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ScienceDirect

Energy Procedia 57 (2014) 197 – 206

Energy Procedia

2013 ISES Solar World Congress

Distributed generation in the smart grid – case study of Parintins

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Abstract

This work presents the results of the design phase of project on integration of distributed photovoltaic power generation into the *smart grid* (distribution level) in the city of Parintins, which is an 17 MW isolated diesel grid located in the State of Amazon, Brazil. PV power generation in isolated systems is economically attractive, as fuel cost of 650 R$/MWh are significantly above PV generation cost. Distributed generation may be implemented without occupying valuable land on the fluvial island.

A literature review provides first the general concepts of distributed generation in smart grids. In a brief description the system design, technical data, telecommunication network structure and the smart metering & billing system of the first *smart grid* implemented in Brazil is given. Within this R&D project financed ANEEL (electric power regulatory body) a *smart grid based* performance monitoring and power control for PV systems has been developed. Impacts of distributed power in the LV network have been analyzed through power flow simulation. The smart grid infrastructure will be used to assess the impact of PV generation concentrated on selected feeders and to test smart grid control strategies for distributed generation.

Keywords: smart grid; distributed generation; Parintins; hybrid systems, photovoltaic systems; smart metering.

1. Introduction

Recent studies in technology development in the area of electrical engineering have pointed out the concept of smart grids as a new paradigm for operation of electrical networks, being beneficial to nation economies and offering new business opportunities for utilities [1] [2]. To be prepared for this new paradigm, utilities have to acquire knowledge in integration of various technological fields that make up

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doi:10.1016/j.egypro.2014.10.024

the smart grid concept: information technology, telecommunications engineering, automation and distributed generation.

According to the reference [3], "the smart grid includes the integration of power systems, communications and information technology for an enhanced power system structure that meets the loads while providing continuous development of applications to the end user". This definition indicates an implicit paradigm shift regarding the relationship of power utilities with their clients: Consumers will have a more active participation in the electric system, as the share of distributed generation and storage in the energy matrix will increase. Smart grid will also tecnically support the progressive incorporation of more renewable energy through micro generation (installed power ≤ 100 kWp), as well as larger renewable power plants.

It is noteworthy that recently ANEEL (National Agency of Electric Power) regulated net-metering for consumers considering micro generation and distributed mini generation (101 ≤ installed power < 1000 kWp), through its normative resolution 482/2012 [4]. So, the paradigm of exclusively generating large amounts of concentrated power through large power companies is about to change in Brazil and utilities will need to understand and adapt to this new framework.

As one of its strategic goals the power company Centrais Elétricas Brasileiras S.A - Eletrobras determined [5] that it's R&D investment will be increased to assure and extend its competitive advantages in the ever more strained power market. Among the fields of technology pointed out as relevant for the company's future are smart grids, broadband power line communication (PLC) and distributed generation. Given this institutional context, the Eletrobras Power Distribution Companies proposed to ANEEL a research and development (R & D) project including the implementation of a smart grid pilot project in Parintins, state of Amazonas (AM). The proposal includes the installation of smart metering, measurement and control equipment, data and telecommunication network, as well as distributed renewable power generation.

The objective of this paper is to present, briefly, the design of the smart grid in the city of Parintins, focusing on integration of photovoltaic distributed power generation.

