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# INFLUENCE ANALYSIS OF PHOTOVOLTAIC AND ENERGY STORAGE SYSTEMS IN A DISTRIBUTION SYSTEM IN THE CONTEXT OF PERMANENT REGIME VOLTAGE USING THE OPENDSS

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**Abstract – This paper presents a study of the reverse power flow and the application of battery banks in the network. Five cases were carried out in which the voltage increase was verified in loads that had no PV connected through the system power flow using OpenDSS software . For this, scenarios with different percentages of distribution generation (DG) were simulated. The use of DG improves the voltage stability in the system when it is decentralized in the network, as observed in case 3. In addition, a set of batteries was inserted to present the increase of the average voltage, and the possible problem that may occur from voltage sinking. This is proven by increasing the batteries in the system, increasing the time lag of the voltage drop.**

**To mitigate the sinking problem, energy storage should be allocated to locations where the voltage drop is greatest, as evidenced by the increased voltage level with the use of only one battery in the system.**

**Keywords: Battery, OpenDSS, Photovoltaic Panel, Voltage.**

## 1. Introduction

The growing energy demand coupled with the possibility of reducing conventional fuel supply, along with growing concern about environmental preservation, has driven research and development of alternative energy sources less pollutants, renewables and that produce little environmental impact. Among the alternative sources, electricity from photovoltaic panels (PV) is currently considered to be the most useful source of natural energy, since it is free, abundant, non-polluting, distributed along the Earth and participates as a factor of all other processes of obtaining energy on Earth [1,2].

The system of compensation through PV in the network allows the surplus energy generated by the consumer unit with micro or minigeneration to be injected into the distribution network, which will function as a battery, storing the surplus. When the energy injected into the network is greater than that consumed, the consumer will receive an energy credit (kWh) to be used to lower consumption at another tariff post (for hourly consumers) or in the invoice for subsequent months. The energy credits generated remain valid for 60 months [3].

In Brazil, the body responsible for the production, transmission and commercialization of electricity is ANEEL – National Electric Energy Agency. It also acts as an electric power inspector, so that there are no problems in the electricity grid.

According to ANEEL, in the billing of a consumer unit integral to the electricity compensation system, the following procedures should be observed: at least the amount related to the cost of availability for the consumer should be charged. The consumption to be invoiced, referring to active electricity, is the difference between the energy consumed and the injected, by time, where applicable, and the distributor should use the surplus that has not been compensated in the current billing cycle to consumption measured in subsequent months. If the active energy injected at a given time station is higher than the active energy consumed, the difference should preferably be used for compensation at other time posts within the same billing cycle and should also be used the relationship between energy tariff values, if there is. The amounts of active energy injected that have not been compensated in the consumer unit itself may be used to compensate for the consumption of other units previously registered for this purpose and served by the same distributor, the holder of which is the same as the unit with electricity compensation system, or whose consumer units are brought together by communion of interests in fact or law. Active energy credits generated through the electricity compensation system will expire 36 (thirty-six) months after the billing date. [4]

Photovoltaic systems connected to low voltage in the network can suffer from very high voltage drops when high solar radiation coincides with high load demand times, or overloaded conductors and transformers [5].

Different solutions to mitigate unwanted voltage levels, or sudden fluctuations of the tension, in low voltage residential networks with photovoltaic systems have recently been proposed and tested, including the use of new devices (e.g., switches, load drifting, battery bank) and topological arrangements (such as ring operation). In some countries such as Germany, simpler measures have been proposed to impose limits on generation in order to avoid the problem of previously mentioned voltage levels [6]. All these methodologies are widely used and viable. In this study, we chose to use batteries for correction.

In this sense, this article aims to study the influence of the flow of surplus power in a given system for different cases with the aid of OpenDSS software. In addition, the system behavior will also be analyzed when a battery bank is inserted into a given consumer, identifying its influence on the circuit.

