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FLISR ALGORITHM IMPLEMENTATION (Self-Healing)

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Abstract *– this document presents a software that implements a FLISR (Fault Location, Isolation and Service Restoration) solution in energy distribution networks. The solution can be implemented independently or integrated to SCADA software available in the Centre of Control the distribution utility (a general or regional centre).*

When implemented independently, it interfaces the field equipment, reading all the states of the contemplated switches (logical loops) and executes commands to isolate the fault and restore the system, taking in consideration technical restrictions of load and tension during the repair period and return to the initial network topological conditions, as well as the same actions, but through the SCADA of the power distribution company.

The solution adheres to the "Smart Grids" concept, executing the FLISR function in real time, using algorithms to maximize the quality indicators, respecting strategies and existing boundaries.

Key words*: FLISR, SCADA/ADMS, Communication Protocols, Electrical System Simulator, Distribution switches.*

1 INTRODUCTION

The solution, named ActionWise, was developed in partnership between the authors companies, being a SCADA/ADMS software that, as will be shown later, can integrate several advanced functions as FLISR, Volt/Var control, load relief, etc.

The first two implantations of the solution, named in the rest of the paper as ADMS/FLISR, were contracted in the end of 2016 for supply in two power distribution companies of the Neoenergia Group, CELPE and COSERN. The in-factory acceptance test of both systems was concluded in December, consisting of leaving the system working in listening and simulator mode. The infield acceptance test should be done between January and February of 2017.

The ADMS/FLISR, as shown in Figure 1, can be implemented in three different ways:

a) **Independent solution**: in this case the ADMS/FLISR is implanted in autonomous form in a hardware that does the field data acquisition (feeders and distribution switches) relating the monitored and controlled circuits. In case of a fault occurrence in the controlled region, the software detects the state changes and defines the best strategy to be adopted to isolate the problem and restore the system. This strategy can be automatically executed or under command of the selected mode, automatic or manual, respectively;
b) **Complementary to an existing SCADA solution**: in this case, there is a SCADA in the clients COS, responsible for the interface with the field equipment of the controlled region. Whenever this SCADA detects a fault, the information is sent to the ADMS/FLISR by a standardized TCP/IP protocol (OPC, DNP3-0, IEC-60870-5-104, etc.). The ADMS/FLISR will do the contingency analysis and will define the best strategy to isolate the fault and system restore, sending to the SCADA os the Centre of Control the manoeuvres that should be executed;
c) **ActionWise is the clients SCADA**: in this case, is enough to add the advanced FLISR function to the operation centre ambient to have the solution controlled in a similar way as the one presented on the item (a).

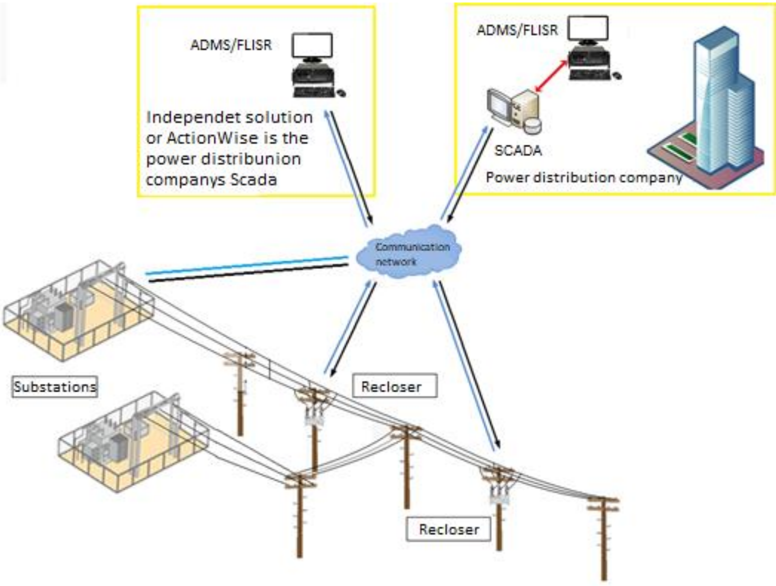

Fig 1 – Possible solutions diagram

The first two implementations are on the diagram (b), that is, on the CELPE the Control Centre is the SCADA ActionView and it integrates itself to the ADMS/FLISR through the IEC-60870-5-104 protocol, and on the COSERN, the SCADA of the Control Centre is Sage and it also integrates itself to the ADMS/FLISR through the IEC-60870-5-104 protocol. In both cases the control centres communicate with the poles switches using the DNP3.0 protocol.

