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Impact of Green Power Distributed Generation to Voltage Profile and Protection Issues by Different Penetration Levels - A Study Developed on ATP Draw

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Abstract - **The connection of distributed generators in distribution systems of medium voltage or low voltage has been encouraged widely. Thus, it is necessary to assess the impacts and contributions to the voltage profile, as well as possible changes in the magnitudes of the short-circuit current and the consequent correlation with the adjustment of protection. This article investigates a feeder voltage profile through three different system load levels and evaluates the influence of the penetration level of a distributed generator. The results are compared in tables providing the reader a better insight into the issue discussed here.**

Key words

Distributed Generation, Independent Power Generation, Islanding, Independent Producer, Auto Reconnection and Energy Systems.

1. Introduction

Demand for electricity in Brazil is growing rapidly, so the issue of exploitation of water resources related to concerns about its scarcity are constantly cited as key to changing the energy paradigm. However, the scenario of world electricity generation has been concerned with the need to seek alternatives to ensure the provision related to environmental issues. In this context, Brazil presents itself as a country that has a rich energy sources thereby enabling the deployment of distributed generation - DG [1].

According to the Normative Resolution - ANEEL 482/2012 - the National Electric Energy Agency, Brazilian consumers can generate their own electricity from renewable sources and still provide a surplus for the distribution network [2].

Distributed generation (DG) is a power generation along or near independent consumer power, technology and power supply, which connects directly to the electrical distribution system or the consumer [3]. This generation may be parallel or isolated, with the network, increasing its guaranteed supply and also being used in remote locations of large power plants, locally serves the consumer. This can be characterized as a mini or micro distributed generation of electricity. However, the distributed generation connection is increasing and the expectations for the coming years is a continuous and rapid growth. In this regard, the electricity distribution system operator is faced with a more complex design, operation, planning and maintenance of medium and low voltage networks because the power flow becomes dynamic, changing thus the fundamental characteristics of distribution networks, as this is designed to operate radially [4]. There are several sources of electricity generation connected to distribution networks. However, there is the technology using the combined generation of heat and power, cogeneration plants, to more recent technologies such as wind turbines and photovoltaic panels [5].

To evaluate the operation to ensure the excellence and quality of electricity service delivery system, it is necessary to study the interaction between DG systems with medium and low voltage networks. However, one has to have knowledge of the key features of the party accessing the generation of technology to be employed and the operating conditions and main contingency occurring on the network in question. With regard to the Brazilian electric sector, it can be said that the generation of electricity from biomass from sugarcane or even straw from sugar cane, play, and already plays an important role when it comes to production independent of electricity [6]. It is observed that the state of São Paulo has the greatest potential to generate surpluses, 2.244,33MW, which shows clearly and prominently raising the number of drive synchronous generators to be connected directly to the electrical distribution systems [7]. It is noteworthy that there is no consensus, meaning clear regulations as to the best mode of operation of the DG when connected to the power distribution system - PDS, nor well-established criteria of protection, connection, product quality and dynamic for a safe and effective connection [8] - [9].

Thus, this article aims to evaluate the main impacts arising from the installation of medium-sized synchronous generators in the operation of distribution networks. The main technical aspects are analyzed profile of steady voltage, with and without the presence of DG, for different levels of penetration of DG in the electrical system. The results will be compared and the main findings will be presented. Nevertheless, protection-related issues will they approach with a primary focus on changes in the magnitude of short-circuit currents for a three-phase fault, through technical situations, penetration levels of DG and load the electrical system, to be studied here.

This paper is organized as follows. The Brazilian electric sector, with regard to the main sources of electricity generation, is presented in section 2. In section 3, the models of the various network components and simulation methods used in this work are discussed. Section 4 analyzes the impacts of the installation of distributed synchronous generators in steady-state voltage profile. Changes in fault current magnitudes for different power system load levels and for different levels of integration of DG, are presented in Section 5. Finally, Section 6 summarizes the main conclusions.