## 2. Methodology

### *A. Software OpenDSS*

OpenDSS is an open source program that operates in the field of frequency and presents special resources to create models of electricity distribution systems and perform analyses related to distribution planning and energy quality. It also has the ability to perform power flow simulations for both a specific time and a time interval. In addition, it is able to model n-phase lines of arbitrary configurations.

This tool was the main tool for analysis of simulations for both the base system and for conditions with distributed generation. This consists of network-connected panels for each of the cases. In a brief way, the main components of the circuit were scaled: the power grid, transmission lines, consumers and transformers. Subsequently, the battery bank was scaled and attached to the customer.

### *B. Electrical System*

The system present in Fig. 1 indicates the base circuit to be simulated in OpenDSS. This represents actual data obtained from [7] and constitute a 30-bus system. In it, the electricity grid is constituted, a transformer with the ratio of 138/13.8 kV at the exit of the substation, and another transformer of 13.8/0.22 kV in consumers, and a set of photovoltaic plates that is not present in the figure, as this is inside the residence.

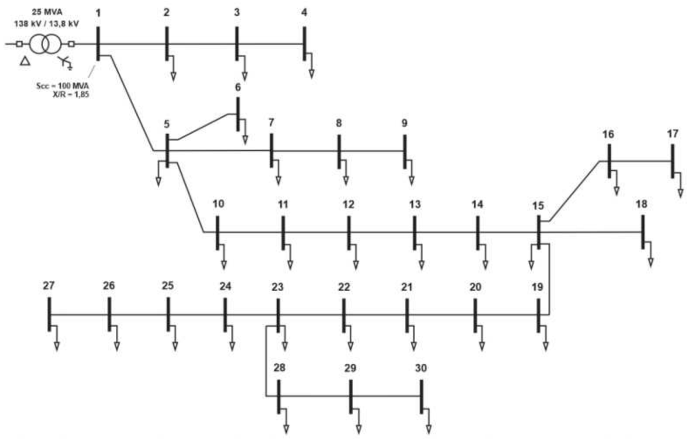


Fig. 1 – Base electrical system.

For the sizing of photovoltaic panels, the demand value of each load was obtained through the active and reactive powers of [7].

To scale the panels using OpenDSS in Time-Series mode, that is, for a certain time interval (for this article a 24-hour period), it was obtained

$$P_{dc(t)} = P_{mpp} * irradiance * irradiance_{(t)} * PTCurve_{temperature(t)} \qquad (1)$$

In what:

- $Pdc_{(t)}$ is the output power generated in direct current.
- Pmpp is the nominal power at the maximum power point at a certain temperature.
- *Irradiance* is the base value of irradiation.
- *Irradiance*$_{(t)}$ is the value of irradiance at a certain time.
- $PTCurvetemperature_{(t)}$ is the temperature curve in degrees Celsius panel as a function of the time.

Since the current power (CC) generated is obtained, alternating current (CA) power is calculated using expression (2).

$$P_{ac} = Pdc_{(t)} * Effcurve_{(Pdc(t))} \qquad (2)$$

Being that:

- $P_{ac}$ is the power at the inlet of the inverter.
- $Effcurve_{(pdc(t))}$ is the efficiency of the inverter for certain value of the active power.

The battery bank was sized considering two charging and unloading situations.

Load situations (Pin[t]) and discharge (Pout[t]) can be observed in Fig. 2.

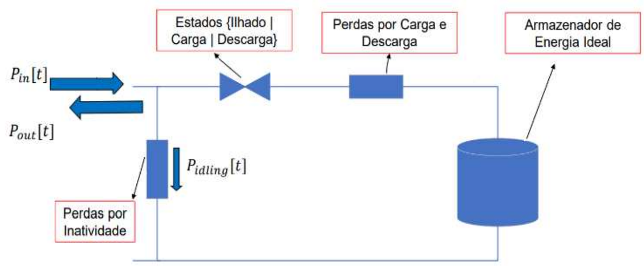


Fig. 2 – Battery storage system scheme. Adapted from [8].