2 SOLUTION PRESENTATION

2.1 Application Configuration

The database with all the topological elements of the controlled region, composed by data collected by circuit breakers, reclosers and distribution switches, can be generated in two ways, as shown in Figure 2, or imported from the company assets register (GIS system) or manually, through a base actualization module, available on the solution itself.

The best way is to import the base from the company assets register, however in this case it will be necessary to develop the integration module with the power distribution company register on the first implementation.

In the first two implementation, due to the four months schedule imposed for all the project, the data entry was done manually. The [YouTube video shows all development process](#).

In parallel to these two first implementations, in one P&D project of one of the companies responsible for developing the ADMS/FLISR, with Neoenergia group, this assets data importer for the companies in the group will be developed.

Fig 2(a) – Data imported from the asset management module

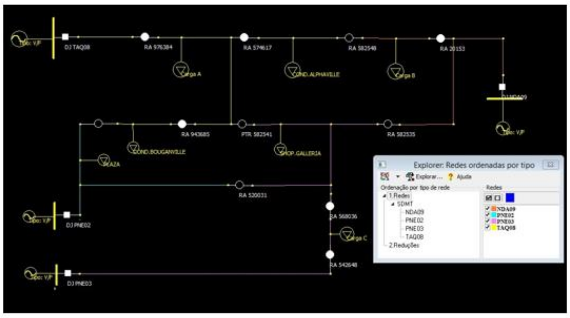

Fig 2(b) – Data manually inserted

The importer is already partially developed, that is, it has two modules, the first reads the data on the power distribution company base and writes it in standard data base tables, and a second module that reads the data in this standard base and writes them on the ADMS/FLISR files. The second module is ready, so only the first module needs to be developed for each power distribution company.

The data provided to the system are organized in logical groups. Each group contains feeders, breakers/reclosers for feeders, segments of power lines, distribution pole reclosers/switches, and consumer loads. Those logical groups are electrically connected and in the event of a fault in one or more elements in one group, the ADMS/FLISR will try to isolate the fault and restore the system, maximizing the system quality indicators.

After entering the ADMS/FLISR data, those data are transferred automatically to the SCADA module in the solution, since it already has templates for each element type in one logical group, as well as a symbol library (Figure 3) with all group elements. This library can be adapted to each power distribution company culture.

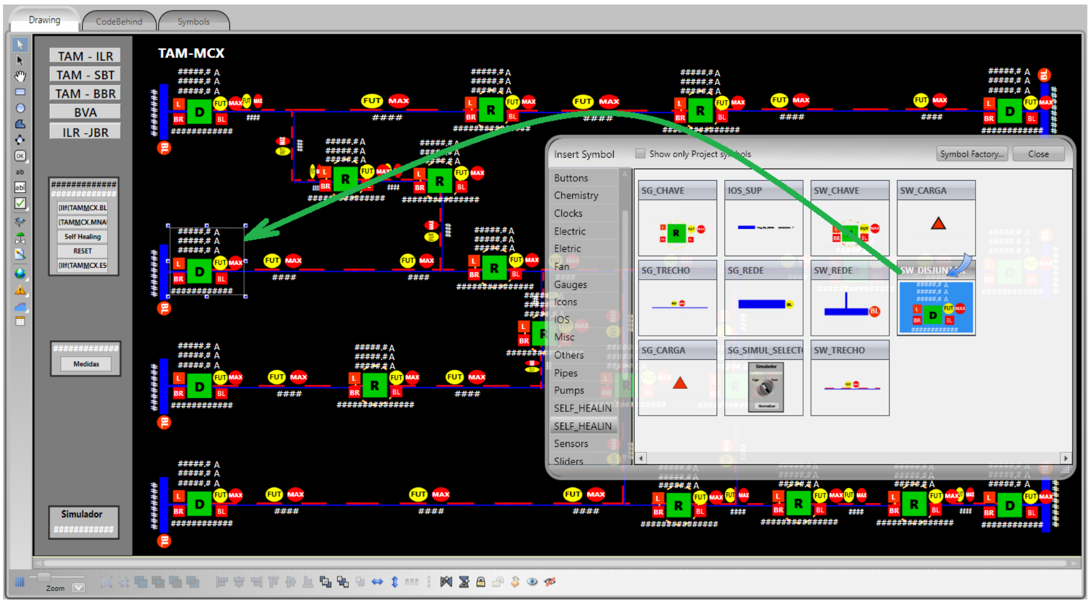

Figure 3 – Symbol library with all elements for a logical group.

