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Energy Losses Minimization in Smart Microgrid

Minimización de Pérdidas de Energía en Microrredes Inteligentes

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ABSTRACT

In this paper, energy losses minimization in smart microgrids using capacitors banks and energy storage systems. An optimization methodology based on heuristic search is presented. The proposed methodology approach was developed as a management system based on losses control. This management system works centrally in order to improve the voltage profile and to reduce energy losses to its minimum values. The 33-bus test system (modified) was used to evaluate the performance of the proposed method.

Keywords: Energy losses, smart microgrid, heuristic search, optimization.

RESUMEN

En este artículo, se investiga la minimización de pérdidas de energía en las microrredes inteligentes utilizando bancos de condensadores y sistemas de almacenamiento de energía. Una metodología de optimización basada en búsqueda heurística ha sido presentada. El enfoque metodológico propuesto, es concebido como un sistema de gestión del control de pérdidas. Este sistema de gestión, actúa de forma centralizada para mejorar el perfil de tensión y reducir al mínimo las pérdidas de energía. El sistema de prueba de 33-barras (modificado) fue utilizado para evaluar el desempeño del método propuesto.

Palabras clave: Pérdidas de energía, microrred inteligente, búsqueda heurística, optimización.

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Introduction

Traditional schemes of generation, transmission and distribution of electric energy still not fit correctly to nowadays necessities and behavior of the market, because today's networks were designed and constructed in order to achieve necessities of last century. Thus, there is an urgent necessity of introduce new research fields of electric engineering that include new technological concepts, such as microgrids (Lasseter and Paigi, 2004) and smart grids (Díaz, and Hernández, 2011), in order to decentralize decisions, to automatize facilities, to systematize and continuous monitoring of networks and installed equipment (Wakefield, 2011).

In the electric networks of the future, information availability and new technologies of communication will allow a better management of the existing resources. In consequence, new infrastructure will allow control and monitoring not only of energy generation systems but final users that consume such energy, increasing the energy efficiency (El-hawary, 2014). Additionally, simulation tools of a dynamic system, such as a smart grid, will allow us to validate new concepts and approaches of resources optimization.

Due to the scenarios described before, an important modernization of electric networks has been developed recently. This modernization implies a more complex operation of the distribution network, because such network is not longer consider as a radiated one where electric power flow starts on the head of the system and ends at the end of the feeder. On the other hand, modern distribution networks show a different behavior, because micro generators (small hydropower units, photovoltaic systems, small wind farms and other removable energies) located all around the distributed system connect and disconnect without any kind of control by the network operator (Pathirikkat et al. 2014).

Microgenerator connection and disconnection and their variability and location on the lowest hierarchical scheme generates new technical and regulatory problems such as power and energy losses minimization or improving voltage level of the network. This issues are the challenges of the scientific community for the future. Thus, optimal defining and location of microgenerators to be installed, as well as optimal specification of size and location of capacitive banks, location of voltage regulator and sizing of ener-

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gy storage systems in modern distribution networks will be the problems to be solve.

This paper gives an approach of discussions that nowadays are present about smart girds in the frame of micro grids concepts. The main focus of the work are the new challenges imposed by this novel concept of power losses minimization methods and improvement of voltage levels in distributed systems.

Electric networks evolution

At the beginning, the electric systems were based on the generation of continuous current close to the consumption site. Then, due to the increase of demand caused by demographic issues, the system became in a centralized one, because the generation facilities were located in the geographic center of consumption, while the users of the service of electric energy were growing up around this place. (Amann, 2013).

Over time, electric generation was established as it is known today, that is to say, based on alternating current, that allows to take the current from the generation center to any place far away. In this structure, planning, management, coordination and operation of electric network is establish as a centralized one.

In a centralized energy system, it can be observed five basic components, such as: (a) generation plants, (b) reducing or elevating voltage transformers stations, (c) high voltage transmission lines, (d) medium and low voltage distribution lines, and (e) control centers where the network is managed, coordinated and operated. This components, are interconnected and allow to transport energy form the generation center to the final consumers.

