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SIMULATION OF VOLTAGE STABILITY IN IEEE 14 BUS SYSTEM WITH THE INSERTION OF DISTRIBUTED PHOTOVOLTAIC GENERATION

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Abstract. *Our country has a large share of renewable sources in its energy grid, the majority coming from hydroelectric plants. This huge amount of energy requires long lines of transmission to travel a considerable distance until reaching the consumer centers. All this complexity in the transmission, due to the increasing demand, may contribute to stress-stability disorders. Faced with this fact, distributed photovoltaic generations emerge with the alternative of approaching between the consumer centers and the generation sources, besides being an alternative considered renewable and non-emitting pollutants directly. Photovoltaic generation, due to being a source from the sun, stands out among the other methods of generations distributed from renewable sources for having an abundant plant availability, needing only sunlight. Therefore, it is significant that, when possible, studies aimed at locating the installation of photovoltaic generations should be done in order to favor distribution systems, reducing forms of hindrance that undermine the voltage stability. With this study, this paper will demonstrate, through a simulation using the ANAREDE® software developed by CEPEL, how a 14-bus System with photovoltaic systems installed in different buses behaves in relation to voltage levels. Through the obtained results it was verified in which site a photovoltaic equivalent generation would increase the maximum load of power of the system and would significantly improve its voltage levels.*

Keywords: *Renewable sources, Energy grid, hydroelectric Power Plants, consumer centers, voltage stability, photovoltaic generation.*

1. INTRODUCTION

Just like water, electricity has become a necessity for humanity, and its access is synonymous with development, making it one of the greatest global challenges to bring electricity to those who do not yet have access. But all this infrastructure affects the environment in many ways (Reis, 2014).

The estimate is that the net generation of world electricity, reach 39 trillion Kwh in 2040, and in 2010 we had a generation of 20.200.000 Kwh. But much of the raw material used to produce this energy is limited, and causes great environmental consequences, causing government policies to support the implementation of renewable energy sources to be stimulated (Moreira, 2017).

In Brazil, renewable energies make up a large portion of its energy matrix, 42.9% according to the National Energy Balance (2022). However, much of the energy production is far from the consumer centers, requiring long transmission lines to make this connection. This long path traveled by energy to the consumer, may come to collaborate with problems aimed at voltage stability (Magalhães, 2010).

Thus, photovoltaic energy emerges as a source that is growing annually, and with a great variability of installation because of its generation coming from sunlight. The present work seeks to demonstrate through simulations, in which region of the proposed distribution network model, the installation of an equivalent photovoltaic generator would benefit the system the most, with a view to the maximum use of this energy source.

2. DEVELOPMENT

2.1 Voltage instability

Voltage instability has been gaining more attention in recent decades due to the increasing complexity of power systems. With increasing demands, and power sources becoming scarcer, systems begin to operate at their capacity limits, requiring studies that can determine the charging limit of the system, before a voltage collapse occurs (Ismail, 2002).

According to Alves (2016), voltage instability begins through several factors, which depend on "the configuration of the system, the mode of operation and, mainly, the type of disturbance."

On the other hand, voltage stability is the result of the system's ability to maintain or restore its balance, and according to Barata (2017), it can be influenced by the "characteristic of the load, by the equipment associated with voltage control, by the automatic control of generation and by the protection system."

Disturbances with voltage stability are often found in highly charged systems Kundur (1994), since loads are primarily responsible for problems with stability (Barata, 2017).

According to Alves (2016), instability has as a characteristic the reduction of voltage values in one or more buses of a system. It occurs when demand grows excessively, causing the tension to decrease to very low values. If the load has the characteristic of constant power, the current will increase with the decrease of the voltage, resulting in a voltage drop in the buses, further increasing the value of the current, becoming a periodic process that can result in a voltage collapse. This process according to Barata (2017), is presented in cycles of seconds or tens of minutes.

There are two ways to analyze stress stability, by methods of dynamic or static analysis (Reis, 2005; Alves, 2016). The stability analyzed by the dynamic method, is done through nonlinear differential equations, being more complex and deeper and used mainly for studies that require the management of protection controls. It has the advantage of being a simulation very close to the real situation, on the other hand it requires a large amount of data and too much computational requirement (Alves, 2016; Reis, 2005).