As shown in Figure 4, the ADMS/FLISR already has all the reports usually used pre-configured in one electrical application.

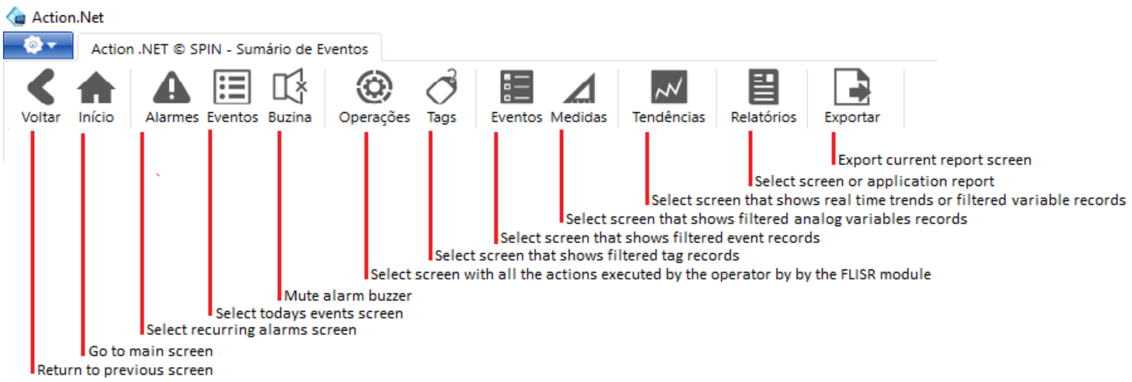

Figure 4 – Pre-configured reports in any ADMS/FLISR application

2.2 ADMS/FLISR Internal Architecture

The Figure 5 presents the organization of the ADMS/FLISR solution. In real time, the system interface with the process can be:

a) Directly with the controlled process, were the ADMS/FLISR reads the field equipment data and actuates in the process following the control strategies;
b) With the SCADA client, that interfaces with the process and sends the data to the ADMS/FLISR using a server protocol about TCP/IP (OPC, DNP 3.0 and IEC60870-5-104). In the event of a fault the ADMS/FLISR sends commands to the SCADA client, following the control strategies.

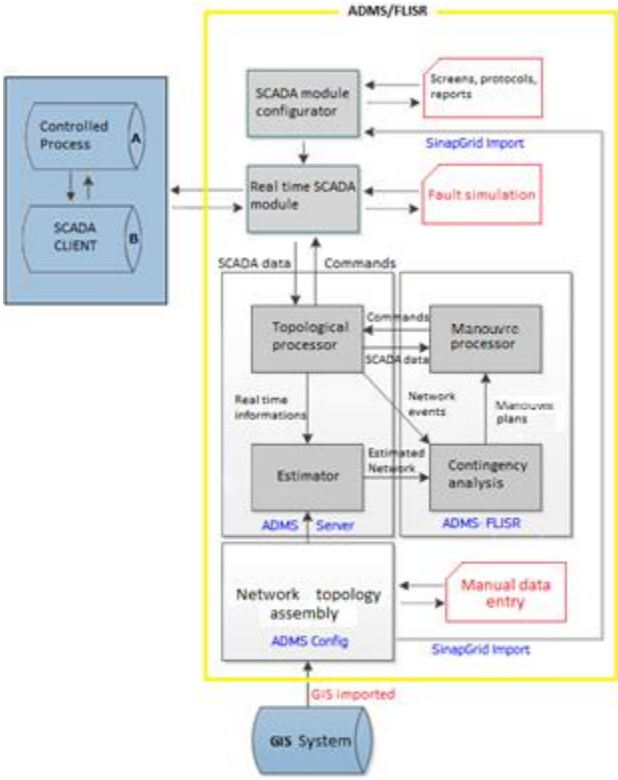

Figure 5 – ADMS/FLISR organization.

The ADMS/FLISR can run in three different ways: the normal mode, the listening mode and the simulated mode. When the ADMS/FLISR enters the *simulated mode*, the communication with the field is suspended and the solution assumes the initial reference state with the Switches and its loading in normal situation for the time. From there, minimum incremental loading values are generated periodically, showing that the system is operational, and, through the ADMS/FLISR screens, it is possible to see every type of fault and the software will respond in a way identical to the real time, stablishing actions to isolate the fault and restore the service.

