ADVANCED COMPUTATIONAL TOOL FOR ANALYSING THE IMPACT OF DISTRIBUTED GENERATION ON DISTRIBUTION SYSTEMS PLANNING

Franz H. PEREYRA ZAMORA* Antonio P. CUNHA* João C. GUARALDO*
*SINAPSIS Inovação em Energia – Brazil
franz.zamora@sinapsisenergia.com antonio.cunha@sinapsisenergia.com joao.guaraldo@sinapsisenergia.com

Henrique KAGAN* Marcos R. GOUVÊA Élio VICENTINI
EPUSP/PEA – Brazil AES Eletropaulo – Brazil
henrique.kagan@sinapsisenergia.com gouvea@pea.usp.br elio.vicentini@aeseletropaulo,com

ABSTRACT

This paper aims to describe the main results of a research and development project for allowing the analysis of impacts due to the connection of distributed generation (DG) units to a distribution network and synergies with the expansion planning. The computational implementation has included innovative modules for optimum allocation of DG units, evaluation of system average RMS frequency index (SARFI) for a specific voltage sag magnitude with or without DG units in the network as well as analysis of the impact of a large number of small photovoltaic (PVs) panels. The impact of PV micro-grids is taken into account using the foreseen seasonal and daily variations of sunlight for calculating the generated energy. Since the model allows an integrated representation of low, medium and high voltage networks, the impacts of the DG units can be analysed in any part of the system under study with a single processing. The software has a full graphics interface with integrated maps for helping the planning activities.

INTRODUCTION

The implications due to both the benefits and the difficulties associated to the integration of Distributed Generation units in electric power distribution systems motivate the development of tools to assess their technical and economic impact. Such tools should consider these units in studies related to the planning of system expansion, protection, dispatch, operation in steady state and transient stability (carried out for transmission only, so far).

This Project has developed methodologies and consolidated practical solutions, using a computational tool in order to analyse distribution systems in the presence of DG units, especially to support expansion planning activities, taking into account diverse potential impacts which are hardly simulation at present.

METHODOLOGIES

The methodologies used to support the development of the calculation modules follow herein:

Expansion Planning considering DG units

Planning the network expansion considers an initial identification of critical points and a corresponding analysis, for all demand intervals (24 intervals or more) throughout the planning period provided.

The data, techniques for network analysis and the search for solutions interact in diagnostic procedures, thus identifying where and what type of facilities should be proposed to reinforce the system. That includes the locations in the grid where DG units should be inserted, as an alternative to supply expansion.

The network expansion process is interactive and allows for the diagnosis of the network with or without DG units.

Planning the expansion of the network is consolidated through the following possible reinforcements:

- Recabling;
- Deployment of new circuits;
- Construction of a new network;
- Construction of a new substation;
- Substation expansion by adding a new transformer;
- Block transfer among substations and feeders;
- Allocation of DG units;
- Allocation of capacitors;
- Installation of network switches.

Evaluation of Impact on Power Quality

Short Duration Voltage Variations (SDVV) are one of the main phenomena to be treated within the power quality, due to the damage they might bring onto customers [1].

SDVV parameters may be obtained by measurements or may be estimated by simulations, the purpose of this methodology.

The estimation of SDVV indicators considers:

- the magnitude;
- the duration;
- the frequency of occurrences.

The estimation of the magnitude of the SDVVs provoked by faults on a certain point in the grid is given by the calculation of the voltages resulting of short circuits, whereas the evaluation of the duration of SDVVs is more complex, for it depends on how the protection reacts to the event.

The most utilized indicator for the analysis of the performance of a given bus or a distribution system in relation to the SDVVs is called SARFI (*System Average RMS Frequency Index*) [2].