Because it is a generation that can be installed at any point of a distribution network, photovoltaic generation can influence voltage stability, and its analysis is ponderable, as it can be favorable to the distribution system if the location of its installation is previously analyzed.

2.2 Voltage Collapse

According to Gómez-Exposito (2011), when a transmission system is not able to meet the necessary demand for the distribution network, the system can collapse, that is, the values of the voltages fall rapidly to levels below the desirable ones.

Certifying the previous paragraph Paiva (2007), states that the voltage collapse is characterized by a succession of events followed by voltage instabilities, causing the system to have sudden drops in voltage in one or a set of buses, which may compromise the fulfillment of the energy demand of a given area, or of the whole system.

To have an estimate of how a system behaves with the increase of load, and if it will collapse, you can use tools such as software that simulate a continuous power flow. Using this technique, it is possible to identify voltage stability disturbances by means of P-V curves and maximum charging points that a system can withstand before collapsing (Gómez-Exposito, 2011).

2.3 P-V Curves

The P-V curves, are curves plotted in the plane (P, V), and depict the variation of the voltage as a function of a continuous increase of active load in a given area or in the whole system, and are commonly used for stress stability analysis (Ismail, 2002; Reis, 2005; Alves, 2016).

Employing the technique of continuous flow, the load can be increased gradually, so that successive continuous flows mount the P-V curve, as shown in Figure 1, up to the limit at which the system reaches its maximum load, this point is important for the operator to evaluate the point of disturbance of the system (Magalhães, 2010).
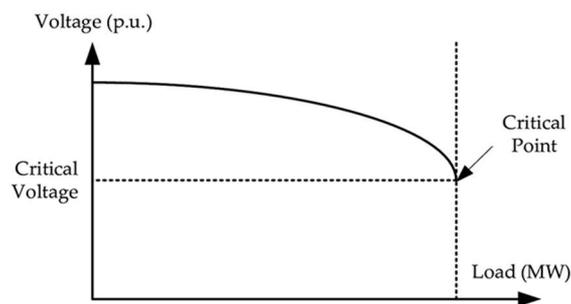

Figure 1. – P-V curve.

As can be seen in Figure 1, when reaching the maximum power (P max.), Reis (2005) mentions that "only a voltage value will be able to satisfy the equation of the curve", that is, if more power is added, the whole system will suffer a voltage collapse.

The P-V curve can be divided into two functional points. Point A located at the top of the curve is more stable, while point B located at the bottom of the curve has an unstable functioning (Alves, 2016; Reis, 2005).

The P-V curves will be used for the simulation that this paper aims to perform, thus analyzing the stability of the system against the penetration of energy through equivalent photovoltaic generators.

2.4 Importance of location for distributed generation in distribution systems

As already mentioned in item 2.1, photovoltaic generation has the advantage of being able to be installed very close to the load, provided that the solar conditions meet the requirements for adequate generation. In this way it is of great importance that its installation is in the place that can benefit the system in the most efficient way possible, as described in (Haiyan, 2006), where the stability of static voltage was analyzed in different scenarios with installation of distributed generation in the system, showing that the installation of distributed generation can be a beneficial factor for the stability of voltage in a distribution system.

In (U. E. Uzun, 2022), a simulation was performed in the IEEE 30-bar system, using as a method the photovoltaic insertion in the bus with lower voltage magnitude, thus determining the weakest bus. Through this method, it was observed that the penetration of photovoltaic energy in the weaker buses, contributes to the increase of the voltage stability of the system.

There is no correct and generic way to decide where the installation of distributed generation would be most beneficial, only thorough studies of the system and the loads inserted in it can help to make a more appropriate decision. As shown in (R. Liu, 2022), which as in this article, used the IEEE 14-Bar System, simulating a photovoltaic penetration of 10% to 50%, based on the total active power of the bars used for photovoltaic penetration. Scenarios were analyzed with the generation being centralized and distributed, showing that the generation of distributed photovoltaic energy contributes in a better way to the voltage stability in this system.

3. SIMULATION

For the simulation that will be performed, a tool will be used to demonstrate the continuous power flow, from the ANAREDE® (Analysis of Electrical Networks) software. This tool employs the Newton-Raphson method, continuously calculating the power flow of the system as more load is added, being possible to verify at the end of the interactions, the maximum point of stability of the system.