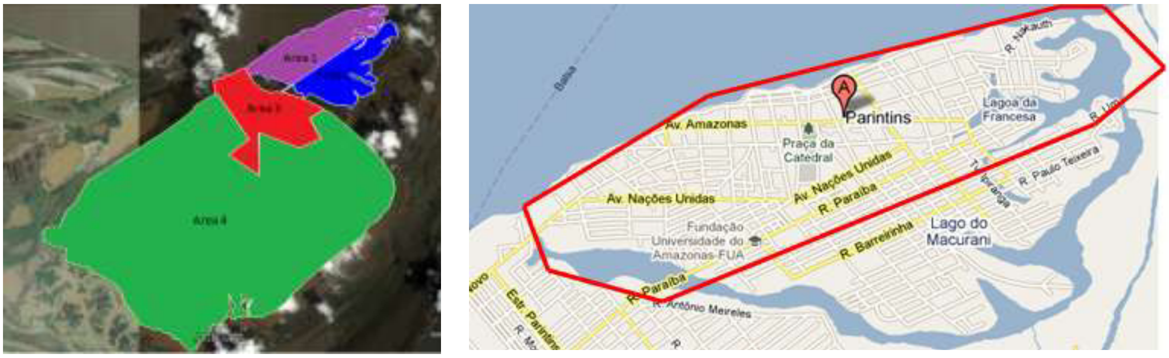
2. Intelligent network in Parintins

The Eletrobras Distribution Companies (EDC) jointly have formed a R&D project, called Parintins Smart Grid Project, aiming to develop a cooperative reference model, based on the development and field testing testing of integrated applications of technologies and methodologies within the concept of smart grid, through a pilot project installed in the city of Parintins [6].

The smart grid represents a leap from the conventional unidirectional analogic grid and distant energy sources to a bidirectional digital network with diversified and distributed energy sources. Bidirectional applies to the flow of information from meters and sensors to distributed control centers and actors through a network telecommunication. It also refers to the power flow in the grid. Furthermore a smart energy consumption meter may send its information to operators and to the consumer himself. This allow a better control of demand, and also provides means to combat commercial losses through remote cut and reconnection of consumers.

Through field testing Project Parintins, the EDCs seek to evaluate which impact smart grids technologies integrated in their technical and commercial operations will have on the power quality indicators and non-technical losses. It will also be the impact of the smart grid on the strengthening of relationship utility-customer will be evaluated; the acceptance and adherence of customer to new technologies and methodologies; the reasonableness of costs, the impact on consumption habits, the integration of various measurement solutions and associated communication technologies. The project will also show eventual technological and regulatory gaps for the adoption of technologies and methodologies associated with concept of smart grids.

The project will be implemented in the urban center of the municipality Parintins-AM, which has about 16.000 customers, 300 distribution transformers, 15 reclosers and 1 voltage regulator installed. The area has been divided into four service areas, marked in purple, blue, red and green (see Figure 1a), where at least two communication technologies [7] will be tested.



(a) (b)

Figure 1 - (a) Indication of the service areas of Parintins (b) Area 1 Project Parintins [7].

Area 1, shown in purple in Figure 1a, was the first area to receive the smart metering systems. The distributed PV generation will also be installed in this area. Consisting of the urban neighbourhoods Francesa, Santa Clara and "Center", area 1 (Figure 1b) has approximately 3.500 low voltage consumers ("group B", mainly residential) and 90 distribution transformers.

The smart grid architecture installed in Area 1 will possess the following components:

- Smart meters, with features for controlling losses, alarm recording, mass storage, cutout relay and radio frequency (RF) communication in order multipoint-to-multipoint (mesh);
- Management of Advanced Metering Infrastructure (AMI);
- Integration of the solution with the Backbone;
- Integration with management systems present in Eletrobras Amazonas Energia (AmE), such as the Management System of Measurement (SGM), the Distribution Management System (SGD) and other legacy systems.

The topology of the communication network, which is characterized by four layers [7]:

- Home Area Network (HAN): composed by internal installations of consumer units.
- Access layer: layer of communication that comes from the end devices (meters, reclosers) coming to a hub / access point. This communication is via radio frequency mesh, frequency of 900 MHz unlicensed.
- Backhaul - Region Area Network (RAN) network with full coverage of the municipal Parintins responsible for channeling communications from access layers. The hub is located in the Backhaul guyed tower in the pre-existing (AmE) substation, in Parintins.
- Backbone (Wide Area Network): Network satellite connection with the measuring center in Manaus city.

2.1. Integration with Systems of Measurement and Operation Centers (SGM and SGD)

The Measurement Management System (SGM) from Senergy [8] is currently installed in Operation Center Measurement in Manaus-AM is MECE and has the following functions: collect the meter data of customers and energy balance; act as interface for operators in the Operations Measurement Center for internal and external customers; generate and maintain a database of measurements, provide information to the other company's operating systems, such as billing, customer relationship, services system management and field teams.