Where $P_{idling[t]}$ are the losses generated by the storer when it is inactive.
Thus, you can calculate the losses of the during loading using the expression (3).

$$Pch_{[t]} = (1 - n_{ch}) * (Pin_{[t]} - Pidling_{[t]}) \quad (3)$$

The battery yield is $n_{ch}$. Losses in the unloading step can be obtained by expression (4).

$$Pdisch_{[t]} = (Pout_{[t]} + Pidling_{[t]}) * \left(\frac{1}{n_{disch}} - 1\right) \quad (4)$$

Once the losses of both loading and unloading are known, total losses are calculated using the equation (5).

$$Ptot_{[t]} = Pin_{[t]}(1 - n_{ch}) + Pidling_{[t]}) * n_{ch} \quad (5)$$

Thus, knowing the losses generated by the battery while charging and unloading, and knowing the value of the power of each charge, considering the efficiency of the charge and discharge of energy is 90%, obtain the total power that the battery banks will have to compensate. Inactivity losses are considered to be 1% of the device's rated power.

### *C. Increased Tension in the Presence of DG*

The installation of distributed generators leads to increased system voltage. This increase, if not controlled, may affect the quality of energy supplied to consumers [9].
In [10] a study was presented in which high energy penetration through large-scale photovoltaic panels improves system stability. Not only that, it was also presented that a dispersed penetration, that is, more distributed among consumers of the network presents greater stability for the system than a punctual incidence (in few consumers). Therefore, for this study, a distribution of DG will be carried out as dispersed as possible [10].

### *D. Reverse Flow*

The installation of PV in the system can decrease the power demand required for the substation. However, at certain times of the day the power provided by the panels is greater than that consumed by the load. When this situation happens, a reverse flow of power will exist at the connection point of the photovoltaic generator with the mains.
The conventional operation of a system without DG is one-way in line, with the power being substation-load. In reverse flow condition active and reactive powers reverse the flow direction following the load-substation direction [11].
In this article, the reverse flow condition will be applied in all simulated cases, aiming to observe the influence of this flow on consumers connected to the network who do not have photovoltaic generation.

### *E. Inserting Battery Bank into Charge*

The use of batteries in power-compensating systems is intended to control the voltage. It is worth noting that this control can be both for increased tension and to decrease it (this, however, is less usual for this application). To perform the control, the battery bank works as follows: while discharged, it acts as a charge being charged (from this arises one of the problems of battery use, the voltage sinking), and once stocked it discharges into the system feeding some particular component on the client.
For an IEEE 123 test system the behavior of medium voltage and losses for different cases with batteries connected to the circuit. As can be seen in Fig. 3, there is a reduction in losses and voltage control by the use of batteries, compared to the system with generation distributed by the use of photovoltaic cells (GDFV), but the use too much of a battery bank to the system (3 SAEBs, 5 SAEBs) causes its yield decays considerably compared to the same system with only one battery bank. You can observe the sinking in the voltage when there is only one battery (1 SAEB) on the network, if compared to the system without battery, but with DG, a situation that will be shown in this article. However, there will be reverse flow due to the excess power generated by the panels, a condition that is not considered in [12].

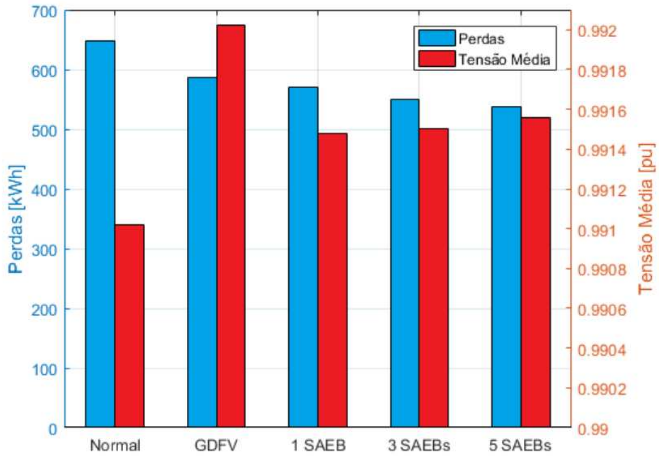


Fig. 3 – Loss and average voltage in a given network during the day [12].