The ANAREDE® software has in its library different models for simulation of distribution networks. For this simulation, the 14-bus System model will be used, as shown in Figure 2.
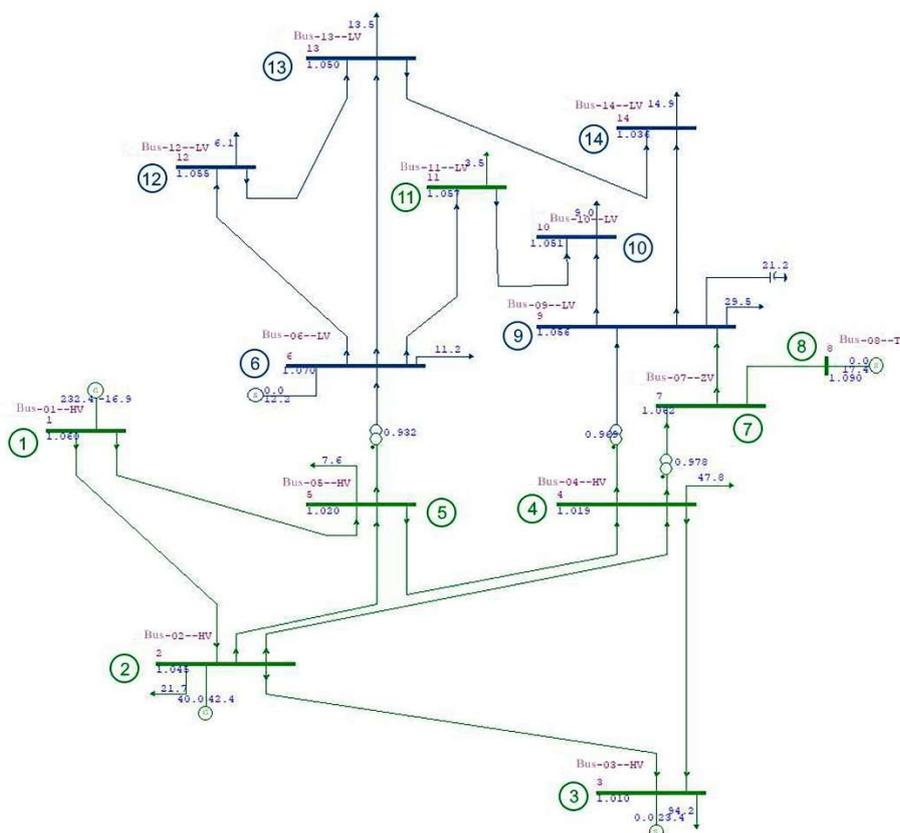

Figure 2. – 14 IEEE bus model.

This 14-bus System, which according to Krauer (2007), is an academic case widely used for simulations, being composed of: a reference bus, bus 01; Four PV buses, (buses that has a generator that regulates the voltage from the terminal to a voltage set point, are they: bus 02 - synchronous generator, bus 03, 06 and 08 - synchronous compensator); Six PQ buses (buses that do not have voltage control devices); Twenty branches (seventeen lines and three transformers); Eleven loads (259 MW in total); a bank of capacitor shunt in bus 09.

Through the continuous flow technique provided by the ANAREDE® software, P-V curves will be plotted in two scenarios, the first without any equivalent generation proposed. In the second scenario, equivalent generations from buses 9 to 14 will be inserted, and for each generation inserted in a bus, the data obtained will be analyzed, so that comparisons between the generations are made, analyzing in which region the insertion of the generation would benefit the system the most. This study becomes relevant for complex distribution networks where it is not possible to define exactly where a distributed generation would favor the system.

