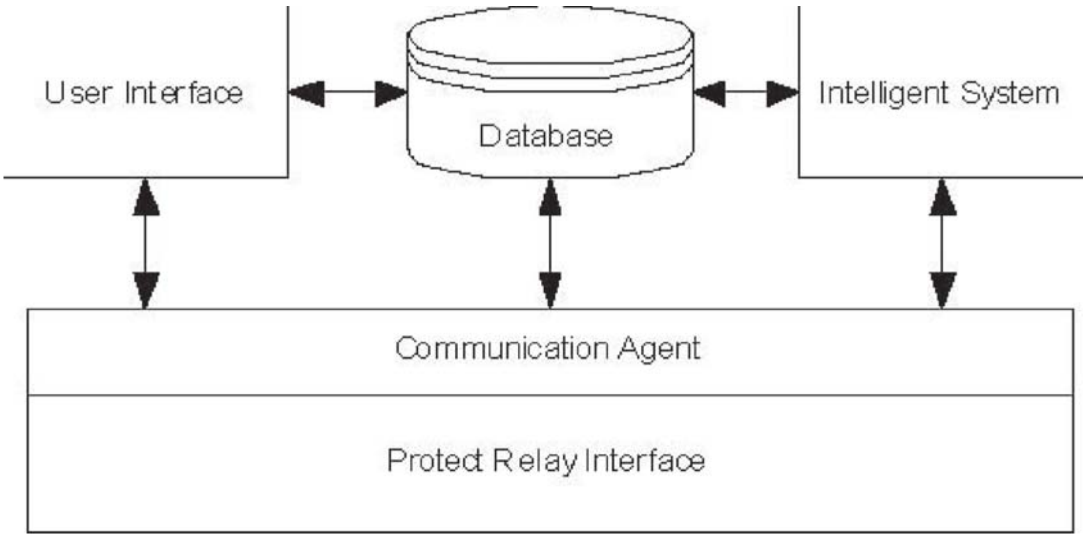


Figure 4 - Program Interface Connections.

Man-Machine Interface

In the development of a more friendly interface for the user it was used the standard system for exploration of the adaptive protection project, introduced by the user. The explorer allows a fast access to the whole functions and tables of the data bank, making possible an easy knowledge entry by the operator, characterizing the distribution branch with the attributions given to it.