In order to provide a system that communicates with different solutions of data acquisition, the integration of advanced metering infrastructure deployed in Parintins with the SGM will be conducted through an Interface Data Collection, where the data will be formatted for your shipping and receiving in the integration with the SGM.

The Interface Data Collection also supplies the data required for the Distribution Management System (DGS) such as fault/restore of voltage data in the customer's energy meter and energy balance.

Until June of 2013 were installed almost 3500 smart meters, 20 concentrators and the backhaul is being implemented.

3. Distributed generation

Technical issues such as voltage control along the feeder, shutdown operation of parts of the network and disconnection of distributed generation for safe networks maintenance, control over levels of harmonic distortions and imbalances in the network, as well as issues management and communication between different systems and processes of distribution can be solved with the use of Smart Grid.

Network data should both be analyzed from the perspective of generation and load, requiring more complex planning studies that examine the multiple contingencies. Distributed generation increases the importance of planning and operation in relation to availability and dispatch of energy, capacity factor, energy transmission capacity, ability to control voltage and frequency. Generation with intermittent sources such control become more complex due to the variability of the source of energy and therefore the energy generated by asking why the monitoring and control in real time. The real-time information will be used for planning studies of the generation, expansion of networks and substations, load flow analyzes and other dynamic analyzes.

Table 1 summarizes some of the challenges that distributed generation impose to the distributors and how the smart grid can help to overcome them [9]. However, it cannot be forgotten that the investment costs of the smart grid will be high. Therefore, the cost-benefit should always be taken into account in planning and feasibility analysis of implementing intelligence in the network.

Table 1 – Summary of Distributed Generation challenges and solutions with the use of Smart Grid [9]

	Challenge from GD	Solution with Smart Grid
Safety	GD can affect the capacity of work of the protection scheme in optimal conditions.	Leverage monitoring devices low cost remote detection of reverse flow of power, operating conditions outside the normal range and status of GD.
Islanding	Potential for the GD to operate in islanding mode, with the distributor unable to provide secure voltage and appropriate frequency.	Services implementation can provide the trip of the system.
Quality impacts of energy	GD may be detrimental impacts on adjacent consumer units, associated with voltage variation, harmonic distortion and transient disturbances.	Using the capabilities of smart meters to monitor and detect negative impacts of GD.
Infrastructure management	GD can result in overloading of the distribution network conductors, transformers, fuses etc.	Distribution systems management (DMS) provide an alarm intelligent processing and load management applications, allowing the safe operation of a distribution network with GD installed, especially with a large amount GD connected.
Requirements for the operation and planning of the system	Increasing penetration of DG will (especially renewable sources) provides complexity and new issues in the planning and operation of the distribution system.	Tools for service processing for the company allow the distributor to receive, process and act on the increasing levels of data coming from the sensing and monitoring of GD and distribution network as a whole.

3.1. Characteristics of photovoltaic generation project Parintins

The total power of the installed photovoltaic systems will be 120kWp distributed over 40 rooftop systems of 3 kWp each.

The performance of all PV systems will be evaluated automatically through a remote monitoring system, that consists of a weather station with data acquisition system and a database of smart meter readings of each PV system obtained from the smart grid interface in Parintins. A software application will calculate the expected daily generation for each system based on the measured solar radiation and temperature, installed power end orientation of each PV generator. The software compares actual and expected generation and generates an alarm to the service team, in case the PV generation is lower than the defined acceptable limit. The remote monitoring system is illustrated in Figure 2.