3.1 Scenario 1

For the monitoring data, the PQ buses (9, 10, 11, 12, 13 and 14) were monitored. For the Automatic Load Increment, a value of 5% of active load was estimated for the PQ buses, and this value was added for each flow executed.
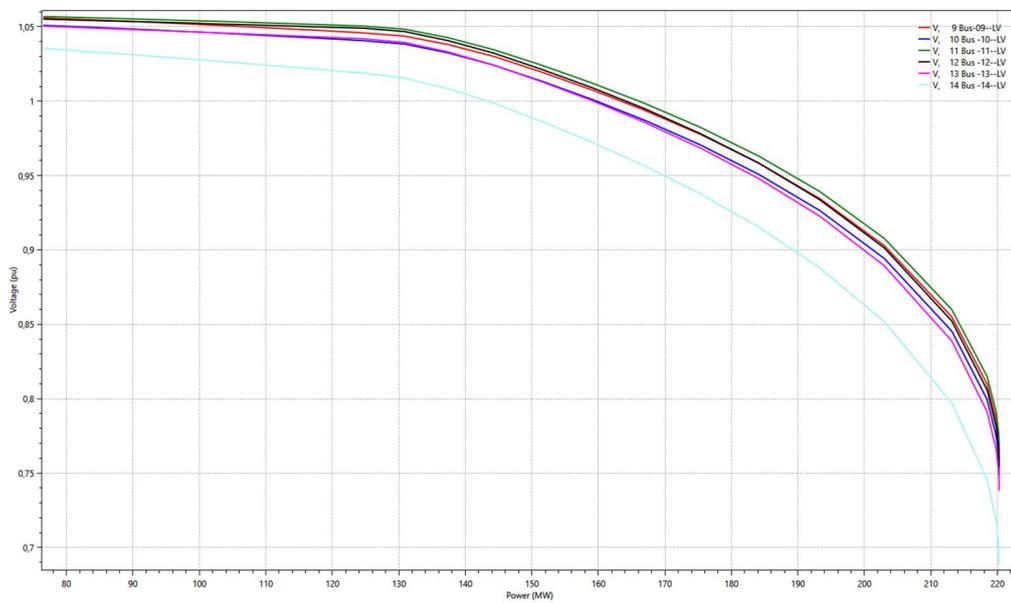

Figure 3. – P-V curve without generation.

Figure 3 shows the P-V curve for the system without generation. The curves from buses 9 to 14 reach a peak power value of 220.243 MW. As for voltage values, the critical bus is 14, because it has the lowest voltage value, with 0.688 p.u.

3.2 Scenario 2

The subsequent simulations will be performed in order to compare which of the buses has a better performance when installing distributed generation. The same monitoring data and load increment of 5% will be used, adding a generation of 30MW for each bus. The next simulation was done in bus 9.
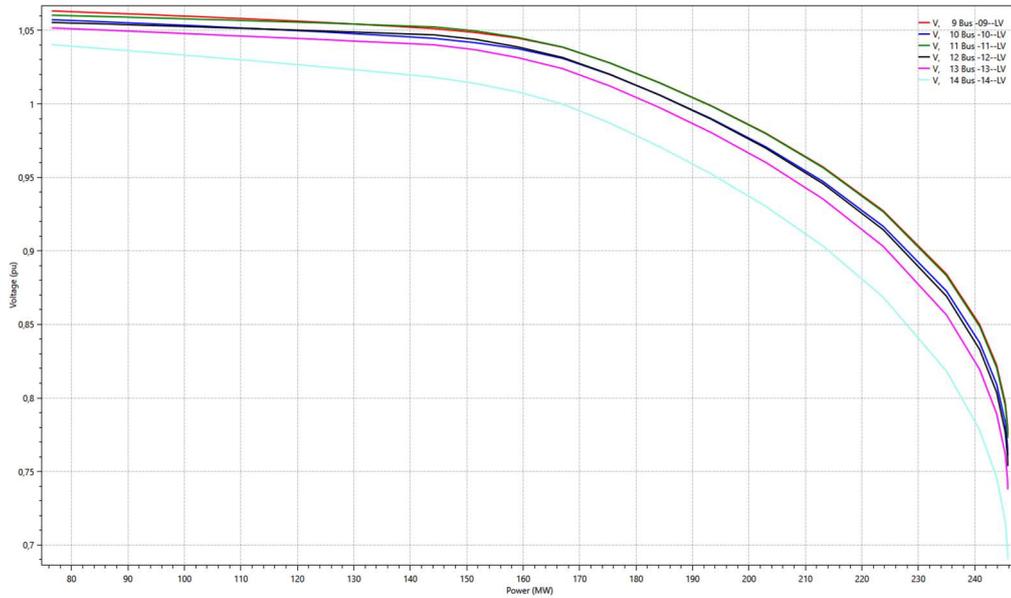
Figure 4. – P-V curve for 30MW generation at bus 9.