2. Brazilian scenario

With an increase in energy demand in the late 1940s we started to generate power in large power stations with the intention of generating energy at less cost, it was discouraged technological advances in the next generation of energy consumers. In recent decades, many issues such as environmental impacts, reduced availability of large hydro projects, increasing demand and rising investments in the construction of hydroelectric plants, culminated by encouraging, vigorously, the change in national energy policy. With the change this new scenario was necessary to seek new alternatives for power generation so that they could meet the present and future needs, thus emerging the distributed generation (DG) [10]. Some alternative energy sources are gaining great prominence in the Brazilian context, such as wind power, biomass and photovoltaic systems [11]:

a) Wind Energy: *has been very encouraged in Brazil showing an increasing trend since the year 2003 there were nine wind farms in operation generating 22.075GW with forecast for the next years of 101 wind farms to generate 6683.950GW* .

b) Biomass: *in Brazil there are now 56 plants operating as cogeneration generating 1206.06MW. Biomass stands out as the primary source of 55.8% of installed capacity, knowing that the most common form is the sugar cane bagasse. The sugarcane sector generates huge amounts of sugarcane bagasse that can be used in electricity generation.*

c) Photovoltaic systems: *due to the still high cost, photovoltaics have a small stake in the energy matrix of the developing countries. In Brazil its installed capacity in 2007 reached approximately 7800MW.*

In spite of Brazil has a lot of sunlight, it is still very small participation of photovoltaic energy in the national energy matrix. ANEEL, in April 2012, as a way to encourage solar power generation raised the discount of 50% to 80% in the Rate of Use of the Electricity Transmission Systems (TUST) and Tariff for Use of the Electricity Distribution System (TUSD) for solar generation projects that inject up to 30 MW in the transmission and distribution network. Plants that begin operation until December 31, 2017 will have this discount that will last for the first 10 years of operation of the system. We may highlight that by 2022 alternative energy sources will match 10% of installed capacity in Brazil [12].

3. System modeling

To represent the electrical system in the software ATP it was necessary to model all components of the system, as detailed below.

A. Modelling of Substation

The power substation was represented as a constant voltage source (infinite bus) in series with an inductance. The magnitude of the voltage source is the nominal rating value of the feeder (13.8 kV) [13]. The software named "Alternative Transients Program" - ATP - was used to perform the simulations. It requires an appropriate modelling of the data and parameters of the electrical system for using this software, as will be presented. Figure 1 shows the configuration of the electrical system studied with all data already represented in the ATP software, identifying the presence of a distributed generator (DG) equipped with voltage and speed regulators.

B. Modelling of Loads

The power demands of the loads were also taken from reference [13], which shows the values of active and reactive powers. These loads were represented in ATP by corresponding values of resistance and inductance (constant impedance).

C. Modelling of Distribution Lines

The lengths of the distribution lines for the modelling by ATP were also obtained from reference [13]. The conductor used in modelling is referred as CAA 336.4 whose technical data can be obtained directly from the manufacturer catalogue, which gives the following values for the resistance, inductive reactance and capacitive reactance, respectively: 0.2051 Ω/km, 0.3770 Ω/km and 0.2266 M.Ω.km. By having such parameters, each distribution line can then be represented by the π model which is described by its resistance and inductance arranged in series, and its total capacitance placed in parallel so that each half occupies one end of the line.

D. Modelling of Synchronous Generators

As regards Brazil, most distributed generation system employ synchronous generators which can be used in thermal, hydro, or wind power plants. The model chosen in ATP to represent such synchronous machine was the SM59 controlled type. The used mathematical model is presented below. The distributed generator used in the simulations is rated 5 MVA, 60 Hz, 4 poles. The other parameters of the generator were taken from reference [13].