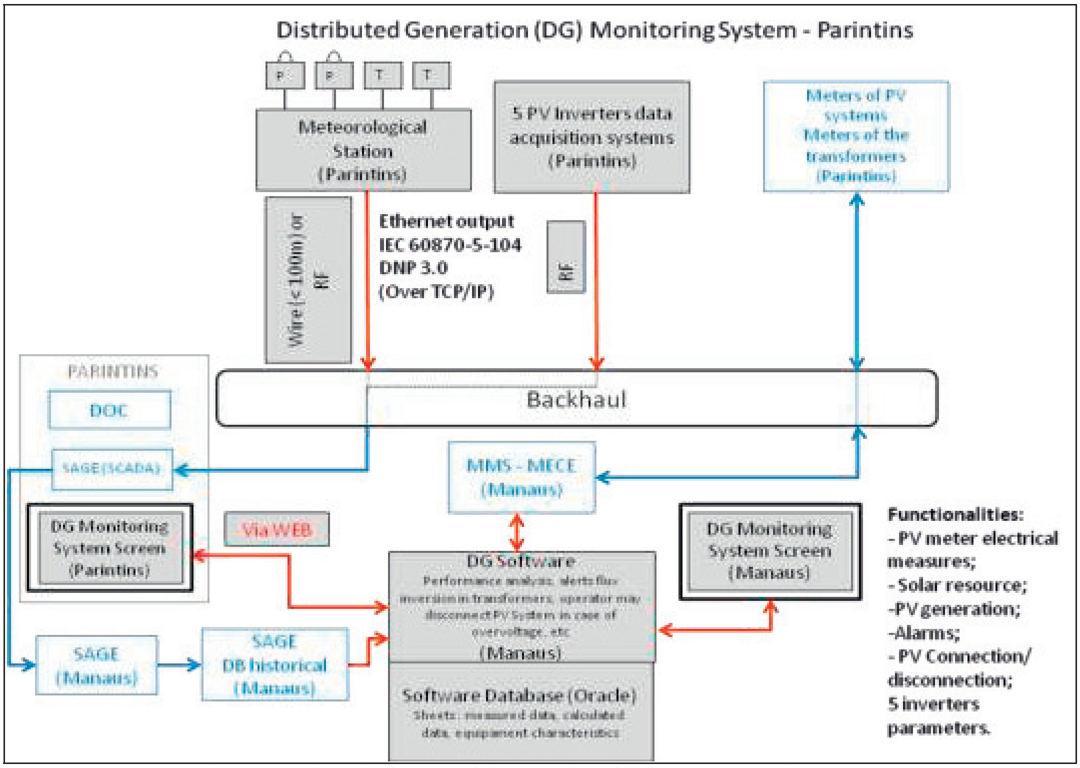


Figure 2 – Schematic diagram of the operation of the remote monitoring system.

Through the smart meters the PV systems will be integrated into the MECE and Operation Center, enabling energy generation billing and remote disconnection by the network system operator.

3.2. Simulations of PV generation on rooftops in Parintins

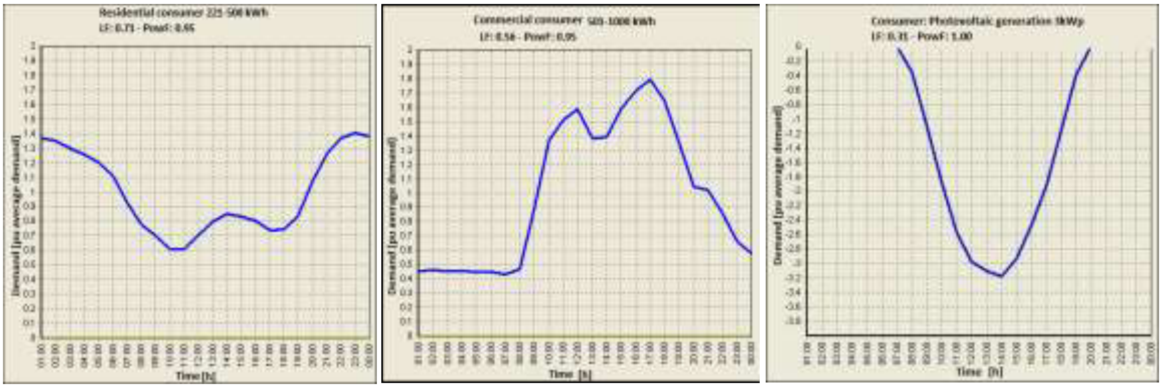
Several simulations were performed using the program PVSyst 5 to estimate PV system performance and energy yield. In a parameter study variation of energy yield and performance has been analysed, changing equipment (modules and inverter models), roof slope and roof orientation. The best orientation found is between -30º and -60º (east direction) for the typical roof slopes. However the difference between the best and worst orientation is only 6%, due to the equatorial location of Parintins. Equipment performance impacts up to 3.5% for modules (all c-Si) and 4.2% for inverters.