The bus 14 when compared to the scenario without generation, increased its load to 245.817MW, lowering the voltage by 0.01 p.u. The other buses also continued to increase their loading, thus demonstrating that the generation increases the peak values of the system.
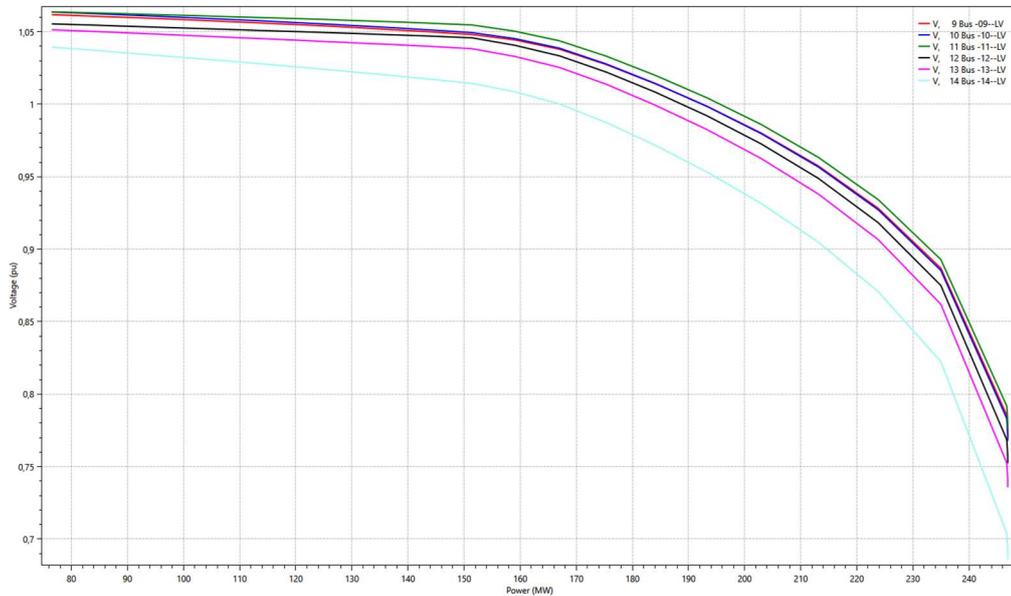

Figure 5. – P-V curve for the generation of 30MW in bus10.

The peak power value of buses 9 to 14 stood at 246.89MW, also slightly changing their voltage values in p.u. bus 10 has an active load of 9MW, which corroborates the idea that if the bus with a high load is supplied with a generation in the bus itself, this is favorable for the stability of the system.
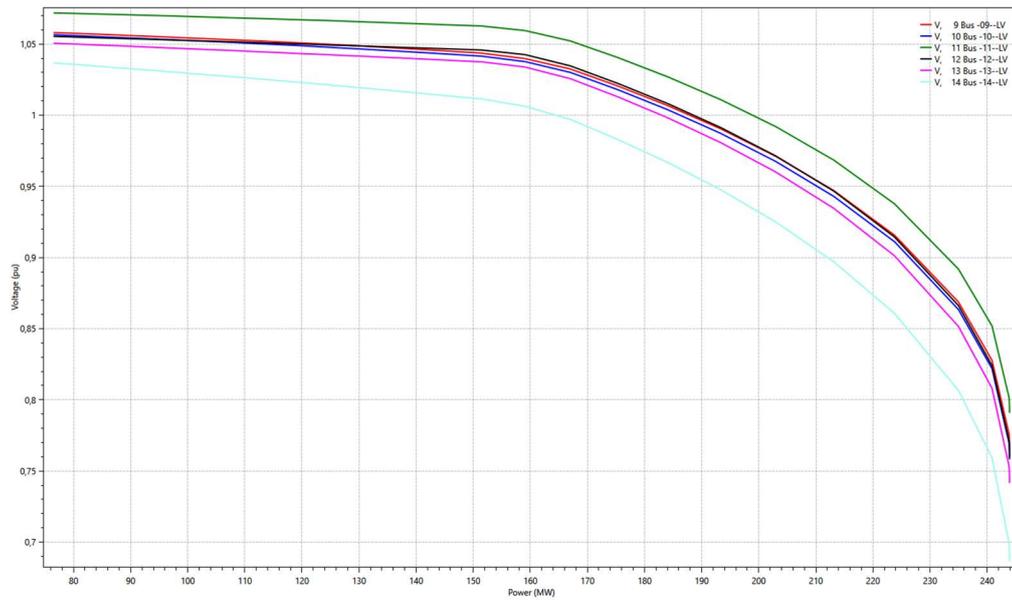
Figure 6. – P-V curve for the generation of 30MW in bus11.