### *F. Cases*

Five cases of analysis were carried out using the Figure 1 system as a reference, which are highlighted below:

- **Case Study 1:** Simulation of the system without DG.
- **Case Study 2:** Simulation with an increase of 30% DG, in which PV was inserted into 9 loads, following the order of buses.
- **Case Study 3:** Simulation with an increase of 60% DG (18 individually connected photovoltaic panels on each bus, in sequence), so that greater stability occurs in the voltage curve of consumers.
- **Case Study 4:** Simulation with an increase of 60% DG (connection similar to case 3), adding a battery bank. The aim of this study is to identify the stress sinking phenomena in the periods in which the battery is in the process of charging, and increased voltage in the period in which the battery is charged and providing energy to the system.
- **Case Study 5:** Simulation with an increase of 60% DG (connection similar to case 3), installing 4 sets of battery bank in different consumers. The purpose

of this case is to prove the decay of the compensation that batteries provide.

For all studies, the tension curve was obtained for two buses: the closest to the substation (bus 2) and another as far away as possible (bus 24). Thus, it becomes possible to perceive the contribution of DG due to the flow of power.
The representative curves of consumption classes for residential consumers were obtained through measurements on weekdays, provided by energy concessionaires, made in tariff review campaigns requested by ANEEL [13]. Residential consumers were classified according to monthly energy consumption (kWh/month). For each consumption class, a mean curve and a standard deviation curve were obtained. These curves are called representative curves of the consumption classes [14].

## 3. Result and Discussion

### *A. Case 1 - Reference*

For the first case, the electrical system without distributed generation was analyzed. Once modeled in the software, the tension curve was obtained for consumers present in buss 2 and 24, as can be seen in Figures 4 and 5, respectively.

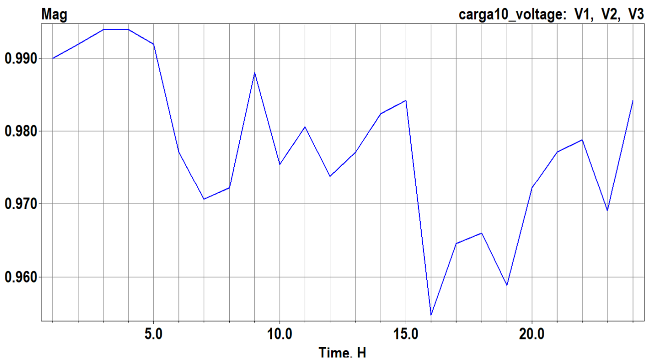

Fig. 4 – Voltage on bus 2 consumer.

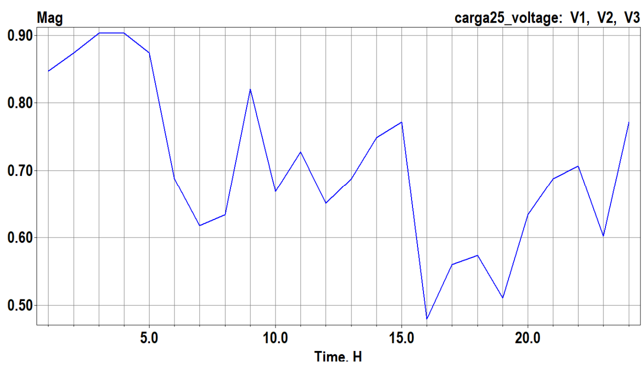

Fig. 5 – Voltage on bus consumer 24.