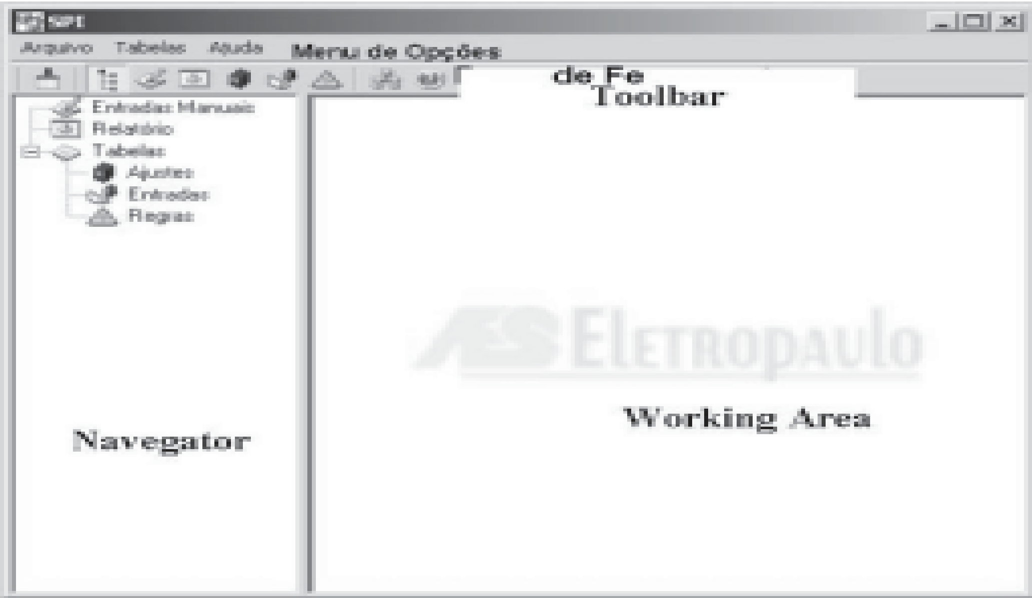


Figure 5 - User Interface

Intelligent System

The intelligent system initially is a compound of an interpreter of expressions, in order to analyze and execute the existing expressions from rules. These expressions are formed by Boolean associations with the entry of data, and numeric comparisons with predefined values, or a set of samples of these values, allowing in this way to define behavior characteristics from the electric system involved in the rule.

For a preview of not characterized states in the rules it was developed an hierarchical rules association structure, permitting the union of many type of rules, involving system spare parts, and mixing them up orderly, defining or not by the user, by the order set up in the rule. This order define the more important rules that must be accomplished, defining its actions taken over the adjustments, they are in a first approach the ones that have defined their values, not allowing that the other one rules of lower level overwrite on the adjustments already changed by the main rules.

In the actions there is another interpreter that makes a function similar to the one of the expression, that besides involving Boolean logics and value attributions, allow the making of complex calculus routines, real and complex, calling basic mathematic functions and functions specially developed for protection relays, allowing that the adjustment values be attributed whether by absolute values or by expressions that depend from other adjustments and entries. For a more advanced user it is possible the making of new simple rules without hierarchy, inside this script allowing in this way a wide adjustment scale, thus defining a great versatility in the system.

Choosing the protection system

In order to evaluate the many type of relays and producers existing in the markets and to choose the ones that better fit to the project conditions and requirements, the staff of "Technical Specification for Acquisition of Prototype System for DTS – Limao".

This 20 pages document was sent to many producers that have presented their products and solutions in a seminar. The chosen was the product REX 521 from ABB and their communication and supervision program MicroSCADA. Following there are some characteristics of the chosen relay: (a) protection functions: three-phase with over-current non-directional three-stages protection, phase-ground fault non-directional and directional protection, under-voltage and over-voltage three-phase and residual protection, thermal overload protection, phase discontinuity protection, and inrush current protection; (b) additional functions: self-closing with 5 trials, phase current measurement, neutral current and residual voltage in primary values and per-unit values, integrated disturbance recorder, circuit-breaker fault protection, trip circuit supervision, measurement of current wave distortion form and voltage, beside others.

Figure 6 presents the structure that was constructed at DTS-Limão.

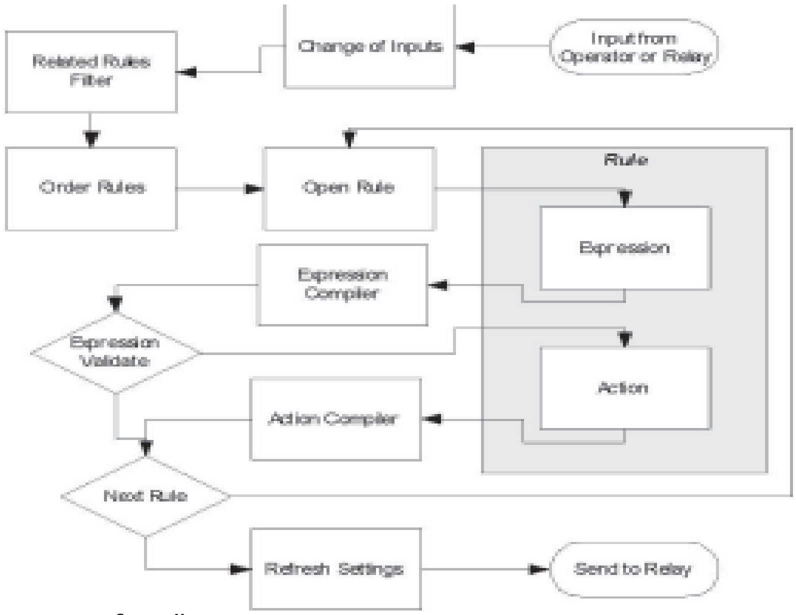


Figure 6 - Basic Diagram of Intelligent System.