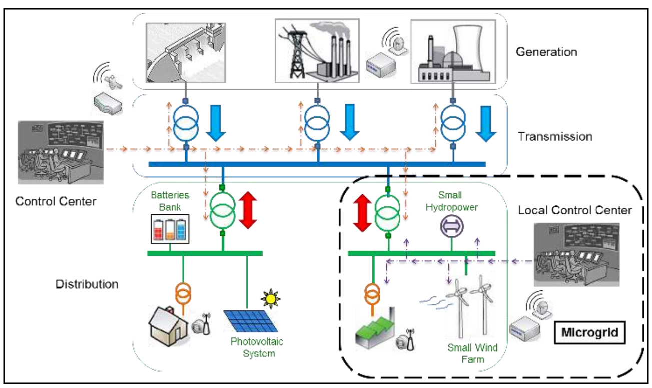

Figure 1. Electric supply system of the future

In the 70s oil crisis, climate change and high rate of demand of electric energy around the world, generated the necessity of alternative technologies to on one hand ensure and on the other hand to save and use efficiently natural resources. One of this alternatives is to generate the energy as close as possible to the consumption place (Peças et al, 2007). This kind of system is known as distributed generation.

In the last years, an alternative solution to obtain a better utilization of distributed resources is to conceive the set of microgenerators and the loads as a subsystem or microgrid (Qiang et al, 2012).

During last years, en alternative solution to obtain a better utilization of generation distributed resources is to observe all the microgenerator set and its loads as a subsystem or migrogrid (Qiang et al, 2012). This solution could be complemented with a new concept of electric networks I which two issues converges: (a) the electric power flow and (b) the information flow. This new thought of electric networks, named smart grid (Fig. 1), tries to find that electricity and information flow together in real time, allowing a better and more efficient management of the power systems, energy distributed sources and microgrids (Zeng et al, 2013).

Smart microgrids characterization

Energy losses control study is important to know characteristics and behavior of electric components that compound an electric smart microgrid. The following characterization and models are carried out in fundamental frequency.

Electric loads models

In this work, the electric loads are characterized and modeled as the complex power consumed by a specific bus.

$$S_k^{load} = P_k^{load} + jQ_k^{load} \quad (1)$$

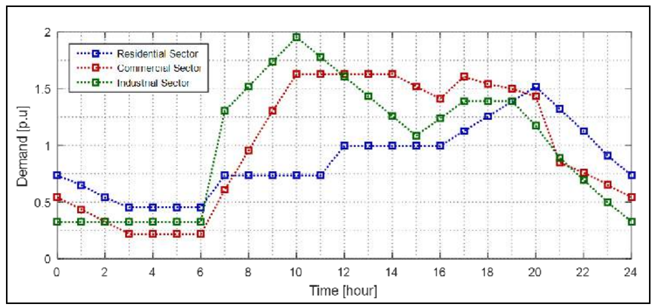

Figure 2. Electric energy consumption (dairy demand).

Fig. 2 shows the typical consumption of electric energy for residential, commercial and industrial sectors in a 24 hour period.

Distributed generation models

A distributed generator (renewable energy source) can be represented, in a basic model, as an ideal voltage source. Such source behaves as a generator that injects active or reactive power with a specific value.

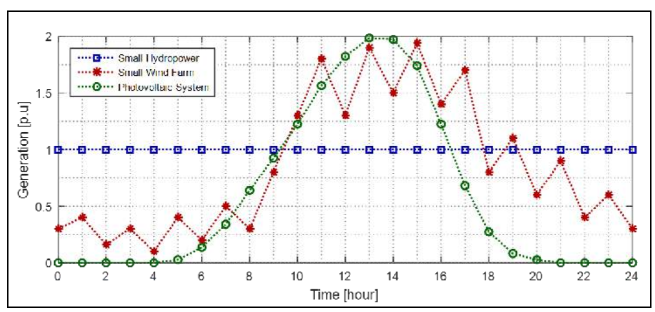

Figure 3. Electric energy injection (dairy generation).

Fig. 3 shows the curves of electric energy injection for each distributed generator in a 24 hour period.