Low voltage values are perceived for certain moments, especially on bus 24. Such values are due to the great distance that the consumer is from the substation, causing the voltage drop on the line to be high, and in the absence of tap switching on the transformers, makes the voltage smaller in the bus.
You can observe for both bus 2 and bus 24 there are time intervals when the tension in both increases (in the first hours of simulation) or decreases (between 18h and 20h). Such variation will be seen in most simulated cases, this is because for a real load curve, as is the case with this study, these time intervals are the moments when consumers least and most demand energy, respectively.
These curves will be the reference for the comparisons that will be made in the next cases, in which it will be possible to observe improvements and possible problems that may occur.

### B. *Case 2*

The second case now consists of the same system, but with 30% distributed generation. The panels were allocated to consumers present in buss 2,3,4,5,6,7,8,9 and 10.
Once photovoltaic panels were inserted into the code, once again the tensions were obtained in buss 2 and 24, which are present in Figures 6 and 7, respectively.

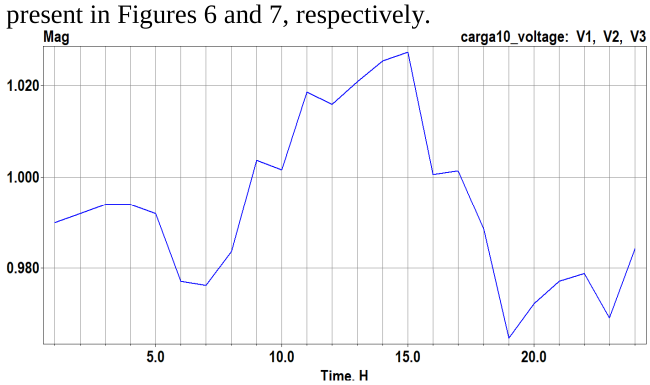

Fig. 6 – Voltage on the consumer of the bus 2 for 30% DG.

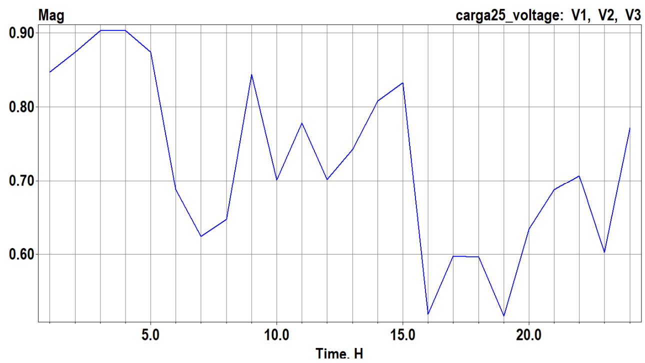

Fig. 7 – Voltage on the consumer of the bus 24 for 30% DG.

Compared with the results of case 1, it turns out that for both buss there was a considerable voltage increase, and in bus 2, in which there is pv connected, the increase in tension was more effective. On bus 24, in which there is no photovoltaic panel, the increase in tension occurs because existing photovoltaic panels provide excess energy, causing the power to be injected into the network, affecting such a bus.

### *C. Case 3*

The third case study consists of increasing the percentage of generation distributed in the network. In this sense, 60% of DG was inserted into the system, and the panels, in addition to those previously allocated in the buses mentioned in the previous study, cells were inserted in buss 11,12,13,14,15,16,17,18 and 24.

Thus, the tensions present in buss 2 and 24 were again obtained and are presented in Figures 8 and 9, respectively.

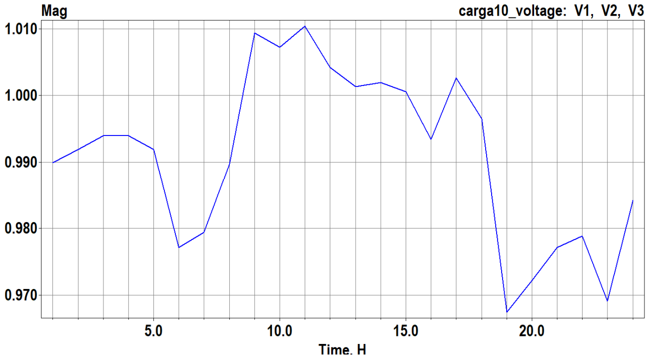


Fig. 8 – Voltage on the consumer of the bus 2 for 60% DG.