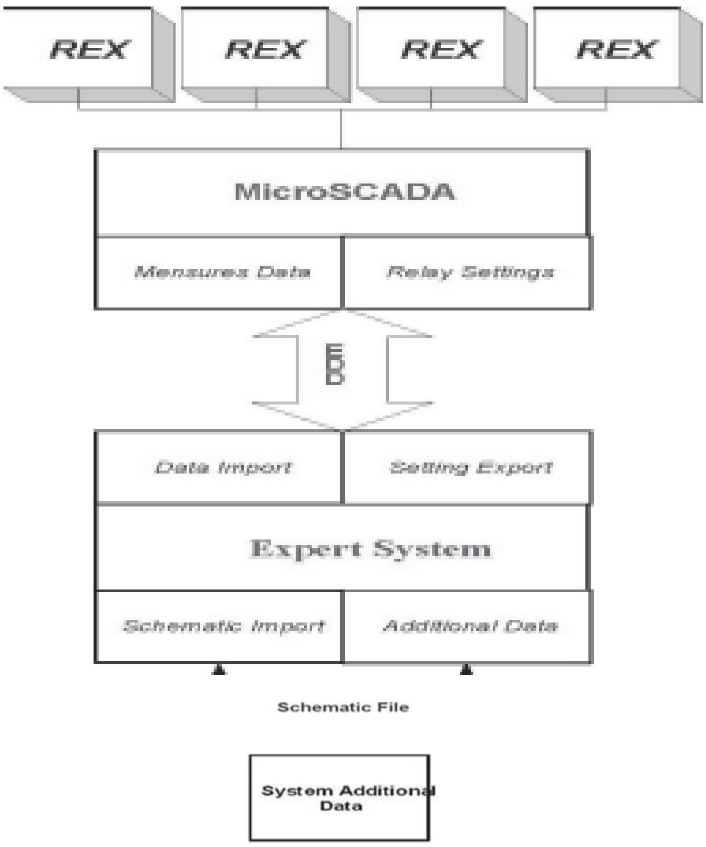


Figure 7 - Adaptive Protection Introduced into MicroScada from ABB for Eletropaulo Energia S.A.

Overall view of SPI program

The SPI Program inside structure was already shortly presented in item 3 of this paper, however the details of functions from Figure 4 will provide a global idea about the program general operation and its interface with the user.

SPI Available Functions

The options menu has the sub-division "File", "Tables" and "Help". Each sub-division will open a new set of options to be executed in these menus. For the menu "File" there are following actions:

Import from GRADE: Open a file from GRADE system of Eletropaulo, changing the data into program data bank form, allowing its use by program analyzes tools.

Import Rules: Allow the rules import, entries and adjustments edited by another windows user or saved – in another non standard file from program, but this action will generate the loss of the present data from program in the part for rules analyzes

Export Rules: Export the whole content of the part for rule analyzes (rules, entries and adjustments) allowing saving them in any disc position or in removable units, like micro floppy disks or CD-R.

Exit: Exit from program, saving all configurations made.