Active and reactive power generated exclusively depends on the kind of distributed generation to be modeled, it means,

small hydropower inject active and reactive power,

$$S_k^{SHP} = P_k^{SHP} + jQ_k^{SHP} \quad (2)$$

small wind farm inject active power and consume reactive pow-

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er,

$$S_k^{SWF} = P_k^{SWF} - jQ_k^{SWF} \quad (3)$$

and photovoltaic system inject only active power,

$$S_k^{PVS} = P_k^{PVS} \quad (4)$$

Energy storage system models

With the aim of using renewable energy in the best way without any kind of problems related with variability, energy intermittence or electric grid instability, the storage system must be designed and constructed as a robust system that allows to local power system interact with renewable energy sources of different characteristics. Storage system implemented in this study has been represented as an ideal battery. Such battery only injects or consume active power, it means, the energy storage system is a constant power model.

$$S_k^{BAT} = \pm P_k^{BAT}; \quad (+):\text{observed}; \; (-):\text{delivered} \quad (5)$$

Energy losses reduction

Location of capacitive banks, voltage regulators and network reconfiguration are the main methods to reduce losses in distribution systems (Aman et al, 2014; Dolli and Jangamshetti, 2012; Ababei and Kavasseri, 2011). Nevertheless, distributed generating units and storage systems also can be used in order to reduce losses (Gopiya et al, 2012; Karanki et al, 2013). The challenges of those technologies are location, size and adequate operating strategies. Even if location is fixed, an incorrect size can increase losses in microgrids.

Proposed methodology

The goal is to find the optimal location of capacitors banks and batteries banks inside the smart microgrid, in order to minimize active power losses and improve voltage profile.

Problem definition: It is necessary to know the effectiveness of the capacitors banks and batteries banks as compensative elements, as well as their behavior when they are interacting with other elements of the system. The problem is established as an optimization case with discrete and non-lineal characteristics.

It is necessary to minimize the objective function:

$$P_{loss} = \sum_{j=1}^{N-1} \left(I_j^{line} \right)^2 R_j^{line} \quad (6)$$

The restriction of power flow equations are

$$U_{\min} \le U \le U_{\max}$$

$$\sum Q_{\text{capacitor}} \le \sum Q_{load} \quad (7)$$

The standard size of the capacitors banks,

$$Q_{\text{capacitor}} = [Q_{C1}; \; Q_{C2}; \; Q_{C3} \; ... \; Q_{CN}] \quad (8)$$

and the standard size of the batteries banks,

$$P_{BAT} = [P_{B1}; \; P_{B2}; \; P_{B3} \cdots P_{BM}] \quad (9)$$

Heuristic search based algorithm: The correct way to select optimally the size of capacitors banks and batteries banks to be placed in any of the buses of the microgrid, consist in check each one of the possibilities and take the one with the lower level of losses. For this reason, the method consist on evaluating the configurations that are created by unitary changes developed in previously defined configurations. This process establish an organized search of the optimal, following the rule "first the best". The pseudo-code of the algorithm based on a heuristic search is described as follow:

Step 1 - to define a base configuration. Generally, this base configuration is chosen as the option when capacitors banks and batteries banks are unconnected.

Step 2 - to develop a local search. In this step, configurations that has only one change respect to the base configuration must be validated and the objective function must be calculated as many times as possibilities of unitary combinations classifying the configurations from the best to the worst.

Step 3 - to carry out a global search. In order to do this step, it is necessary to take some decisions that allow organize the search with the aim of improve the objective function using the results obtained from the local search as follow: (a) In depth *"Selecting the best change obtained in the local search, establishing the taken decision and repeating the process"* and (b) In width *"Taking the established decision in depth, taking the opposite decision and establishing now this one in order to keep searching the optimal depth"*

Set 4 - to define truncating criteria, which must reduce the searching space without affecting the algorithm capacity to find the optimal.

Among the most important characteristics of the algorithm can be remarked: (a) The algorithm always works better when the depth search is carried out, (b) in most of the cases there are a reduction of the options to find an optimal when a width search is carried out and (c) the search can be represented in a tree form.

Test system

The proposed methodology has been applied to a radial distribution system with variable conditions of load and generation. This test system is a modification of the 33-bus radial distribution system presented by (Kashem et al, 2000), where a small hydropower of 1,6 MW/0,9 MVAr in the bus # 3, a small wind farm of 1,5 MW/-0,7 MVAr in the bus # 9 and a photovoltaic system of 1,2 MW in the bus # 27 have been included. Single-line diagram and electric data of the smart mirogrid are shown in Fig. 4 and Table 1 respectively.