In the listening mode, the ADMS/FLISR receives the field data and, in the event of any fault, it shows the manoeuvre that it would do, but won't send them to the field.

In the normal mode, every time one or more faults occur in the field, the topological processor module is executed, as well as the state estimator and the contingency analysis module (that defines the actions to be done to isolate the problem and restore the system). Finally, the manoeuvres processor is executed, building the actions to be executed and sends them to the operator/field. The manoeuvres can be configured as manual or as automatic. If in manual mode, they are shown to the operator in a window, with the manoeuvres to be executed and he authorizes or not the execution. If in automatic mode, the manoeuvres are shown in a window and executed in sequence.

2.3 Manoeuvres Selection Algorithm Characteristics

The obtaining and the execution of the manoeuvres sequence for network reconfiguration after a contingency can be divided in three steps:

- Topology assembly and network state estimation;
- Contingency analysis;
- Manoeuvres processor.

2.3.1 Topology assembly and network status estimation

With information from the network topology obtained from the GIS system, the solution acquires the measurement data and the field equipment status and performs the network status estimation.

To estimate the network status consists in setting the value of the other network points, starting from an established set of measurements, and also being capable of detecting possible errors in the measurements provided by the equipment.

The status estimation in the system developed is executed constantly. This way, in the event of a fault, it is possible to start the optimization algorithm with the status estimated immediately before the defect occurred.

Moreover, by utilizing the load typical curves for each feeder, it is possible to predict the status of the network hours ahead. The solution uses this tool to obtain a sequence of manoeuvres that is sustainable for the whole period that the fault has been present in the network, not only for the initial moment.

2.3.2 Contingency analysis

When detecting the occurrence of a fault in the network, before initializing the optimization algorithm, the solution verifies some limiting conditions, such as the presence of a new event in the network, the blocking of the group by the operator or the blockage of a switch due to problems in the communication system.

The optimization algorithm starts with the identification of the switches that can participate in the network reconfiguration specifically for this fault. So, the manoeuvres sequences considered the simplest are identified, being used as entry variables of the modified genetic algorithm, to improve its performance.

To choose the best manoeuvres sequence, the algorithm takes in consideration the following variables in its objective function:

- Continuity indicators;
- Number of manoeuvres;
- Difference between the acquired current and the current capacity for the neighbouring circuits considered to receive the loads that were turned off.

The sequence obtained must maintain the network inside its operational limits, respecting the nominal values for equipment and stretch loading, besides the tensions in the system bars.

2.3.3 Manoeuvres processor

With the best manoeuvres sequence obtained, the solution starts sending the command to the field equipment.

First of all, the solution verifies if there is a logic blockage command sent by the operator or if there is a new occurrence in the network. If there are no more blockages or events, the solution sends the first command separately to the SCADA system. Before starting the procedures to send the second manoeuvre command, the solution waits for the field equipment answer regarding the last manoeuvre. This way it is possible to interrupt the sequence and restart the optimization algorithm if an unexpected event occurs in the network. It is also possible to exclude from the logic an equipment that has presented problems in its communication system.

2.4 Solution Functionalities

The main functionalities of this solution are highlighted bellow:

- Has the ability to perform the automatic load transfer, in events characterized as contingency (actuation in protection functions). Other ADMS functions are available in the solution.
- The optimization algorithm is initialized by the identification of the manoeuvre equipment that can participate in the reconfiguration of the network for the detected event. So, the sequences of manoeuvres considered the simplest are identified, being used as entry variables in a modified genetic algorithm that improves its performance. In the configuration of the entry parameters for the algorithm it is possible to program it to observe the feeders load, as well as the substation transformers, aiming to determine if there is power available to be used. The overload manager can reconfigure the network as well when the load in any system feeder exceeds the parameters predefined by the user.
- Depending on the changes of the network topology, the ADMS/FLISR can change the equipment protection settings of the controlled area.

