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## APPLICATIONS

# Power System Simulation Module for a Dispatcher Training Simulator Project

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**Abstract**

In this paper the set of submodules which form the electrical network simulation module of a dispatcher training simulator are described. The simulation of the network requires the efficient solution of a set of non-linear equations (load flow submodule) built upon the data provided by the topological analysis submodule. Other auxiliary submodules interconnect this module with the man-machine interface of the simulator.

Keywords: Power System Simulation, Control Centers, Load Flow.

## 1 Introduction

The Spanish power control centers are organised in three hierarchical levels. The centers belonging to the lowest level control the sub-transmission portion embraced by a province. While each utility has only one central dispatching center, many provincial control centers are currently being installed. The operators in charge of these centers monitor the telemetered state of the network and take the right actions so that the service is maintained. It is very important for this large number of people to be properly trained because a wrong decision during an emergency could lead to a blackout. A dispatcher training simulator has proved to be an efficient tool in improving this personnel's skills ([1], [2], [3], [4]).

Basically, the simulator comprises three major modules:

1. Data base generation and updating (off-line).

2. Man-machine interface.

3. Network simulation.

This paper is concerned with the third module which, referring to figure 1, takes as an input the fixed topological and electrical information coming from the data base, as well as the commands processed by the Man-Machine interface (described in [5]).

Moreover, an external equivalent computation submodule, which is part of the first off-line module but is closely related to the network simulation, will be included.

This simulator has been designed under several constraints. On the one hand it should resemble the actual control center as closely as possible. This has affected the man-machine interface and some other important aspects. For instance, only minor generators lie, in certain cases, within the range of provincial control centers. No information or control is available at these centers concerning the load-frequency mechanism. So, it is wasteful, and probably useless, to develop a dynamic simulator. On the contrary, the effect that the external high-voltage system produces on the simulated network must be correctly modelled.

On the other hand, computational efficiency has been sometimes sacrificed to reliability. This has been the case of the load flow routine, where the well-known Newton Raphson method has been adopted.

Finally, the computer used ($\mu$VAX-II), and the need to get a sufficiently small refreshment cycle has discouraged sophisticated protective devices from being implemented. However, part of their actions may be simulated by means of programmed events [5].

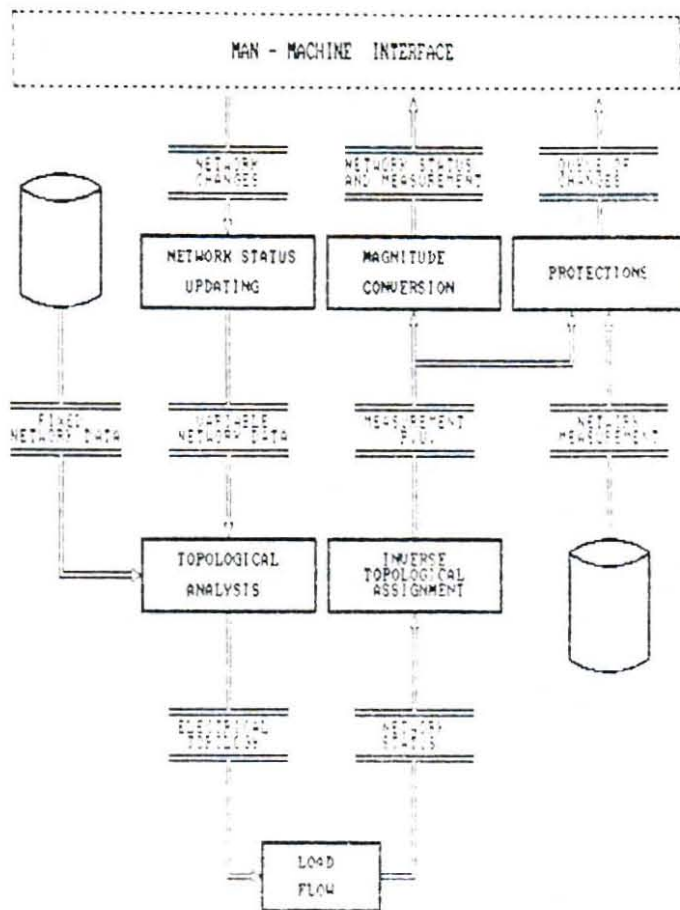The next sections are devoted to a discussion of the submodules shown in figure 1.