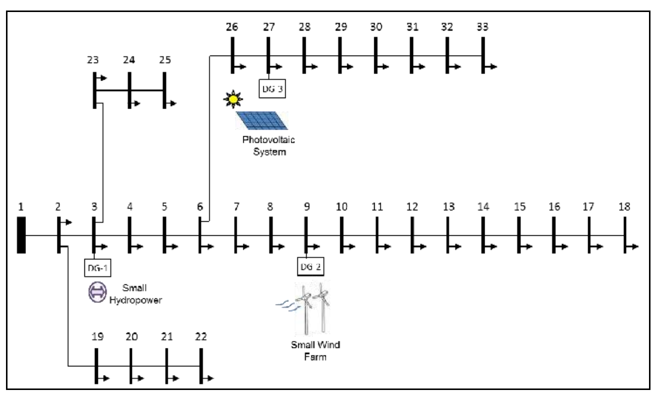

Figure 4. Single-line diagram for 33-bus smart microgrid

Table 1. Data for 33-bus smart microgrid

BUS	LINE	LOAD IN BUS - K

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J – K	R (ohm)	X (ohm)	Load Type	P (MW)	Q (MVAr)
1-2	0,0922	0,0470	Commercial	0,100	0,060
2-3	0,4930	0,2512	Commercial	0,090	0,040
3-4	0,3661	0,1864	Commercial	0,120	0,080
4-5	0,3811	0,1941	Commercial	0,060	0,030
5-6	0,8190	0,7070	Commercial	0,060	0,020
6-7	0,1872	0,6188	Commercial	0,200	0,100
7-8	0,7115	0,2351	Commercial	0,200	0,100
8-9	1,0299	0,7400	Residential	0,060	0,020
9-10	1,0440	0,7400	Residential	0,060	0,020
10-11	0,1967	0,0651	Residential	0,045	0,030
11-12	0,3744	0,1298	Residential	0,060	0,035
12-13	1,4680	1,1549	Residential	0,060	0,035
13-14	0,5416	0,7129	Residential	0,120	0,080
14-15	0,5909	0,5260	Residential	0,060	0,010
15-16	0,7462	0,5449	Residential	0,060	0,020
16-17	1,2889	1,7210	Residential	0,060	0,020
17-18	0,7320	0,5739	Residential	0,090	0,040
2-19	0,1640	0,1565	Commercial	0,090	0,040
19-20	1,5042	1,3555	Commercial	0,090	0,040
20-21	0,4095	0,4784	Commercial	0,090	0,040
21-22	0,7089	0,9373	Commercial	0,090	0,040
3-23	0,4512	0,3084	Industrial	0,090	0,050
23-24	0,8980	0,7091	Industrial	0,420	0,200
24-25	0,8959	0,7071	Industrial	0,420	0,200
6-26	0,2031	0,1034	Industrial	0,060	0,025
26-27	0,2842	0,1447	Industrial	0,060	0,025
27-28	1,0589	0,9338	Industrial	0,060	0,020
28-29	0,8043	0,7006	Industrial	0,120	0,070
29-30	0,5074	0,2585	Industrial	0,200	0,600
30-31	0,9745	0,9629	Industrial	0,150	0,070
31-32	0,3105	0,3619	Industrial	0,210	0,100
32-33	0,3411	0,5302	Industrial	0,060	0,040

Simulation results

All simulations have been carried out using software developed in Matlab®. The following are the restrictions used in the cases studied in this work. (a) the lower an upper limits of voltage are fixed in 0.95 p.u. and 1.05 p.u., (b) the slack bus is always located at the bus # 1, (c) the base voltage is 13,2 kV and (d) the base power is 100 MWA.

Additionally, in order to test the optimization algorithm propose, some aspects must be defined (a) the 16:00 hour of operation in the production and demand curves are defined as the mean operation condition, (b) the standard size of the capacitors banks are [300; 600; 900] kVAr, (c) the standard size of the batteries banks are [250 500 750 1000] kW, (d) several capacitors banks can be placed and (e) only one batteries bank can be placed.

Table 2 shows the optimized compensation results for the test system. Results includes location and optimal size of the capacitors banks and the batteries bank.

Table 2. Optimized compensation results with heuristic search

BUS	CAPACITOR [kVAr]	BATTERY [kW]
8	600	-
10	900	-
25	300	-
30	900	-
11	-	750

Fig. 5 shows the voltage profile of the 33-bus electric microgrid. It can be observed the results for the base configuration (uncompensated) and the case when the compensative equipment are located, connected and optimally dimensioned (compensated).