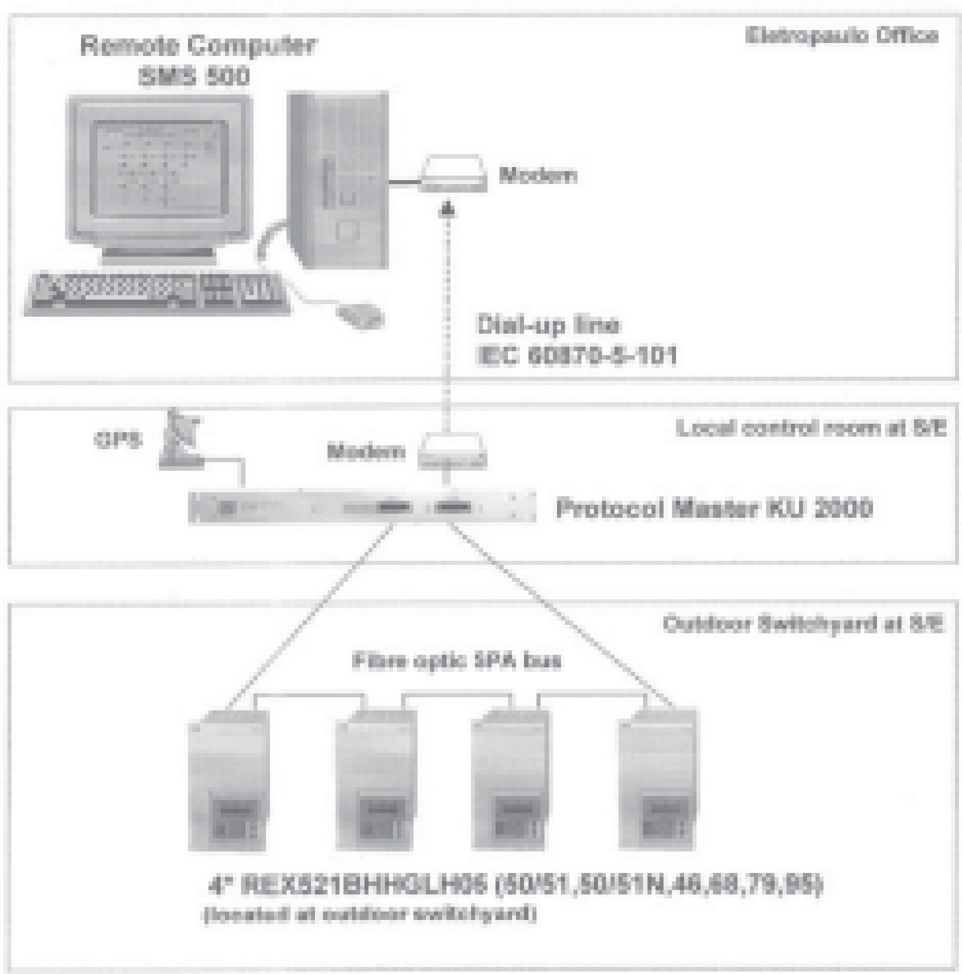


Figure 8 - Structure Made Interconnecting the DTS-Limão and Central Office.

For the menu “Tables” we have following actions:

Hand Entries: Open in the work-desk all the entries defined as hand entries, making easy the adjustment of its values by the operator, allowing a fast introduction of system characteristics, not made available by the protection relays.

Execution Report: Hand or automatic feedback of a simple report of intelligent system execution, informing the monitored entry values, rules that were attended by the expressions and values from modified adjustments.

Entries: Open in the work desk the window for edition of entries for the intelligent system.

Adjustments: Open the window for edition of adjustments of system relay allowing its addition, edition or deletion.

Rules: Open the window for edition of system rules on the program work desk.

Options: Open the options window for connection with the relays communication programs, so making possible the information exchange between programs.

For the menu “Help” we have the following actions:

Topics: Open the help topics from program.

About: Gives the staff for software development.

Tests Making and Integration with MicroSCADA

Many tests were performed on SIP Program for the DTS-Limão. Figure 8 shows the sub-station circuits presenting its information’s, accounting the components number.