Figure 1: Power System Simulation Module

## 2 Operator's Command Processing

All the commands coming from the trainer, the trainee, or from the module that manages the protections, are filtered by the man-machine interface, formatted and sent to the network simulation subsystem via a queue.

The module being described sequentially analyses the commands stacked in the queue during the last cycle, and updates the data bases according to the logical model of the element being modified. There is a logical model for each one of the following components: switch, circuit breaker, generator, variable transformer tap, variable shunt capacitor and load. As an example the model for the circuit breaker (CB) is shown in figure 2.

The instructor may force the CB to behave as defective. In this case any command will be ignored and the CB will remain in its present state. Otherwise, a closing command will be made effective provided the synchronoscope allows it, while an opening command coming from the trainee is only possible if the CB is remotely controlled. The instructor may simulate any local command on the CB.

In the same way, the other logical models are intended to resemble the actual behavior of the simulated element as closely as possible. For instance, the nominal value of each individual load is periodically updated according to a pattern defined by the user in the data base.
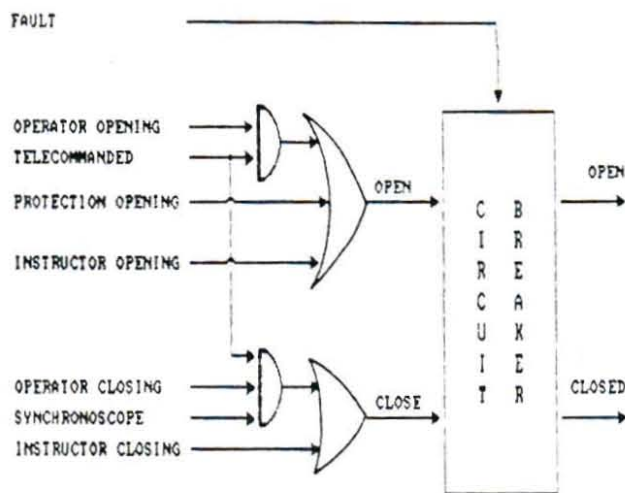


Figure 2: Circuit breaker logical model

## 3 Topological Analysis

The objective of this module is to supply the data required by the Load Flow module. As an input it uses the variable data coming from the present status of switching elements, as well as the fixed structural data taken from the network data base. Its main functions will be described below following the same order in which they are executed ([6]).

### 3.1 Physical to electrical nodes assignment

From the point of view of the topological analysis, each substation within a network is composed of busbars, transformers, circuit breakers and switches. Power is drawn from the substation by local loads and lines, and is fed by generators and lines. The busbars and the edges of the other elements are potential electrical nodes which will be denoted as "physical nodes". In figure 3 encircled numbers represent physical nodes.

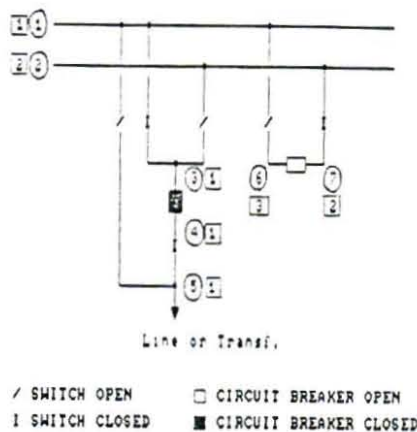Depending on the present status of the switching elements one,



Figure 3: Part of a substation showing several nodes

two or more physical nodes are merged by this submodule into an electrical node. The three squared numbers in that figure are the electrical nodes. For instance, the set of nodes 3, 4 and 5 constitutes the electrical node 1 because the elements joining them are closed.