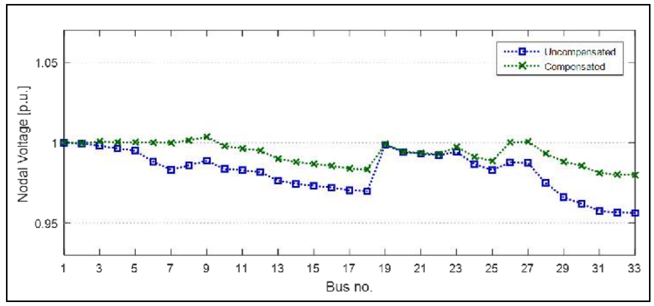

Figure 5. Comparison of voltage profile for 33-bus smart microgrid

Table 3 shows the load flow results of the 33-bus smart microgrid before and after the optimal compensation. It can be observed that a reduction of 74,2% for active power losses and 72,8% for reactive power losses when 4 capacitive banks and one storage system are installed.

Table 3. Load flow results of 33-bus smart microgrid

CASE	NODAL VOLTAGE				LOSSE POWER	
	Max.		Min.			
	Bus	p.u.	Bus	p.u.	kW	kVAr
Uncompensated	1	1,0000	33	0.9562	214,40	153,11
Compensated	3	1,0036	33	0.9799	55,38	41,61

After all simulations carried out in this section it can be concluded that the methodology for optimal locating and dimensioning of capacitive banks and storage systems presented is adequate to be implemented in a management system of energy losses control in electric smart microgrids.

Losses Control Management

In general, the voltage and reactive power control management applied to a smart microgrid must be an advanced system running periodically in response to request of the network operator in the control center (Rahimi et al, 2012). This process uses the ability of remote control that compensative equipment have, in order to optimizing the management of the smart microgrid in real time.

For this reason, the control variables in management systems are the control adjusts of the commutable capacitive banks and the storage power or injected by the battery banks.

Automation system integration

For operating and maintenance of electric networks some system monitoring and management tools are necessary. Traditionally, Supervisory, Control and Data Acquisition System (SCADA), Order Management System (OMS) and Distribution Management System (DMS) have been designed to offer this kind of support. Nevertheless, those systems only acquire information in real time up to the distribution feeder heads and are not able to process big volume of data.

On the other hand, during last years it has been a growth of automated substations, automated feeders and Advanced Measurement Infrastructure (AMI). This issues have presented a new approach of centralized control (Keping et al, 2014). All this automated possibilities have deliver adequate sensors, actuators and bidirectional communications between installed equipment and the control center of the smart microgrid under design.

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Proposed management system

Implemented strategy: The implemented strategy look forward reducing power losses in 33-bus electric microgrid, using the heuristic search algorithm automatically. In this case, the computational procedure has been carried out for each level of load and generation in a 24 hours period as a base scale (see Fig. 2 and Fig. 3). The smart management system characteristic implemented is that microgrids studied operate under optimal criteria of minimization of losses and centrally controlled.

Circuital scheme: Losses control management in smart microgrids and distributed optimization are an open field for future research of electric systems. Fig. 6 shows the automated control system implemented. The arrows interconnecting each compensation equipment with the control center represent the adopted communication system. This two ways communication system allows to control each SVC and the storage system.

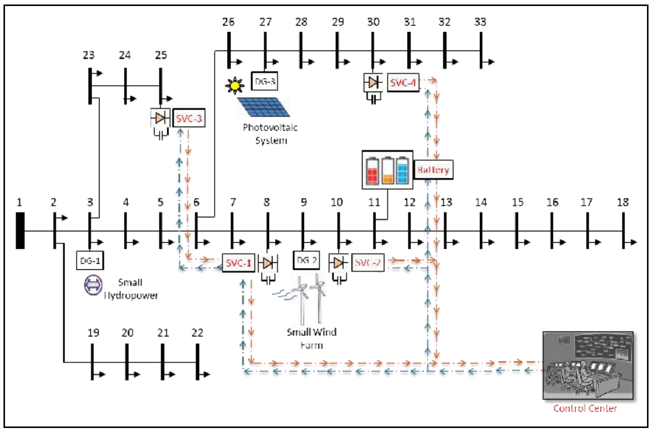

Figure 6. Circuital scheme of the proposed management system

Simulation results

In order to test the proposed management system, it has been assumed that the capacitive banks are replaced by Static VAR Compensators (SVC). These devices commute in steps of 10 kVAr in the Rank of (0 - 900) kVAr.