To the electrical system of the generator:

$$V_d = -R_a i_d - \frac{d}{dt}\lambda_d - \lambda_q \frac{d\theta}{dt} \qquad (01)$$

$$V_q = -R_a i_q - \frac{d}{dt}\lambda_q + \lambda_d \frac{d\theta}{dt} \qquad (02)$$

$$V_0 = -(R_a + 3R_n)i_0 - \frac{d\lambda_0}{dt} \qquad (03)$$

$$V_f = -R_f i_f - \frac{d}{dt}\lambda_f \qquad (04)$$

$$0 = -R_g i_g - \frac{d}{dt}\lambda_g \qquad (05)$$

$$0 = -R_{kd} i_{kd} - \frac{d}{dt}\lambda_{kd} \qquad (06)$$

$$0 = -R_{kq} i_{kq} - \frac{d}{dt}\lambda_{kq} \qquad (07)$$

$$T_{em} = \frac{NP}{2}(\lambda_d i_q - \lambda_q i_d) \qquad (08)$$

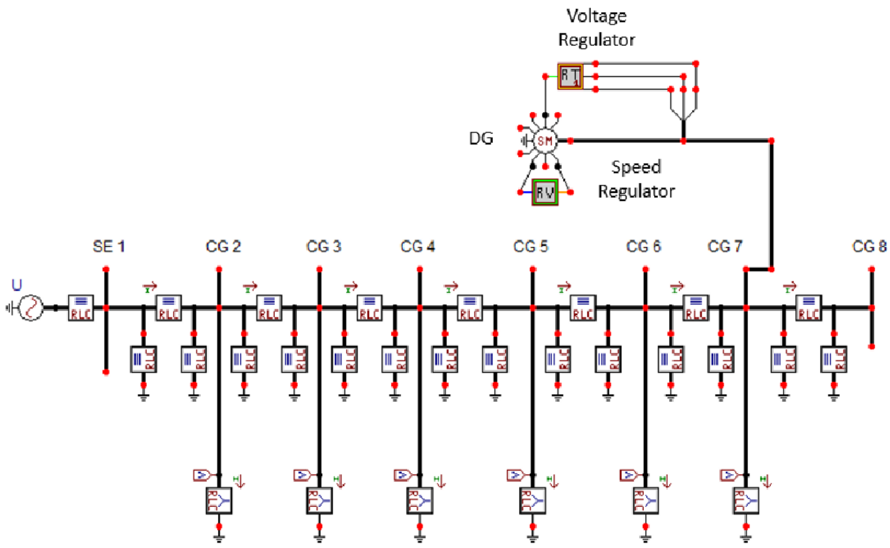

Fig.1. Schematic of the electrical system in the ATP software

and:

$$\begin{bmatrix} \lambda_d \\ \lambda_q \\ \lambda_0 \\ \lambda_f \\ \lambda_g \\ \lambda_{kd} \\ \lambda_{kq} \end{bmatrix} = \begin{bmatrix} L_d & 0 & 0 & L_{af} & 0 & L_{akd} & 0 \\ 0 & L_q & 0 & 0 & L_{ag} & 0 & L_{akg} \\ 0 & 0 & L_0 & 0 & 0 & 0 & 0 \\ L_{af} & 0 & 0 & L_f & 0 & L_{fkd} & 0 \\ 0 & L_{ag} & 0 & 0 & L_g & 0 & L_{gkq} \\ L_{akd} & 0 & 0 & L_{fkd} & 0 & L_{kd} & 0 \\ 0 & L_{akq} & 0 & 0 & L_{gkq} & 0 & L_{kq} \end{bmatrix} * \begin{bmatrix} i_d \\ i_q \\ i_0 \\ i_f \\ i_g \\ i_{kd} \\ i_{kq} \end{bmatrix} \quad (09)$$

System mechanic:

$$\frac{d}{dt}\omega_m = \frac{1}{2H}(T_e - T_m) \quad (10)$$

$$\frac{d}{dt}\theta_m = \omega_m \quad (11)$$

E. Modelling of automatic voltage regulator

Currently, it uses two forms of control that can be employed: to maintain constant the terminal voltage (voltage control mode), or to maintain constant the power factor (power control constant mode) [4], [7]. In this paper will be employed philosophy of terminal voltage control. The voltage regulator is designed based on the model recommended by IEEE termed Type I. Figure 2 shows the block diagram for this control.