3.3 Simulation of impacts on the distribution network

The installation of PV systems and making use of the net metering option (ANEEL Resolution 482/2012) currently is accessible only for a small share of Brazilian consumers due to the high investment of around R$ 8 to 10.000/kWp for small systems. This will limit the uptake of distributed photovoltaic micro generation to middle or upper class consumers and the related urban quarters.

In order to assess impacts of distributed PV generation on the distribution network, load flow simulations of several feeders have been performed. The software Interplan (developed by the company Daimon) has been chosen by the team of Eletrobras-Cepel as it is already used by Eletrobras Amazonas Energia and a geo referenced model of the electrical network of Parintins was readily available. With power flow simulation in distribution feeders has the parameters of interest like voltage levels, phase unbalance have been analyzed.

Each consumer is done through typical load curves, representing the most relevant residential and commercial customer, available in the program derived from regional data, and the measured historical consumption of the specific consumer. Figures 4a and 4b show examples of load curves for the major classes of consumers. These typical curves are parameterized by the monthly consumption of each UC ("per unit average demand"), available in the database.



(a) (b) (c)

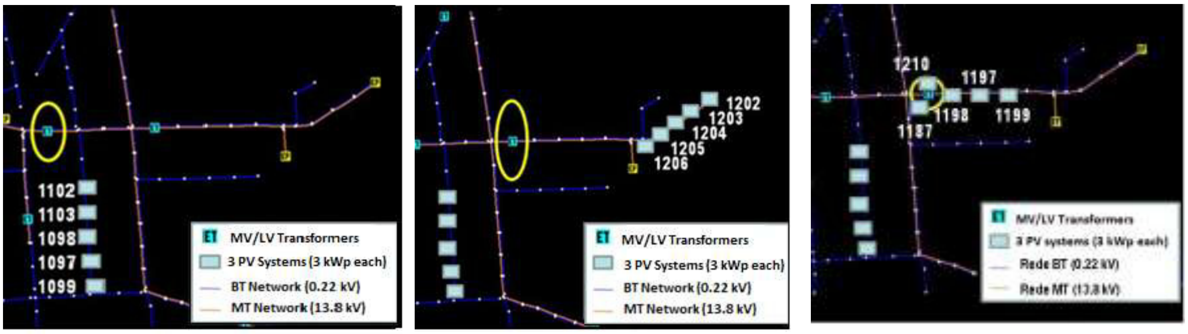
Figure 3 – Examples of load curves for (a) residential and (b) commercial customers and (c) photovoltaic generation.

To allow modeling of distributed generation, so the software provider kindly added the option of negative load curves, which can be superimposed on the demand curves of single consumers, thus allowing simulation of distributed generation at consumer level. The negative load curve used (Figure 3c) corresponds to the critical case, i.e. the maximum generation based on the best day (August/21) in the annual photovoltaic generation hour-by-hour simulated for a solar PV system of 3kWp. For the purpose of simplification, the curves of photovoltaic generation comprise only active power. This is realistic as single phase inverters (<10kW) generally operate with a power factor close to one.

Figure 4 indicates the load situation of 45 kVA transformers chosen for the first simulation (simulation 1 – Fig. 4a and simulation 2 - Fig.4b). The maximum demands are close to 50% of the transformer capacity. Each white dot in the diagram represents a connection point ("bus bar") to the low voltage network, to which one or more consumers can be connected. Simulations were made by inserting three 3kWp PV systems each connected to two phases (to obtain the standard inverter voltage of 220V from the 127/220V system) in order to avoid unbalanced PV generation. Figure 4 shows were the PV systems are connected to the bus bars (rectangle symbols).