### 3.2 Islands detection

The network model is now composed of electrical nodes, lines and transformers joining them, and shunt devices (e.g., generators, loads and capacitors). A common problem is that the network may be split into several connected components called "islands". It is necessary to perform this step, since the Load Flow algorithm requires a slack node to be assigned to each island. Typically, most of the islands found, like the node 3 in figure 3, make nonsense. Other less trivial cases where the load clearly exceeds the generation, must also be discarded since the Load Flow would not properly work if they were not. These ill-conditioned components will be called "dead islands".

### 3.3 Optimal node ordering

The load flow calculation [8] is an iterative process that requires the efficient solution of the linear equation system arising from each iteration. Due to the nature of the problem in hand, this system of equations is very sparse, but tends to become full during the gaussian elimination process. A great deal of operations and memory may be saved if this fill-in remains as low as possible, which is an important issue for real-time code. An appropriate choice of the order in which the equations are eliminated is enough to avoid this problem. The well-known minimum degree ordering strategy [7] has been adopted in this project. It represents a compromise between complexity and optimality and has proven to be near optimal in practice.

### 3.4 Other auxiliary functions

Besides the former functions, the topological analysis module carries out the following ones too:

- Computation of the node admittance matrix.

- Computation of the power injected into each node.

- Initialization of node voltages.

- Coherence analysis of regulating elements (e.g. to make sure that the regulating and regulated nodes are not in different islands, etc.).

## 4 Load Flow

In the actual control center, the dispatcher acts on the network and knows of its response after the refreshment cycle has elapsed and the

screens have been updated. In the simulated control center, however, the static behavior of the network in the face of a perturbation must be computed with the help of the Load Flow tool. Given the nodal power injections this routine calculates the nodal voltages and the active and reactive power flows through the lines.

The basic equations for this routine are:

$$P_i = \sum_{j=1}^{j=n} V_i V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \qquad (1)$$

$$Q_i = \sum_{j=1}^{j=n} V_i V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) \qquad (2)$$

where $P_i, Q_i$ are the net active and reactive power injected at node $i$; $V_i, \theta_i$ are the polar coordinates of its voltage, and $G_{ij}, B_{ij}$ the real and imaginary components of the admittance matrix element $Y_{ij}$.

The Newton-Raphson (N-R) algorithm [8] is the standard adopted by the power industry for solving the nonlinear equations 1 and 2. Other faster versions, like the so-called Fast Decoupled Load Flow [9], have not proven to be so reliable, especially for the kind of networks this simulator is intended.

The N-R method is based on the iterative solution of the equation:

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = -J_k \begin{pmatrix} \Delta \theta \\ \Delta V \end{pmatrix} \qquad (3)$$

where $J$ is the jacobian of expressions 1 and 2. Each time equation 3 is solved, better values of $V$ and $\theta$ are obtained. Eventually, the values of $\Delta P$ and $\Delta Q$ will be small enough and the iterative process is stopped. An extra iteration may be required to refine the voltage values once the transformers taps and the output of certain reactive compensators are definitively fixed at their closest discrete values. (see figure 4).

Besides the usual $PQ$ and local $PV$ nodes, other types have been considered which introduce additional programming complexity and
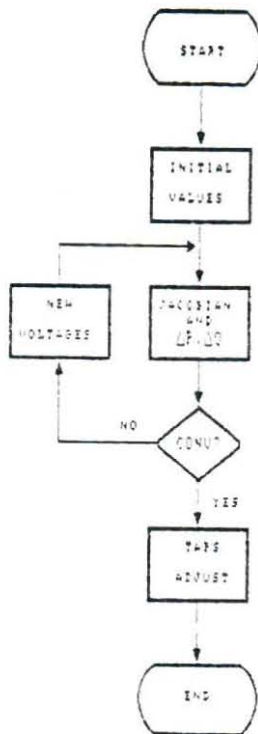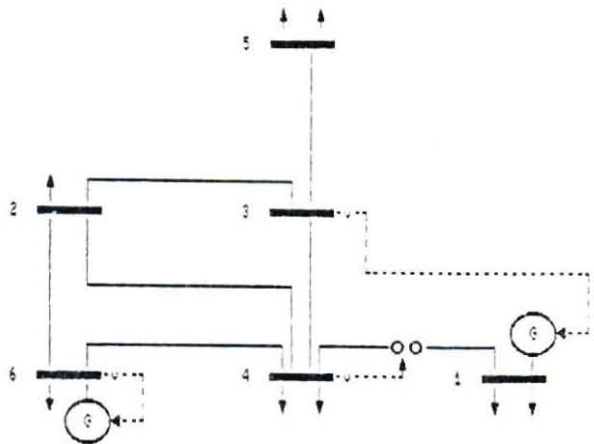


Figure 4: Newton-Raphson's algorithm flow chart.