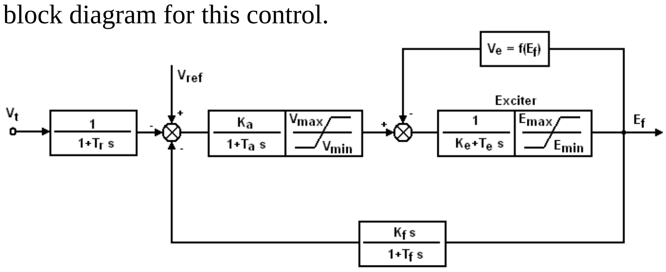

Fig.2. Voltage regulator model

F. Speed Governor

The speed governor was built in a simple IEEE model, that is frequently used in dynamics and transient stability studies [13]. It is needed to remember that the influence of these governor parameters won't be studied in this paper. Figure 3 shows the model of the speed governor used, that is already associated with a steam turbine (if T4 = 0) or a hydraulic turbine (if T4 ≠ 0). Data regarding the speed governor constants are listed [13].

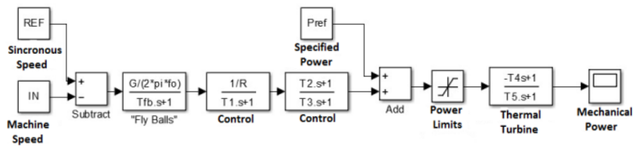

Fig. 3. Speed governor model.

4. Case Studies

One of the primary technical factors that can limit the level of penetration and the amount of distributed generators in the distribution network is increasing nodal voltages for light to medium loading system in the presence of distributed generators. This anomaly, change of the voltage profile, occur in distribution networks due to the low value of X / R ratio and radial configuration adopted these systems [4]. Thus, before proceeding the installation of a generator in a distribution network, it is necessary to ensure that the voltage profile is not significantly changed. With the main objective of evaluating the impact of distributed synchronous generators in electric distribution network connection, with regard to the steady state voltage profile, six conditions most critical were here established and analyzed.

1- *system with 100% load and without distributed generation;*
2- *System with 50% load and without distributed generation.*
3- *System with 30% load and without distributed generation.*

However, in order to analyze the influence of DG penetration level in the electrical system, the above cases will be simulated here again, but the following assumptions are adopted:

4- *System with 100% loading in the presence of the GD*
   a. *The GD injects 1MW in the system;*
   b. *The GD injects 2MW in the system;*
   c. *The GD injects 3MW in the system*
5- *System with 50% loading in the presence of the GD*
   d. *The GD injects 1MW in the system;*
   e. *The GD injects 2MW in the system;*
   f. *The GD injects 3MW in the system*
6- *System with 30% loading in the presence of the GD*
   g. *The GD injects 1MW in the system;*
   h. *The GD injects 2MW in the system;*
   i. *The GD injects 3MW in the system*

It is noteworthy that in Brazil, Procedures for Electricity Distribution in the National Electric System, Module 8, Quality of Electricity, 2012, specifies how maximum variation of allowable stress the benchmark of 5% (1.05 / 0.95pu) [14]. Nevertheless, in order to assess the impact of DG inclusion in the protection of electrical distribution systems, by virtue of this protection consist usually of a simple over current protection since there is only a generator, the problem of the blind spot protection will be evaluated for the above conditions (loading and penetration of GD). However, to study this effect will apply a three-phase fault in the number of bus 8, Figure 1, with a maximum duration of 100ms. Thus it will be measured the magnitude of the utility contribution of current without and with distributed generation, for the above three loading levels. Results are presented in tables in order to clarify the reader the possible impacts and solutions to be employed to ensure safe and effective connection.