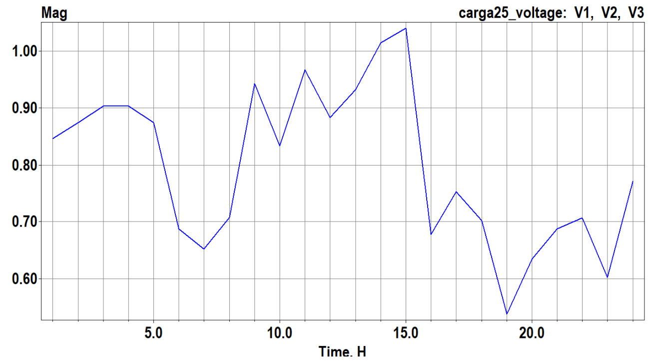


Fig. 9 – Voltage on the consumer of the bus 2 for 60% DG.

In this situation, you now have both buses under PV analysis. With regard to bus 2, which before there was already solar energy, there was no increase in tension like that occurred for the previous study. Because in this case, the electrical system because it is almost full energy compensation becomes more stable. In relation to bus 24, a better level of tension is observed during the day, during which time the panels operate.

It stands out how the behavior of curves in both loads became more stable for the circuit with the highest percentage of DG.

### *D. Case 4*

In this analysis, the system was maintained with 60% DG and a battery bank was added in bus 2 Figures 10 and 11 present the voltage curves referring to buss 2 and 24 respectively.

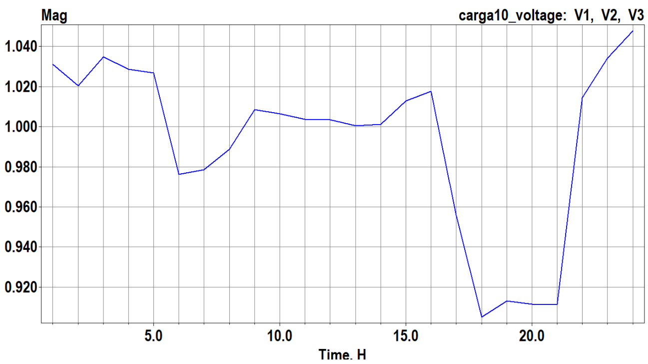


Fig. 10 – Voltage on bus 2 consumer.

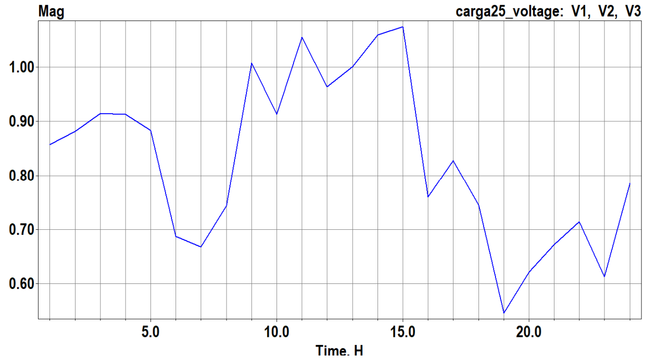


Fig. 11 – Voltage on 24 bus consumer with battery.

With the battery bank, the charge present on bus 2, during its operating period, caused a considerable increase in voltage, reaching an increase of almost 5%. However, in the time interval in which the battery bank was in the process of charging, there was a voltage sinking, as can be seen between 18h and 21h fig. 10, causing a reduction of almost 5% compared to the previous case. In bus 24, in turn, as expected, in the moments when the battery did not act, nothing occurred with the curve, see Fig. 11. However, when the battery provides power, part of that power is sent back to the system, causing an increase in voltage even in consumers that the battery was not connected.