Moreover, the energy storage system presents three operation options: (a) storage at 750 kW/h, (b) injects at -750kW/h or (c) it disconnected.

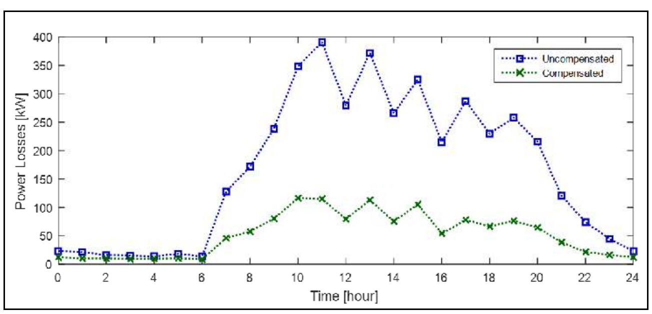

Figure 7. Comparison of power losses for 33-bus smart microgrid

Fig. 7 shows the behavior of the power losses evolution before and after the compensation of the 33-bus Smart microgrid. Here, energy total losses can be calculated in the 24 hours scale of time. In the uncompensated case, this losses are 4,1 MWh/day and in the compensated case 1,3 MWh/day, for a losses total reduction of 68,7%.

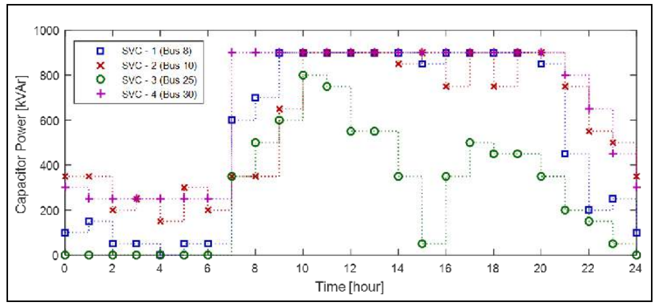

Figure 8. Optimal capacitor power injected

Fig. 8 shows the optimal reactive power injected by each one of the SVC in each hour of the day. It can be observed how few injection of reactive power is presented during valley time in the demand curves and a high injection in peak hours, helping the voltage profile control. On the other hand, the SVC located in the bus # 25 presents a different behavior in relation with the others, even with a disconnected period between 0:00 to 6:00 time.

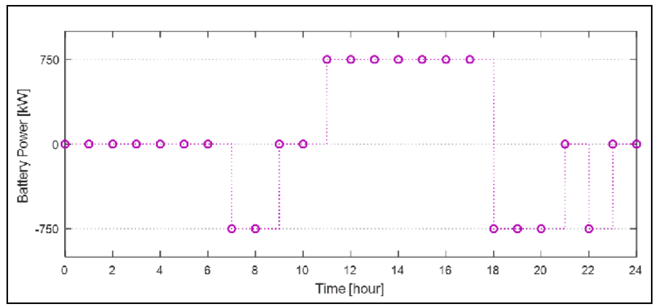

Figure 9. Optimal battery power stored/delivered

Fig. 9 shows the optimal active power stored/delivered by the storage system in each hour of the day. It can be observed that the hours when solar energy or wind energy generates the most, the batteries bank storages and during the hours when the demand requires this energy, it is injected again into the mirogrid.

Consequently, the methodology implemented shows an adequate control of reactive power injected and active power stored/delivered, thus an important reduction of energy losses is obtained.

Conclusion

An optimization algorithm based on a heuristic search for improve the voltage profile and minimize the power losses is presented. The algorithm is adapted for determine le location and sizing of reactive power of capacitive banks (commutable or SVC) and the injection/storage of active power in energy storage systems. The methodology implemented had shown very good results, guaranteeing an efficient and reliable process to be adopted into the nowadays concept of smart microgirds. From the results, it can be remarked the following observations: (a) an optimal location of storage system and capacitive banks for smart microgrids is a very important issue during planning and operation of the future distribution networks and (b) a system of management and control centralized is one of the most desirables and important functions of smart microgrids in order to improve the voltage profile and minimize the energy losses.

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