– No language or routine is required to implement the solution, because it uses a topological processor that, in every change of status of one switch, is executed, redefining the topology of the system, separating it in observable islands and, after, depending on the stablished restrictions, defining the manoeuvres that are necessary to restore the system.
– The system performs the complete registration of each device in operation and the status of the modifications. Every record is dated with a millisecond resolution, allowing to audit the events in the distribution network.
– The screens of the solution are accessible in any mobile device, such as tablets and smartphones.
– In the event of any indication that can put at risk a security of the operation, both of lives and the network, the transference will be blocked, and an alarm will be shown with the reason why the transfer was not executed.
– Disposes of a simulation module for testing the logics before its field application.
– Any operation done by the system is preceded by all security possible. Before performing network reconfiguration command, the systems analyses and makes sure that:
    – All the manoeuvre devices of the network are in communication;
    – There is no signalization of work in an energized line (maintenance tag);
    – All the devices are in normal mode;
    – All of them are with the remote operation indication turned on;
    – All the devices indicate a normal health status;
    – The automation is turned on;
    – The manoeuvre devices normally open are not with “by-pass” signalization (usually manually set).

3 EXEMPLES OF IMPLEMENTATION ON THE NEOENERGIA GROUP

Some characteristics of the first two implementations of the system are shown below. The Figure 6 shows the screen of the **BVA** group, that has a total of 57 distribution switches and feeder breakers. Due to its size, this group is presented in two screens: BVA and BVA II.

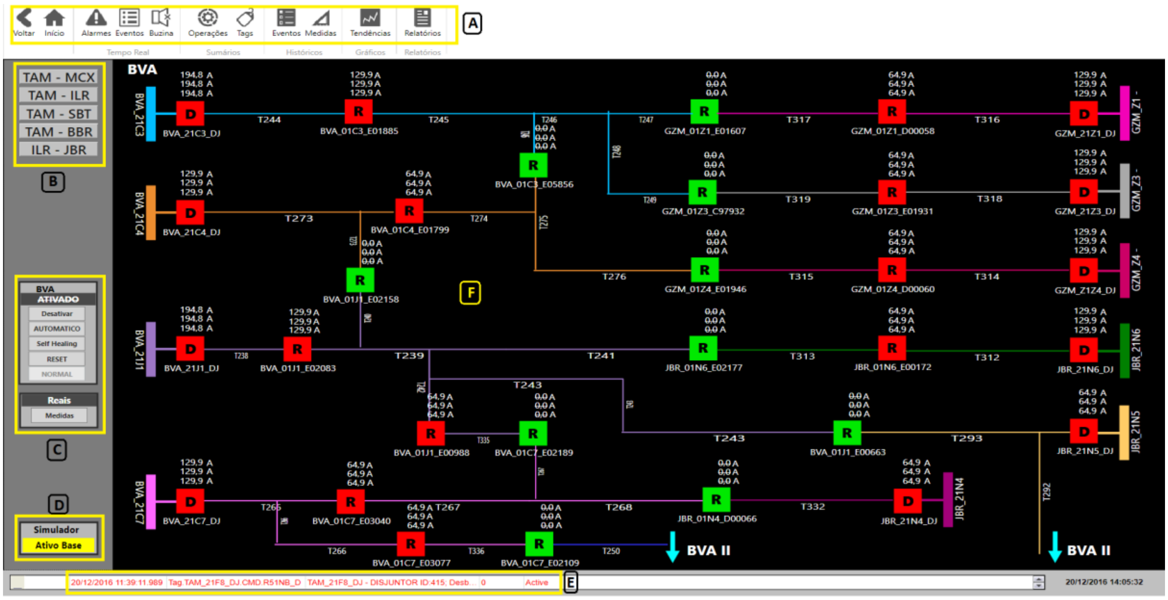

Figure 6 – BVA logical group screen

To facilitate the understanding of the content in this screen, 5 areas were selected:

a) Toolbar to select alarm reports, events, operation log, tags research, events record, measurements, real time tendencies graphs and records.
b) Other logical groups available in this application. One click over any of them opens a group screen.
c) Options that can be selected in the group:

– Activate/deactivate a logical group. If the logical group is inactive, nothing will happen in the event of a fault.
– Manoeuvres in automatic/manual. If in automatic, after a fault is shown a window of manoeuvres and, automatically, the available orders in this window are executed. If in manual, the manoeuvres window is shown and the operator decides if he will or not execute those orders.
– Call self-healing window.
– Reset – Restore the default situation of distribution switches. This button is used in simulator mode, to restore the system after the simulation of one or more faults.
– If it's in normal or simulator mode. When in simulator mode, as in the screen shown as an example, the normal button appears inhibited.
– Measurements shown are the ones read or estimated. Given that the software has a state estimator, one can choose witch type of data is shown, the read or the estimated one.