A. Steady-state voltage profile

The network voltage profile considering maximum load (100% load), with and without the presence of the GD for the three levels of penetration, is shown by Figure 4. However, Table I shows the magnitude of the voltage, phase - neutral in all system buses shown in Figure 1. It is verified by Figure 4, the failure to meet the lower limit of voltage magnitude presented by reference [14] (0,95pu). This occurs because of the steep voltage drops along the feed for a nominal load situation. This fact implies precarious tensions the number of bus 4-8. This, because it is at the end of the feeder, has the lowest value in magnitude, 0.935pu, Table I. It is noteworthy that the consumers connected to this bus may suffer from low efficiency and even improper operation of their electrical equipment by virtue of this magnitude service voltage. This fact appears more pronounced in electrical induction machines, since the torque is directly proportional to the square of the attendant stress [15]. However, Figure 4, it is observed that the insertion of DG strongly contributes to the improvement of the electrical system voltage profile. From the generation of 1 MW DG, the bus experience a significant change in magnitude of tension caused by lightening current from the electric utility, for the DG happens to meet in a timely manner the electrical charges coming your installation. Thus, there is a reduction in feeder voltage drops. However, from the generation of 2MW by the DG, tensions on the buses start to meet the legislation contributing to power quality [14], [15]. However, the network voltage profile considering the average load (50% load), with and without the presence of the GD, to the three levels of penetration is shown by Figure 5. However, Table II shows the voltage magnitude, phase-neutral, in all system buses. Regarding the magnitude of tensions in buses without the presence of DG, there was no transgression the reference limit, 0.95 - 1,05pu because the voltage drops in the system is reduced sensitively to the situation presented here. Table II shows a clear and evident that for the bus 8, the end of the feeder, the magnitude of the voltage is 0,97pu. However, as the DG increased penetration level there is a significant increase in voltage magnitude. This fact strongly contributes to improved power quality, reducing system losses, reducing the loads and therefore the postponement of expansion and network reinforcement. However, the network voltage profile considering a minimum load (30% load), with and without the presence of the GD for the three levels of penetration, is shown by Figure 6. Table III shows the magnitude of the voltage, phase -neutral in all system buses.

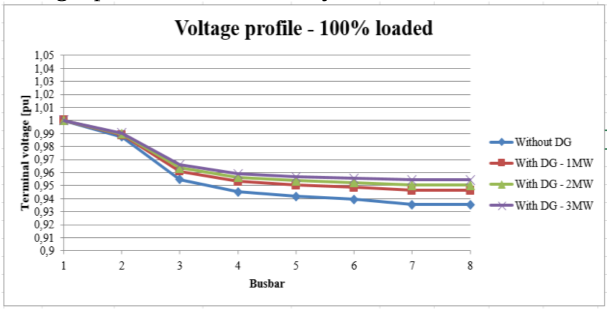

Fig. 4. Voltage profile on the bus - 100% loaded.

Table I – Voltage phase-neutral in the system -100% loaded

Bus	Without DG	With DG - 1MW	With DG - 2MW	With DG - 3MW
SE1	1	1	1	1
CG2	0,98732111	0,98895305	0,98970625	0,99033391
CG3	0,95455686	0,960959076	0,96346974	0,96585488
CG4	0,94526738	0,953175998	0,95631433	0,95907607
CG5	0,94175244	0,950288727	0,95380366	0,9568164
CG6	0,93936731	0,948656791	0,95242279	0,95568666
CG7	0,93535023	0,946271655	0,95041426	0,95443133
CG8	0,93535023	0,946271655	0,95041426	0,95443133

The curves shown in Figure 6 show a voltage profile in magnitude better compared to the other cases studied here. This was expected, because due to the low electric system load level, the voltage drop will be mitigated, thus contributing to a significant improvement of power quality supplied to consumers. Such statements are better presented through a detailed analysis of Table III. This is observed that the voltage on the bus 8 without the presence of DG is 0,98pu. Therefore, it falls within the reference range indicated in [14]. However, to the extent that it increases the contribution of the DG, the voltages rise throughout the feeder because of mitigation of the voltage drops originated by the load relieving for the utilities. This becomes even more evident on the response magnitude of the bus voltage 8. In this, from the insertion of 1MW DG, tension has already reached 1,0pu, Table III. Nevertheless, introduce the reader that the benefits reported here, extend the transmission of electricity, as the cost of expanding the system will also be mitigated due to service of power demand by DG installed near those. However, operators of electrical distribution systems should be aware of possible surges by pressure drop situations. Figure 6 alerts operators to pronounced surge on maximum penetration of DG and possible loss of load. In addition, another risk inherent in the installation of DG, is the postponement of network reinforcement work, because according to the responses obtained, and the technical literature, the reduction of the current supplied to the feeder by the concessionaire can raise a false impression as to real network loading, for the DG is addressing the next load your locality. Thus, through the loss of the DG, the magnitude of current applied to the concessionaire may exceed the overload principal amount of feed, thereby requesting the protection operation. This will be reflected in quality indicators of supply of electricity.