3.3.1. Results of Simulation 1

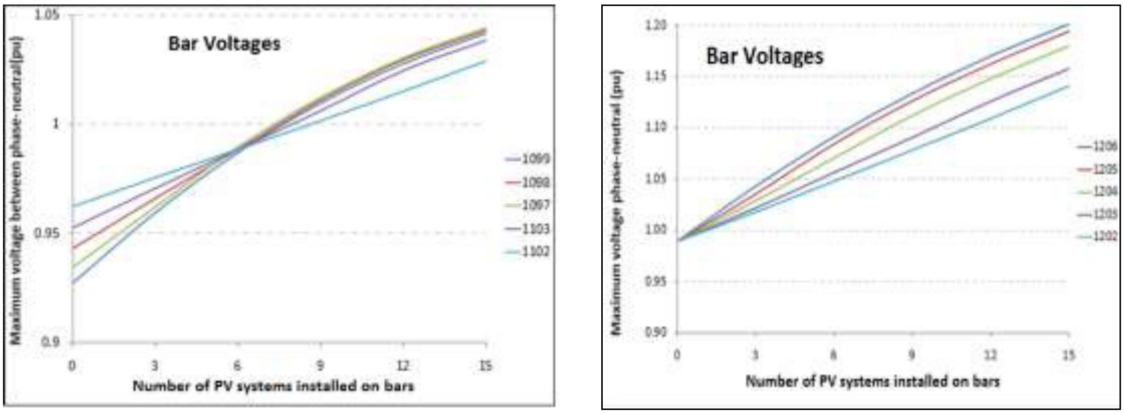
The transformer of Figure 4a, indicated by the yellow ellipse, called X, feeds 48 consumers, 4 of them being commercial and the rest residential. The transformer X feeds 15 bus bars.



(a) (b) (c)

Figure 4 - Schematic diagram of (a) the first simulation, (b) the second simulation and (c) the third simulation.

The five bus bars chosen (1099, 1097, 1098, 1103 and 1102) are among the 9 bus bars that are connected the transformer X, those with the lowest voltage profile (about 0.94 PU in steady state), as shown by the graphs of Figure 5a. It is observed that the insertion of PV systems increases the voltage profile of the bus bar, but bus bar voltages still are maintained within the proper operating range (the curves represent the highest voltage between phase and neutral resulting from each of the six flow simulations of three-phase power system: no PV system, 3, 6, 9, 12 and 15 PV systems.



(a) (b)

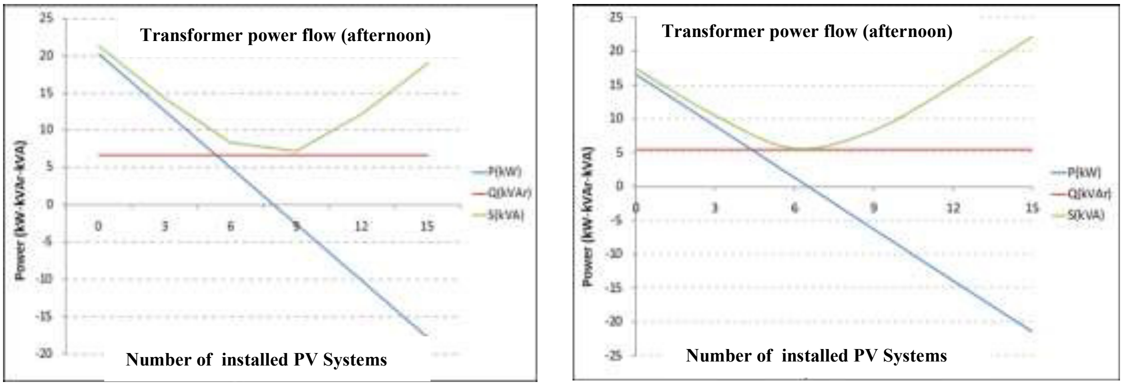
Figure 5 - PU voltage profiles for each of the buses shown in Figure 4, with the inclusion of 0, 3, 6, 9, 12 and 15 PV systems for the afternoon periods: (a) Simulation 1 and (b) Simulation 2.

Figure 6 presents the results of the power flow. Figure 6a shows that 9 PV systems could meet the load of 48 consumers connected to the transformer and X still would export active power to the high voltage grid. Since no reactive power generation from the PV systems has been considered, no change in the reactive and apparent power flow at the transformer is observed.

Distribution losses reduce as solar power supplies the load, however, when the system starts exporting surplus energy, there is a trend of increasing losses (Figure 6a).