We can observe in Figure 6 that the tension in bus 11 increased considerably when compared to the curves obtained by previous generations. Its peak power decreased in relation to bus 10, getting a value of 243.92MW. As for the instability of the system, there is little difference from bus 10.
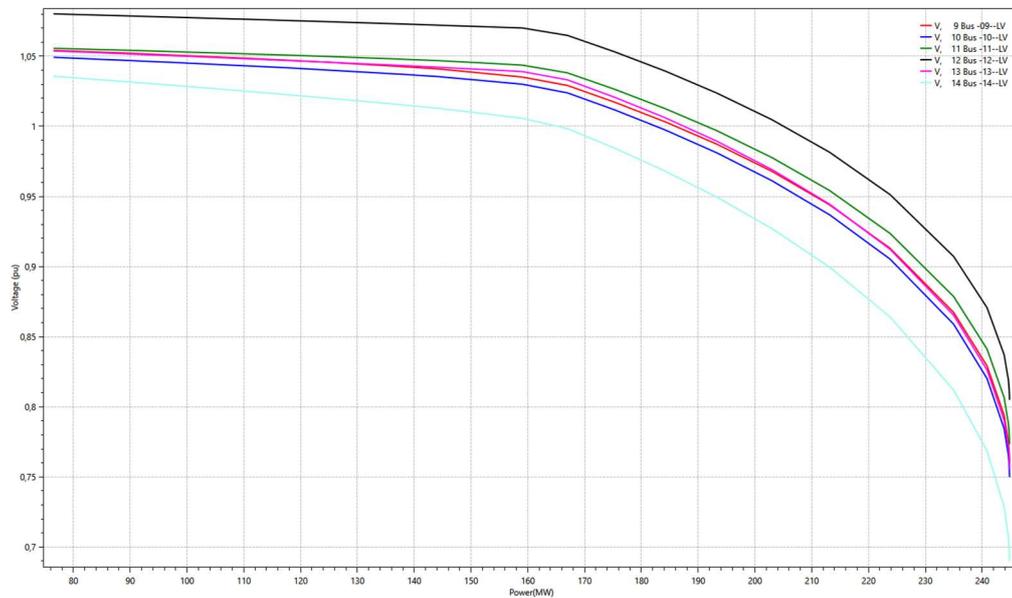

Figure 7. – P-V curve for the generation of 30MW in bus12.

Just like the simulation on bus11, in the Figure 7 the bus 12 also had a very prominent increase in tension. Both buses 11 and 12 have very low active load values (3.5MW and 6.1MW respectively), which contributes to this increase in voltage.
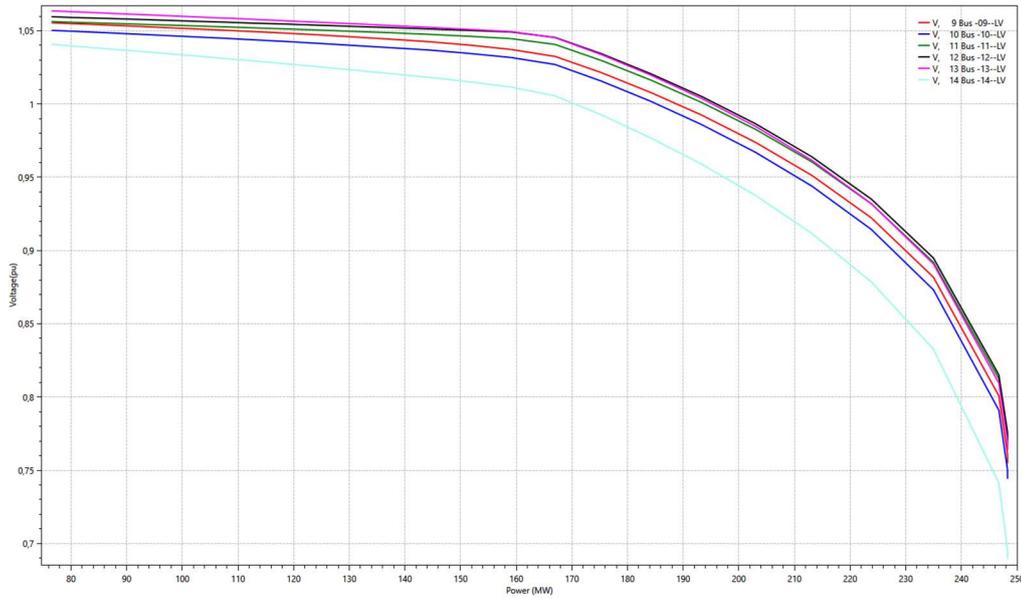
Figure 8. – P-V curve for the generation of 30MW in bus13.