It is possible to have information of each circuit just clicking on it. It is possible also exhibit the elements present in the respective circuit and allowing the user to define the name of the circuit breaker and relay that actuates upon it. With data from GRADE it is possible to extract geo-referred position of all recorded components, making possible to have a diagram of all circuit branches, allowing its exhibition in a graphic way and also giving way for the calculation of power flow and short-circuit level along them. Thus this window was developed having the function of to show the branch graphic diagram turning possible the execution of the power flow checking the voltage drops along the lines. Figure 8 shows the diagram of one branch from DTS-Limão already with its executed power flow.

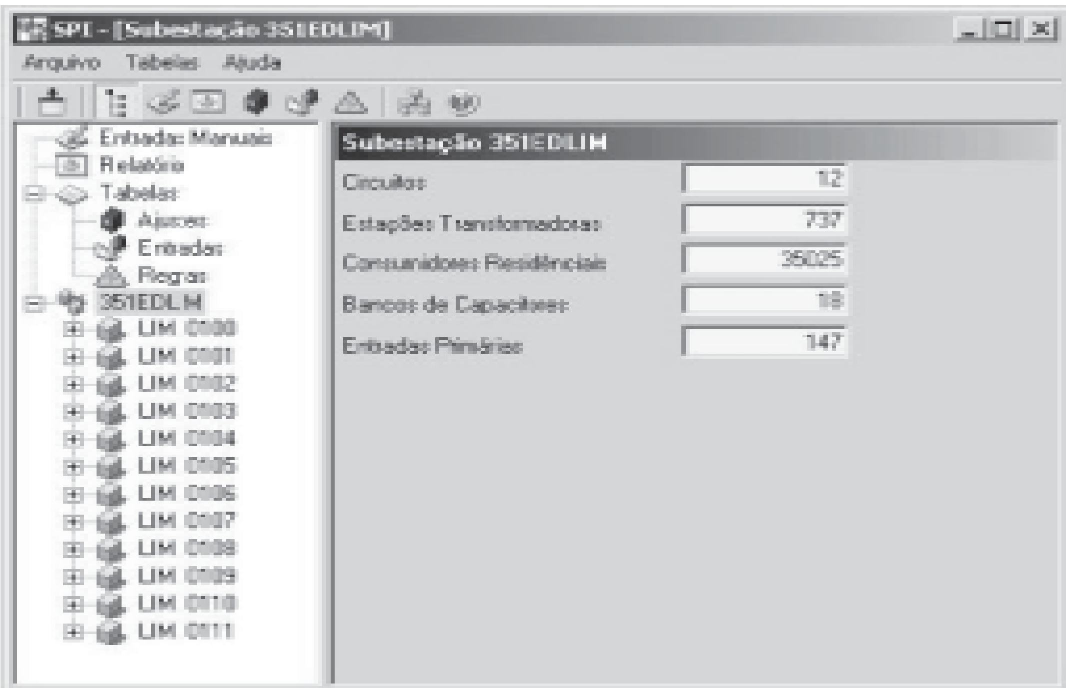


Figure 9 - Information of DTS-Limão

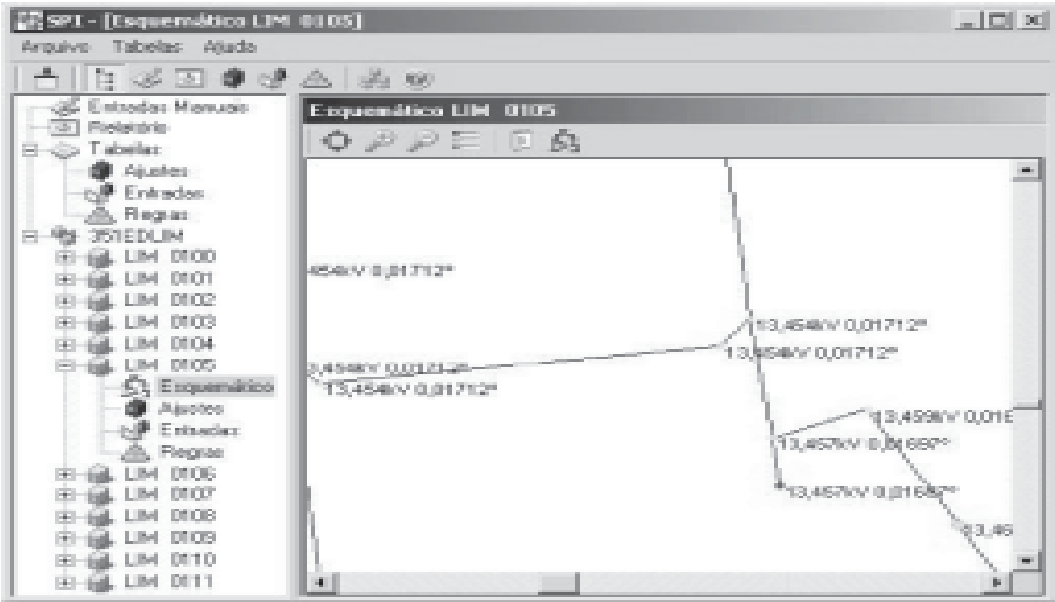


Figure 10 - DTS-Limão's Circuit Diagram

Introduction of Computer Package at Eletropaulo

As mentioned before, the programs SIP and MicroSCADA will act together. The icon  chosen in the tool bar on main window may call the connection options. Three parts for communication configuration with the programs compound the window.

The general option has a list of the main communication configurations:

Connection Type: Inform about the form for communication with the other programs. It may be of the file type, in which the data is forwarded into a text file defined in the option file, type DDE (Dynamic Data Exchange), where data is forwarded by the system memory accessing directly the variables and dependent from the adjustments made in the option DDE, or simply inactive, in which the program no longer will have more actualization of its automatic entries requiring hand adjustments.

Adjustment Dispatch: Inform the type of adjustment dispatch to be made for the relays program. The same way that the connection has the file type and DDE, but also the hand type that makes possible to user to check the data before forwarding to relay.

Reading Cycle: Define the reading intervals from relay program, in the event of the option DDE or file be selected in the connection type or adjustments dispatch.

The DDE option enlist the configurations for communication of type "Dynamic Data Exchange":