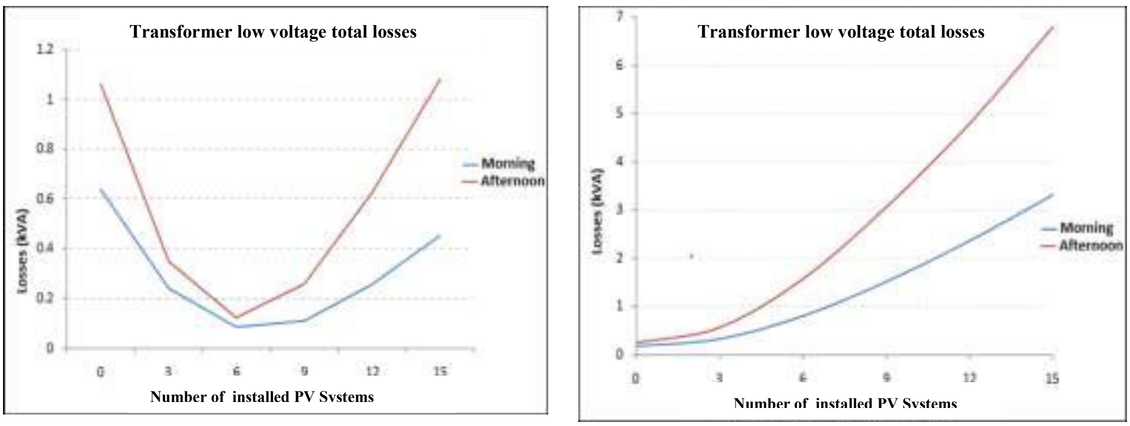
3.3.2. Simulation Results 2

In simulation 2, 15 PV systems were inserted in the first simulation, whereas in the second simulation 15 PV systems were inserted in sets of three at each bus bar point and fed by the transformer Y (see Figure 4b yellow ellipse). The results of this simulation are different in relation to the voltage profile. The five bus bars close to the transformer Y are also those with low voltage profile but had voltages close to 1.0 PU, as can be seen in Figure 5b. It is found that the voltages in virtually every bus bar rise. In certain situations the operational limit of 1.1 PU is surpassed slightly.



(a) (b)

Figure 6 - Power Flows: (a) the transformer X - Simulation 1 (b) the transformer Y - simulation 2.



(a) (b)

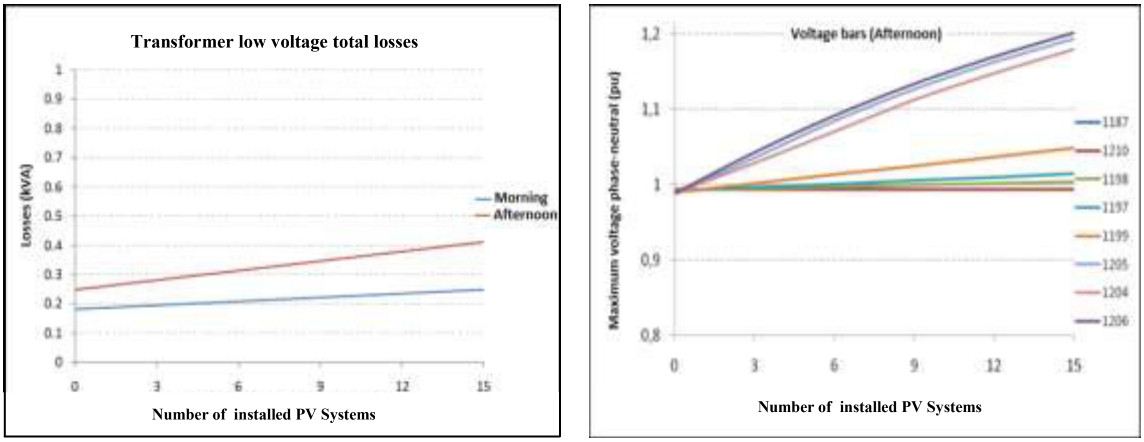
Figure 7 - Total losses (kVA) in BT's network (a) transformers X - simulation 1 and (b) transformer Y - simulation 2.