The SARFI Index classification is given in ranges and corresponds to the usual values in specialized literature; *i.e.*, $SARFI_{40\%}$, $SARFI_{70\%}$ e $SARFI_{90\%}$.
Given the information about the magnitude and the frequency of events, it is possible to map areas of risk and vulnerability concerning the phenomena of interruption and short duration voltage variations. In this sense, areas bearing the problems mentioned are defined, according to the values obtained, through graphical views.
Following a simulation method that consists in the generation of short circuits and in the application of faults according to failure rates (failures/km/year) on the network buses, voltage values may be obtained, providing data suitable for its classification in terms of magnitude and frequency.
Applied short circuits correspond to several kinds chosen according to some occurrence probability, estimated for the distribution system (for instance.: phase-to-ground 80 %, double-phase 11 %, three-phase 5 % e double phase-to-ground 4 %).
Thus, one may estimate indices related to SDVV (voltage dips and interruptions) on buses and for every consumer within the electric power distribution network.
This methodology provides for the implementation of predictive analysis of SDVV for a number of alternatives. These may both include networks with or without the presence of DG units allocated in various parts of the network, and evaluate such phenomena also in expansion planning.
The presence of DG units in the network has the potential to attenuate the disturbances of short duration voltage, in that a generator contributes to support the voltage (assuming its stability upon the occurrence of short circuits).

Allocation of DG units by Genetic Algorithms

The problem of allocation of new DG units in distribution networks is to evaluate the most suitable locations and determine the optimal capacity of DG units, such that the overall benefit to the system is maximized. The methodology involves a series of steps, highlighting the use of Genetic Algorithms (GA) for the optimization process.
The implementation of a GA in a simple way is given as follows:

- Random generation of an initial population;
- Evaluation of individuals in each population;
- Reproduction of the population;
- Use of crossover and mutation operators;
- Completion of iteration of generations;
- Presentation of results

The first important aspect for the correct implementation of the genetic algorithm is the encoding of the potential solution and its validation based on the evaluation function. For each solution, all technical constraints are checked, such as loading in network elements and the bus voltages by efficiently processing a load flow module. If a restriction is violated, a penalty term is added to the objective function. The level of penetration of DG units admissible within the distribution network is also a restrictive criterion in the optimization process.
A number of candidate buses are given for the installation of DG units. These candidate buses are chosen abiding by the criterion of the load centre of the block, that is, each demand block in the network presents a candidate bus for the allocation of DG units. And the optimization process will determine the most suitable buses for installation. The computational implementation determines the location and capacity of DG units in real low, medium and high voltage networks, also including technical constraints of maximum DG penetration.

Photovoltaic Systems connected to the network

The characteristics of photovoltaic (PV) generators are defined in terms of solar radiation [3], the demand to be met and the electric features of the solar panels [4].
Allocation refers to the possibility of installing panels on top of roofs of houses and buildings, relating their position to the geographic allocation of every consumer who becomes a self-producer or an independent power producer connected to the distribution network (MV or LV).
Photovoltaic systems placed in some specific geographic area can also supply micro-grids, as considered in the simulation tool.
The integration of the available network data, solar radiation and consumers' load curves with concepts and techniques of network simulation provide the conditions for evaluating the insertion of one or more photovoltaic systems associated to consumers or micro-grids.
The load flow method available allows for assessing the impact on the network, produced by an entry of one or more photovoltaic systems, considering network power flows, voltage profile and losses.
Given a configuration of photovoltaic systems and their corresponding radiation curves, the computational tool determines the production of energy over the period of analysis.
The consumers' load curves are then taken into account for the analysis of the flow direction, based on the consumption balance and on the power injection into the network.

Integration with Google Maps™

Bearing in mind the position of lines, substations and networks within the given geographic area is vital. A functionality was implemented in the computation platform to draw the proposed network over Google's maps or satellite images.

SIMULATION PLATAFORM WITH DG

Once being an object-oriented system, the SINAP T&D was chosen to support the Project, for it allows the inclusion of new modules in a clear manner and with friendly GUIs, besides providing suitable functions to be used by the new modules developed. The following characteristics in the platform are herein outlined:

i) User friendly network editor;
ii) Representation of either schematic or geo referenced diagrams;
iii) Relational database, allowing for using either local or corporative database;
iv) Load flows for either balanced or unbalanced networks, able to solve mesh networks based on several different methods (Gauss, Newton-Raphson);
v) Calculation of different types of short circuits, considering fault impedances;
vi) Integrated representation and simultaneous processing of all network branches at any voltage level (high, medium and low);
vii) Use of network equivalents, enabling both the analysis of a major area of interest and a specific area, bearing in mind the influence of neighboring sub-networks;
viii) Representation of arrangement of buses and switching devices in substations, allowing for simulation of switching operations;
ix) Auxiliary modules for analysis and simulation of system operation in normal or emergency conditions.