Figure 5: Jacobian structure of a representative problem.

convergence problems, like the following:

- Remote $PV$ nodes. The voltage at a specified node is supported by a reactive source (a generator or a capacitor) located at other node.

- Tap-regulated $PV$ nodes. A transformer shifts its under-load tap to keep constant the voltage at a specific node, which may be one of the transformer sides or a remote node.

The structure of equation 3 must be modified accordingly when those nodes are present. Furthermore, since both the taps and the reactive sources may reach their physical limits, this structure may change during the iterative process, leading to rather complex situations which challenge the robustness of the N-R method.

Figure 5 shows the resultant structure of equation 3 for a small representative problem. In this example, node 0 is the slack or reference node, node 1 is a local $PV$ node, node 2 controls the voltage at node 3, the transformer regulates the voltage at node 4 and node 5 is a conventional $PQ$ node.

State-of-the-art techniques have been used when dealing with the solution of the sparse linear equation 3. Specifically, a customised sparse matrix package has been developed especially for this project.

## 5  Inverse Topological Assignment

This module takes as an input the state vector computed by the load flow module, as well as the equivalence table between electrical and physical nodes generated by the topological analysis. As an immediate result it supplies the voltage of the physical nodes where this measurement is actually telemetered. Straightforward computations also give the values of currents and active and reactive powers flowing through any desired element.

## 6 Protections

Since the computer adopted for this project has got a relatively limited computational power, it is not possible to perform a real-time simulation of complex processes, like the dynamic behavior of the network or the control actions of sophisticated protective relays. This is why only the overcurrent relay function has been incorporated to the model. Each computed current level exceeding its maximum value triggers an opening command for the appropriate circuit breaker.

## 7 Magnitude Conversion and State Updating

This auxiliary module converts all the magnitudes which are to be represented later on the operator's screens from the "per unit" system to Amperes, Kilovolts, MWs, etc. It also supplies the present state of switching elements and transformer taps to he man-machine interface.

## 8 External Equivalent

The different networks into which a power system can be divided are strongly interconnected. Thus, when studying one of them, the effect of the overall system has to be taken into account. This effect is much more important for the kind of networks we are dealing with, which have no inner generation. Including the whole power system in the study is not a good solution, because it is much larger than the area of interest. It is preferable to model in detail the area of interest, and to substitute the remaining by some equivalent attached at the boundary buses.

After evaluating the most commonly used equivalencing techniques, the method implemented in this simulator has been the Ward Equivalent with Buffer ([10],[11],[12]). The buffer zone, consisting of a small number of generators with large reactive capability, provides enough reactive power support to the area of interest whenever needed. This is particularly important for the kind of simulated networks, which usually have no generation inside, and have to be supported from outside. The buffer zone also provides a realistic slack bus for the network. The slack bus will be one of the retained generators.

## 9 Conclusions

The network simulation submodule of a dispatcher training simulator is presented in this paper. The simulator is basically intended for the small provincial control centers which are currently being installed. The specific nature of these centers has greatly conditioned its design. A sophisticated stationary load flow model has been developed, including remote voltage control, tap-changing transformers, etc. In addition, several auxiliary submodules like topological analysis, external network equivalent computation, simulation of telemetered magnitudes, overcurrent protection, etc., have been described.

The simulator can handle several contingencies, like loss of load and generation, line switching, islanding, etc. Other more severe disturbances, e.g., the sequence of events and alarms after a short circuit, might be handled as programmed events and/or by means of trainer actions.

## 10 Acknowledgements

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