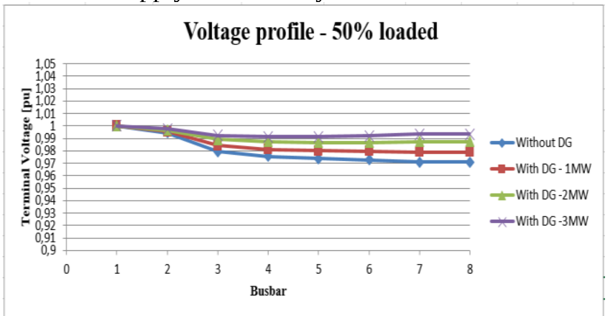

Fig. 5. Voltage profile on the bus - 50% loaded.

Table II – Voltage phase-neutral in the system -50% loaded

Bus	Without DG	With DG - 1MW	With DG - 2MW	With DG - 3MW
SE1	1	1	1	1
CG2	0,99435099	0,995480793	0,996736129	0,997614863
CG3	0,97953804	0,98430831	0,989204117	0,992467989
CG4	0,97539543	0,981295506	0,987321115	0,991463721
CG5	0,97376349	0,980291238	0,986818981	0,991463721
CG6	0,97263369	0,979789104	0,986944514	0,991965855
CG7	0,97087622	0,979161436	0,987572182	0,993472257
CG8	0,97087622	0,979161436	0,987572182	0,993472257

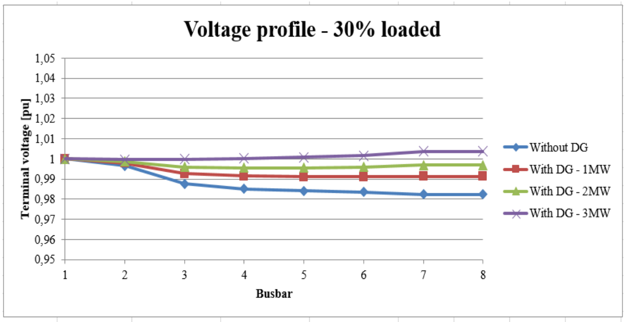

Fig. 6. Voltage profile on the bus bars - 30% loaded

Table III – Voltage phase-neutral in the system -30% loaded

Bus	Without DG	With DG - 1MW	With DG - 2MW	With DG - 3MW
SE1	1	1	1	1
CG2	0,996485062	0,99786593	0,998619131	0,999623399
CG3	0,987572182	0,992719056	0,995982927	0,999748933
CG4	0,985061511	0,991463721	0,995480793	1,000125534
CG5	0,984057243	0,99108712	0,995480793	1,000753201
CG6	0,983429576	0,99108712	0,995857394	1,001631936
CG7	0,982299774	0,991212654	0,996861662	1,003640472
CG8	0,982299774	0,991212654	0,996861662	1,003640472

B. Blinding of protection

Figure 7 shows a distribution feeder with a DG. In the event of a fault, there will be the contribution of the network and the DG for short chain. The magnitude of fault current of each will depend on the network configuration, Thevenin impedance to the fault point, pre-fault voltage and therefore depend on the DG penetration level.

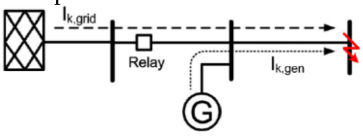

Fig. 7. Blinding of protection

Before the integration of the DG, the magnitude of the short grid current contribution decreases, causing thereby the possibility of non-sensitization of the feeder over current relay, because it can not achieve the required pickup. This phenomenon is called blinding of protection and is also known as protection under reach. To determine the impact of DG in the short-circuit current, and assess the above issues, a three-phase fault is applied on the bus 8, Figure 2, at time t = 15 s, a maximum of 100 ms.