The new modules to meet the needs of process automation in utilities included in the development were: expansion planning considering DG units, impact on power quality related to voltage sags and swells; optimal allocation of DG units, analysis of photovoltaic systems connected to the network, simultaneous viewing of networks and maps (Google Maps™).

CASE STUDY

The simulation environment consists of Tucuruvi, Vila Medeiros and Gopouva districts' networks.
In all case studies, a microcomputer with a 2.20 GHz Intel Core 2 Duo processor, a 4 GB RAM and Windows 7 operational system was used.

Impact on Power Quality - SDVVs

Using the Vila Medeiros' network, two alternatives are considered, after installing a 3 MVA capacity DG unit. In Alternative 1, a DG unit is allocated at the end of the feeder. In Alternative 2, a DG unit is allocated close to the middle of the feeder. The aim is thus to observe the SDVV for different allocations of the DG units along the distribution network. Alternative 3 analyses the impacts of SDVV when a network expansion takes place.
The input data used to illustrate the simulation correspond to failure rates and types of faults. Once the failure rate is known for each component on the network, one can assess the number of SDVV occurrences per year. The application estimates $SARFI_{40\%}$, $SARFI_{70\%}$ and $SARFI_{90\%}$ indicators as well as number of interruptions per year.

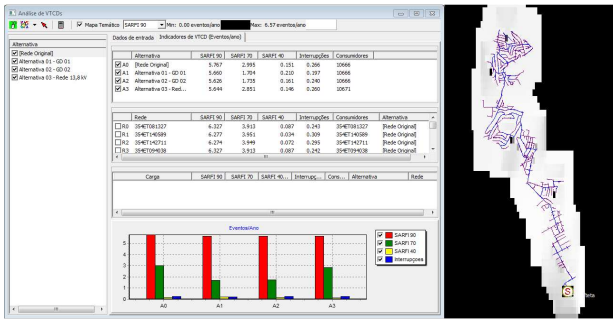

Figure 1 – SARFI 90% and interruptions.

Figure 1 shows the results for the SARFI 90% indicator and the interruptions. This computational tool also assists in the identification of indicators for specific buses.
The processing time for a 5277 bus network was 93.7 seconds.

Allocation of DG units

Three feeders belonging to the Tucuruvi, Vila Medeiros and Gopouva substations were used in order to perform the simulation.
For the analysis of the DG unit allocation using the genetic algorithm technique, two penetration levels were considered, namely 20% and 25%, in order to observe the changes imposed on the network, due to the DG penetration rate.
The simulation results for a 25% DG penetration show a 0.5 MVA allocation on the Gopouva feeder and 1 MVA penetration on Tucuruvi's and Vila Medeiros' feeders. A total amount of 2.5 MVA were allocated.

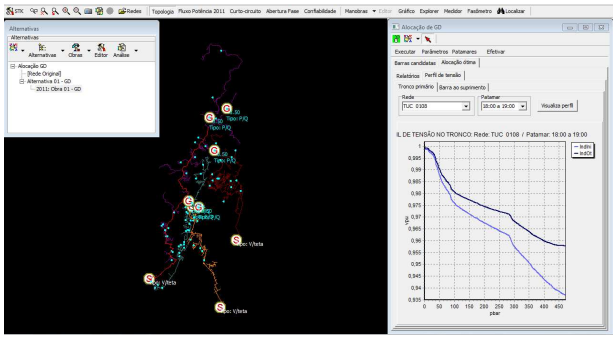

Figure 2 – Voltage profile with a 25% penetration

The voltage profile can be seen in the graphic functions provided by the application. Figure 2 shows the voltage

profile for one of the feeders under analysis (Tucuruvi – 6pm to 7pm demand interval).
The simulations with 20% and 25% penetration levels show a reduction of losses in the Tucuruvi's and Vila Medeiros's feeders.
Moreover it proves a better voltage profile in Tucuruvi's feeder. In view of the total losses for the 3 feeders analysed, one notes a 0.55 MW/day decrease.
The process lasted 26.2 seconds for a 2350 bus network.