### *E. Case 5*

This last study is similar to the previous one. However, battery sets have been connected to different consumers. Figures 12 and 13 present the characteristics of the tension curves in buss 2 and 24, respectively.

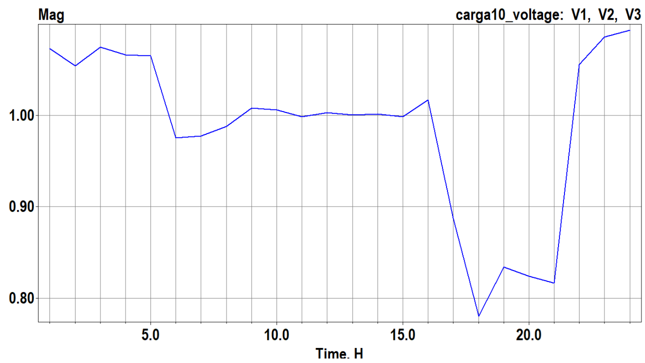


Fig. 12 – Voltage on bus 2 consumer with 4 batteries.

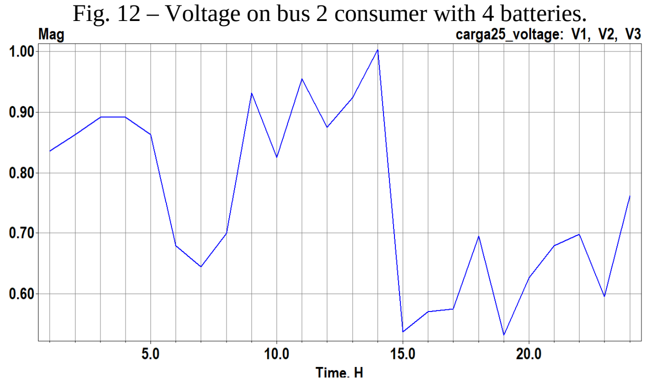


Fig. 13 – Voltage on the 24 bus consumer with 4 batteries.

Compared to the previous case, where there was only one battery, the four-battery set decreased the compensation supplied to the network. The problem of sinking in bus 2 is much more noticeable compared to the previous case, and the increased tension that had occurred becomes unadvantageous for this situation. Bus 24, however, even with a battery bank connected to it, suffered less impact than bus 2. There is an increase in tension in certain moments of time, although there has been longer foundations for this configuration.

In summary, for better analysis of each simulation performed, Table I and Table II present the stress peaks in each of the simulations for buss 2 and 24, respectively.

Table I – Result of each simulation for bus 2

| Case | Maximum voltage [V] | Minimum voltage [V] |
|---|---|---|
| 1 | 0,99 | 0,96 |
| 2 | 1,02 | 0,97 |
| 3 | 1,01 | 0,97 |
| 4 | 1,04 | 0,92 |
| 5 | 1,01 | 0,80 |

Table II – Result of each simulation for bus 24

| Case | Maximum voltage [V] | Minimum voltage [V] |
|---|---|---|
| 1 | 0,90 | 0,50 |
| 2 | 0,90 | 0,53 |
| 3 | 1,05 | 0,53 |
| 4 | 1,00 | 0,60 |
| 5 | 1,00 | 0,60 |

## 4. Conclusion

In this work, a study of reverse power flow and the application of battery banks in the network were presented. Five case studies were conducted in which tension increased strain was proven in loads that there were no photovoltaic panels through the system's power flow. For this, scenarios with different percentages of DG were simulated. The use of DG improves the stability of tension in the system when it is decentralized in the network, as observed in case 3, which consisted of the insertion of 60% of generation distributed in the system.

In other time, a set of batteries was inserted to present increased average voltage, and the possible problem that may occur from voltage sinking. This situation is seen in the case of simulation 4 in which there was overvoltage in bus 2 and at the same time there was improvement in the voltage level of the bus 24.

Moreover, there was a drop in compensation provided by the battery bank with the increase in it in the network, with tension sinking on bus 2, as noted in the case study 5.

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