d) Active/inactive simulator. Every time that the simulator is activated, the communication with the field is suspended and the ADMS/FLISR shows on the screen the default situation of the system, with the typical loads for the time. Besides that, little alterations on the circuit breakers and distribution switches currents are done, simulating that the program is active. In this case, clicking on the circuit breakers and the distribution switches can simulate different fault situations.
e) Last event in the system;
f) Screen with logical group where circuit breakers and distribution switches in red are closed and in green are open. The line segment has the same colour of the feeder responsible for it energization. Over the energized equipment are shown the present current. One click over a segment of line shows the maximum current in this segment.

The Figure 7 shows the ADMS/FLISR after the simulation of a fault in the circuit breaker BVA_21C4_DJ. Since the option "execution in automatic" is selected, as soon as the ADMS/FLISR detected the fault, it opened the switch BVA_01C4_E01799 and closed the switch BVA_01C3_E05856. With this manoeuvre, the red hatched line segment was restored, being fed through the BVA_21C3_DJ feeder (line in blue). The manoeuvred equipment is also hatched in yellow.

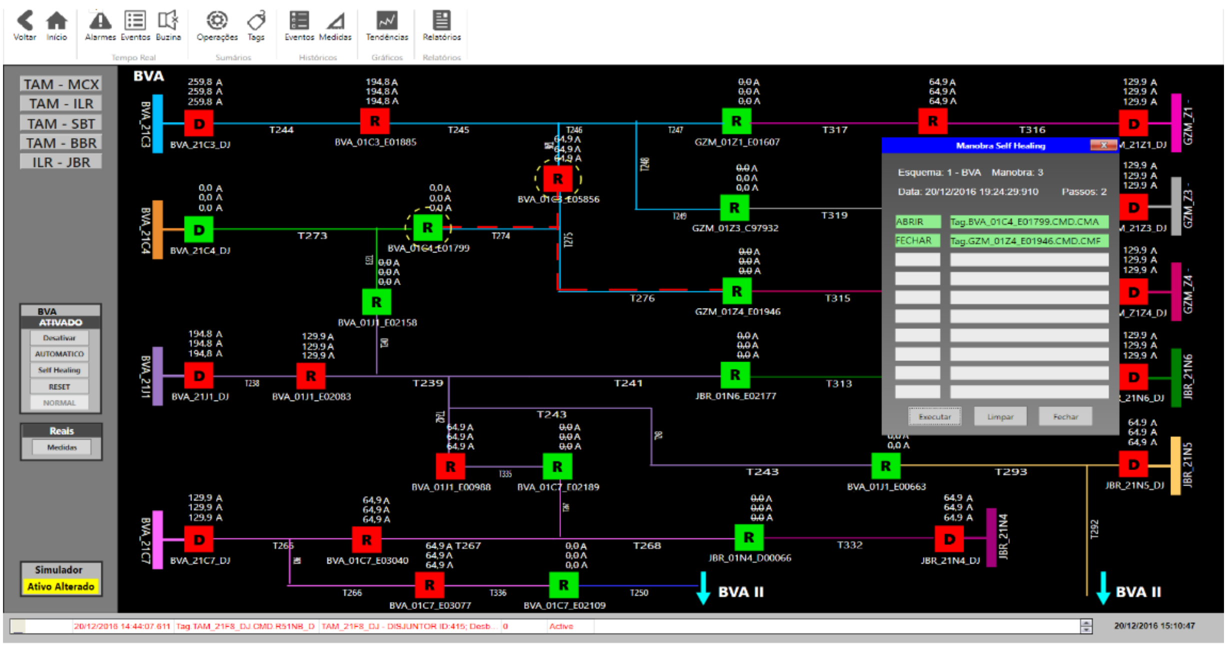

Figure 7 – BVA logical group screen after the fault in BVA_21C4_DJ

As can be observed in Figure 8, if a click is done over a distribution switch it opens a window that shows the switch status and allows the operator to do some commands such as: open/close the switch, select/deselect blockage by energized line, block/unblock reclosing or define if the equipment will function as recloser or as disconnector.

If the simulator is turned on, a button is made available to allow the simulation of a fault in this switch. Attending a request of the Neoenergia Group, in this implantation was also placed a reconfigure button, that if pressed executes the reconfiguration module considering the current situation, that is, independently if there was or not a fault.