How shows in the Figure 8, the generation on a bus with a higher active load contributes to the stability of the system. The simulation in this bus exceeds in the peak value of the power, 248,286MW against the 245,817MW of the bus 9, proving to be a better choice for the generation installation. Another reason that begins to become evident from this bus, is that the distance from the analyzed bus to the rest of the other generations also influences the stability of the system.
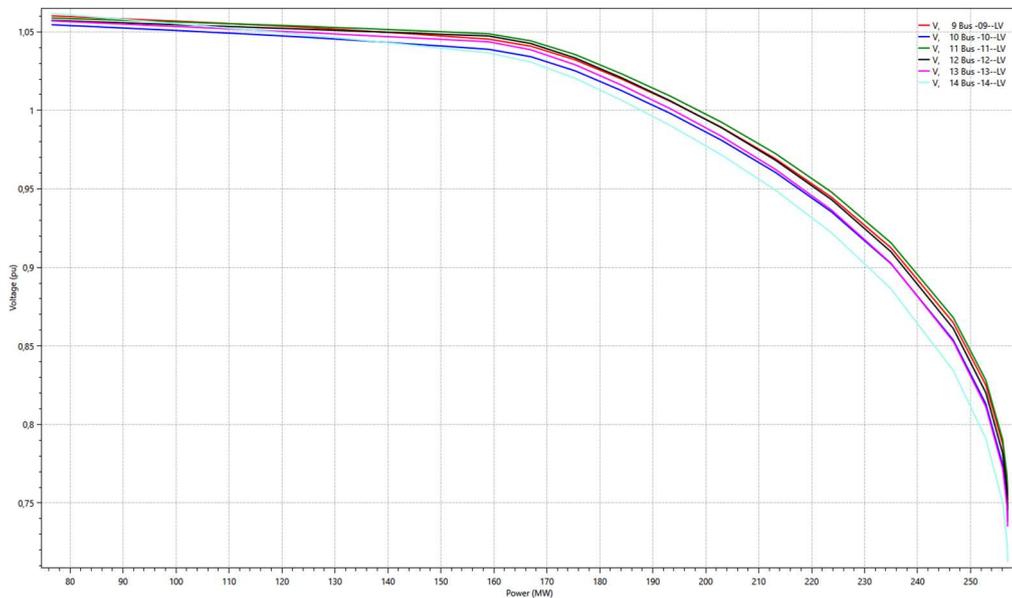

Figure 9. – P-V curve for the generation of 30MW in bus 14.

In the Figure 9, the bus 14 as well as the bus 13, are the furthest from the center of the model used, so a generation in bus 14 greatly improves the stability of voltage in the system as a whole, even not having the highest load of the system. In this last simulation, it is evident that for the study of this system, the photovoltaic installation on the periphery of the system, would end up having a very positive effect on the voltage stability, increasing the load levels supported in the system, as we can see in the Figure 9.

4. CONCLUSION

In this paper, two simulation scenarios were developed, using the 14-bus System through the ANAREDE® software. At first, a simulation without generation was performed to analyze the stability of the system, and later its stability was analyzed with the insertion of a generation of 30MW, from buses 9 to 14.

As a result, we noticed that buses 9 and 14 stood out for having a greater stability of tension when simulated generations in their buses, compared to the scenario without generation. The bus 9 has an active load of 29.9MW, and that when simulated a generation in this bus, the system presents a very good stability, by the demand to be supplied by the bus itself. In contrast, bus 14 even having an active load of 14.9MW, half the value of bus 9, has a better stability than the generation in bus 9. We can then conclude, that generations at the extremities, end up contributing more to the stability of this system.

5. ACKNOWLEDGEMENTS

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