Figure 6b shows the graphs of the results with power flows in the transformer Y, which are similar to the results obtained in the first simulation, but with less need for photovoltaic generation for reverse flow. The graph in Figure 7b draws attention to the loss of the secondary of the transformer Y reaching about 7 kVA in the afternoon.

3.3.3. Simulation Results 3

In simulation 3, the PV systems were connected to the bus bars which are closest to the transformer Y, as shown in Figure 4c. The distribution loss in this configuration are shown in Figure 8a, while the voltages at the connection points of the PV systems shown in Figure 8b. Through this positioning of PV systems losses decreased considerably compared to the situation in simulation 2: the closer distributed generation is located to the transformer, the smaller the losses are.

Figure 8b shows that voltages at the 5 bus bar points where the PV systems are connected (1187, 1197, 1198, 1199 and 1210) are all within the limits set by the regulator. However voltages at 3 bus bar points at the end of the low voltage line (1204, 1205 and 1206) are critical even without a single PV system connected. In the case of a connection of 9 PV systems voltage levels exceed 1.1 PU. In the case of 15 PV systems installed near to the transformer voltage reaches even 1.2 PU. The effect is observed also in simulation 2 (different position of PV systems). One can conclude that only a relatively small number of PV systems can be connected to the considered transformer, without requiring an adaptation of the distribution network.



(a) (b)

Figure 8 - Simulation 3 (a) Total losses (KVA) to the BT network adapter Y, (b) stress profiles in the 5 pu bars PV systems 0 to 15, and in the three bars end extension

The standard load profile of residential and commercial consumers shown in Figure 3 (a) and (b) are quite complementary: residential consumers show consumption peaks during nighttime, while commercial consumption peaks during day. As the pilot project area includes also the commercial center of Parintins, it will be interesting to study the impact on feeders with different consumption profiles.

Adaptions which will be required in the protection of the grid have not been analyzed yet. This will be part of the next step of the study, i.e. when the feeders and location of PV systems will be defined.

4. Conclusion

The factors that currently drive the advent of smart grids [10] are the rapid technological development of telecommunication and IT, a more dynamic development of electric power trading (spot and capacity markets), a more diversified set of actors in conventional generation, transmission and distribution as well as distributed generation. Especially for the integration of intermittent renewable sources to high penetration levels smart grid is expected to provide the means to control the electrical system.

With the approval by ANEEL Normative Resolution No. 482, of April 17, 2012, a framework is created that allows Brazilian consumers to generate power on the distribution level through distributed micro and mini generation using the net metering approach. With distributed PV being economically viable for residential and commercial consumers some parts of the distribution network may change their characteristics significantly over the next years.

The study shows that DG has the potential to reduce losses. However in the case that the installed PV power exceeds significantly the gross loads power flow inverts and the network (or the PV systems) may need to be adapted to keep voltage levels in an acceptable range. The Parintins Pilot project will provide insights on real-life impacts of concentrated PV generation on the LV-grid which is complementary to the desk analysis performed.

The study also shows how the smart grid infrastructure can be used to provide a new service to customers – the performance monitoring of distributed PV generation – and for the grid operation and control of GD.

In dozens of isolated diesel grids in northern Brazil, PV generation is economically viable. In combination with smart grids PV could implemented on the distribution level, but operated centrally in perfect coordination with the requirement of the diesel plant operation.

In this sense the results obtained with this design study and the pilot project of 40 PV systems under implementation are of great importance for ANEEL and the utilities to further develop and revise the regulations and technical standards on distributed generation and smart grids which currently are prepared. It will also be a reference case for the power distribution companies which have to adapt their systems.

Acknowledgements

The authors thank the engineer Mário Filho from the software company Daimon for the adaption of the Interplan program and all its guidance on the use of the software. Especial thanks also to Elaine França Fonseca, Maria Helena Schaedler and Ildefonso Madruga of Eletrobras Distribuição Rondônia, Paulo Maciel, André Couto, Benjamin Cordeiro, Deolinda, Kedson and Roberto of Eletrobras Amazonas Energia and their teams.

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