It is presented in Table IV contributions DG machine and the concessionaire for 100% system load. It is evident the increase of the short-circuit magnitude compared scenarios before and after insertion of DG which leads to purchase sizing and circuit breaker interrupting capacity greater the magnitude of the fault current. In addition, there is the inherent need for a new project and selective coordination of protection. Nevertheless, there is an easing in input current from the power utility, this now contributes 2.29kA.

Table IV – Contributions of the fault applied – 100% loaded

DG - 1MW	Without DG	With DG	
System 100% loaded	Power Grid	DG	Power Grid
I [KA]	2,362	0,6661	2,29

DG - 2MW	Without DG	With DG	
System 100% loaded	Power Grid	DG	Power Grid
I [KA]	2,362	0,6325	2,289

DG - 3MW	Without DG	With DG	
System 100% loaded	Power Grid	DG	Power Grid
I [KA]	2,362	0,6049	2,289

However, Table V shows the contributions of DG machine and the concessionaire for 50% of system load. Evidence is an elevation of the system short-circuit level. This was expected due to the increase in the voltage profile. Again, one can see the need for replacement of other breakers for higher current interruption capability. In addition, one should analyze withstand the thermal and dynamic forces of electrical equipment at this feeder. However, by increasing the level of short-circuit system, it becomes more robust with respect to the voltage imbalance [15]. However, it emphasizes the attenuation of the magnitude of the contribution in current (2.26kA - with DG) by the network, compared to the value in magnitude without the presence of DG (2,34kA).

Table V – Contributions of the fault applied – 50% loaded

DG - 1MW	Without DG	With DG	
System 50% loaded	Power Grid	DG	Power Grid
I [KA]	2,34	0,6832	2,264

DG - 2MW	Without DG	With DG	
System 50% loaded	Power Grid	DG	Power Grid
I [KA]	2,34	0,6738	2,26

DG - 3MW	Without DG	With DG	
System 50% loaded	Power Grid	DG	Power Grid
I [KA]	2,34	0,6588	2,26

However, Table VI, depicts the contributions of DG machine and the concessionaire for 30% of system load. Again, demonstrates the reduction in the magnitude of fault current from the network without DG (2.332kA) and the presence of DG (2.25pu).

Table VI – Contributions of the fault applied – 30% loaded

DG - 1MW	Without DG	With DG	
System 30% loaded	Power Grid	DG	Power Grid
I [KA]	2,332	0,6958	2,254
DG - 2MW	Without DG	With DG	
System 30% loaded	Power Grid	DG	Power Grid
I [KA]	2,332	0,6726	2,252
DG - 3MW	Without DG	With DG	
System 30% loaded	Power Grid	DG	Power Grid
I [KA]	2,332	0,658	2,252

Generally, the pickup of the feeder over current protection is set to 50% of the fault current in the line endings. Thus, for Table IV, the protection would be adjusted to 1.2kA, being so sensitized to a 2.29kA current. The same is true for other loading of the system, Table V and Table VI. Thus, there will be the problem of the blind spot protection for the electrical system studied here [5].

5. Conclusion

This paper presents a study on the distributed synchronous generator connection impacts in distribution networks, operated with voltage regulator for the voltage profile, compared to three system loading conditions as well as three levels of penetration of DG. The results point to a significant improvement of the magnitude of the voltage to the bus immediately next to the DG, thus contributing to a better quality of energy supplied to consumers at the end of the feeder. However, reducing the loading to the distribution feeder alert operators and the need to continue grid reinforcements, since the possibility of loss of distributed generation may cause overloading the feeder. This fact may lead to a sustained interruption if the feeder protection is touched, or even unwanted under voltage. On the other hand, can have a voltage on front elevation of a high degree of penetration of the DG and a load rejection, which makes the operation of more complex network.
Regarding the blind spot protection, it is clear that it will not occur to the electrical system analyzed here. The results point to the need for prior studies of network load (load flow), power quality, dynamic electrical systems, protection and coordination of protection for safe and efficient connection to the DG. However, it is being developed by the authors, investigations as the best topology excitation control system to be adopted, by the machines of the DG, as our findings may be significantly changed before contingencies common to power distribution systems.

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