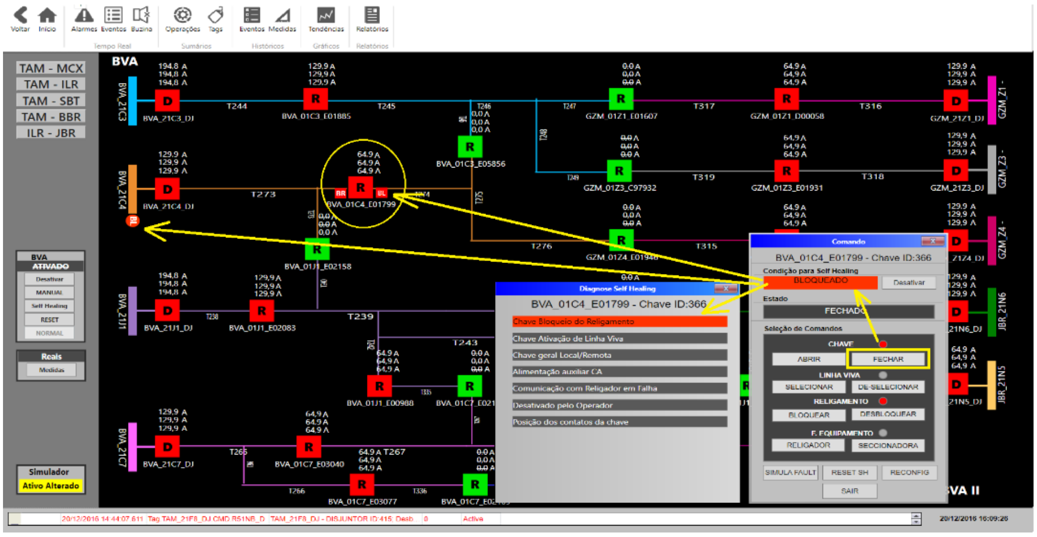

Figure 8 – Distribution switches command window and switch blockage options window.

4 CONCLUSIONS

The presented solution is more than an ADMS/FLISR software, it is in fact a SCADA/ADMS with different advanced distribution functions, among which one of them is the FLISR function.

As shown in Figure 9, the software architecture allows the implantation of other functions such as Volt/Var control, load relief, substations manoeuvres, etc.

Therefore, in project environment, the software can import the data from the GIS system with the company assets used in the study and energetic planning module, as well as other corporative systems. In real time, the software connects with the field through any of the protocols in the electrical area as, for example, the IEC-608-5-104, DNP 3.0, IEC61850, etc.

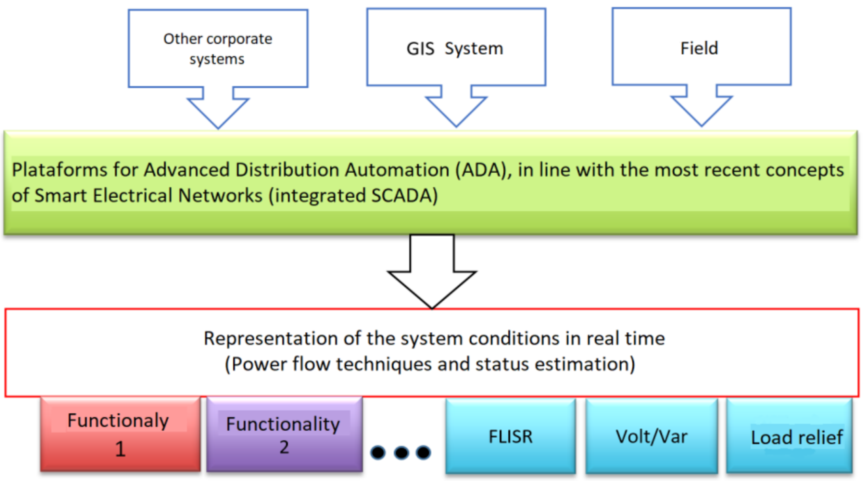

Figure 9 – SCADA/ADMS architecture.

The companies responsible for the solution are specialized in SCADA systems for the electrical area and studies in electrical systems for the distribution and transmission area.

More important than implementing a software with a feature set is to be an expert in those functionalities and on the techniques used in the implementation of algorithms that make the solution robust, functional and fast.

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