Photovoltaic Systems connected to the network

The module for Photovoltaic Systems model connected to the network provides options for analyzing the impact of either individual or micro-grids inclusion.
It is also possible to analyse consumers belonging to the micro-grid (analysing a PV system set and the individual load curve).
The consumers' typical load curves and their corresponding consumption are included in the analysis for the energy balance. It is useful to evaluate the potential purchase and sale of energy. The graphic representation for photovoltaic systems on Gopouva's network is shown in Figure 3.

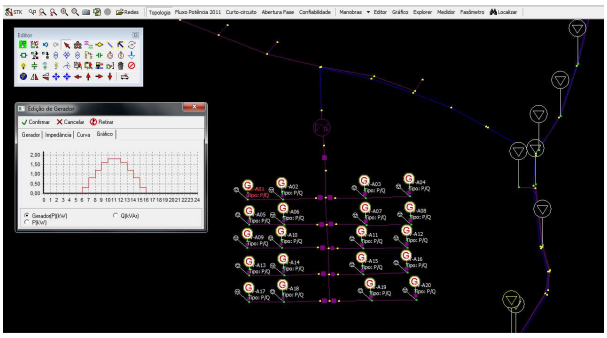

Figure 3 – Photovoltaic micro-grid and dispatch curves.

The results of the energy balance per hour are shown in Figure 4. Similarly, energy balance graphics can be drawn per day, taking the whole year into account.
When implementing the energy balance for January to December, the processing time was 12.0 seconds, considering a 5624 bus network.

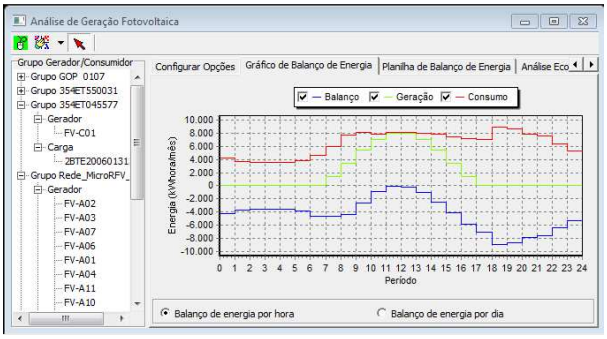

Figure 4 – Energy balance per hour.

Integration with Google Maps

When planning with DG units, Google Maps™ allow for a geo-referenced visualization of the network topology over the layers provided in the application, based on API Google (illustrated in Figure 5).

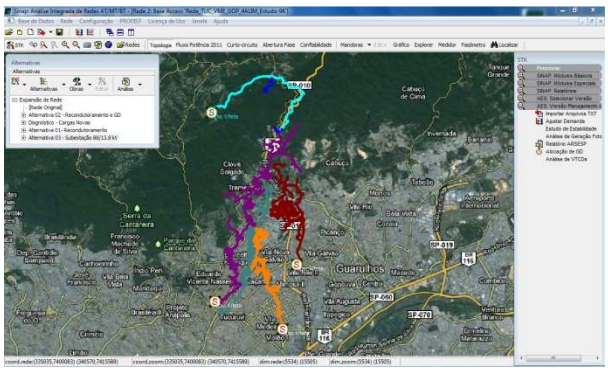

Figure 5 – Network over a hybrid layer (map and satellite).

Considering a 2250 bus network in the planning process with DG units, the load flow implementation for 24 time intervals lasted 2.0 seconds.

CONCLUSIONS

The methodological approach carried out for this Project was comprehensive and supported the development of a useful analytical tool for planning with distributed generation, including the impact on power quality (SDVV evaluation); optimal allocation of DG units and the study of photovoltaic systems connected to the network.
The computational implementation was performed based on modules integrated into a friendly simulation platform, including map displays, aiming at providing efficient means for the analysis of distribution networks, both geo-referenced and schematic, that involve the presence of DG units as well as micro-grids.

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