Server Name: Server name of DDE from program for connection and data searching. -Service Name: Name of inside service from DDE server for direct access to reading data of relay.

The file option enlist the configurations for dispatch and receipt of data by file: -Work Folder: Inform to program the work address for the exchange of files with the relay program. To make easy  to find it was introduced the search button allowing a thorough access to the computer folders or other shared sites available into an intranet network.

Entry File: File name used by relay program for writing the information that will be read like entry.

Exit File: File name in which will be written the new adjustments to be made on relays and read by its adjustment program.

File Type: Supply the type of separator used to separate the variable name with its corresponding value in the entry and exit files. As an option there is the tabulation (TAB), space, point and coma, coma, or signal for equal. It is important to remember that the numeric variables written by relay program should use as unities separator the point as used by the international system.

CONCLUSION

The Multi-Agent Systems (MAS) shows to be adequate for working with the object-oriented model, given to the characteristics of distribution of both the technologies. The MAS architecture is divided into packages of agents that interact to solve the same problem. This packaging is organized as to facilitate the development process, which can be done by different developer groups. In addition, it gives the possibility of including hierarchical analysis of power systems, and flexibility to extend the system through addition of new agents.

The main benefits obtained with the multi-agent model were: cooperative behavior, characterizing dynamic exchange of information between entities and making possible segmentation of tasks, besides allowing the reduction of the hierarchic characteristics of the decision process; competitive processing, making possible better use of the hardware resources and reduction of the computational load, improving the execution speed; distributed topology, making possible in the abstraction process, the division of the system in lesser number of parts, limited by functional characteristics; Open architecture, allowing the addition of components and the expansion of the system, as part of a bigger system, with creation of new environment levels.

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