Hosting Capacity of Distribution Systems Connected with Wind Turbines Type IV

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***Abstract* - The Hosting Capacity of an Electrical Distribution System is the maximum number of distributed generators or electrical machines that can be connected to the system, without violation of operational parameters of the system. Although this definition, it is not very clear in the literature, which are the impacts, that different technologies of wind turbines, can cause in the parameters of hosting capacity. The objective of this paper is show what is the hosting capacity of IEEE 13 bus test system, when the type IV of wind turbines are connected at 680 node. The simulations are performed with unitary, inductive and capacitive power factors. The simulations reveal that for the wind generators connected through frequency converter and with the system operating with voltage regulator, the hosting capacity is achieved in a higher point of injected power than considering the synchronous wind generator directly connected to the grid.**

***Index terms* - Power Flow, Power Systems, Wind Energy, Hosting Capacity.**

I. INTRODUCTION

With the advent of new technologies in the wind generation sector, driven by the increasing use of this source and the recent competitiveness in relation to other sources, several lines of research have emerged with the aim of studying the impact of the integration of wind farms to the transmission systems and distribution systems. These studies culminated in a modern way in assessing the hosting capacity of distribution systems, given that distributed generation has come to represent a significant number of machines connected to the distribution system.

Some papers study the hosting capacity analyzing different aspects:

The increase of the hosting capacity considering voltage and current parameters are analyzed with the use of real-time information and calculation of dynamic performance indications that govern the hosting capacity [1].

Another work identifies when the transmission network local hosting capacity for a wind harvesting network may be limited because of steady-state bus voltage limits. In addition, the paper addresses how with the wind farm voltage control provision, such constraints may be overcome and the local hosting capacity can be increased. To answer these questions, actual Spanish system data is used on different network models of increasing complexity [2].

The use of active-management strategies (AMSs) has been proposed to increase the hosting capacity of distribution systems. This reference incorporates AMSs into two optimization models whose objectives are to maximize the net benefit of distribution system operator and wind farm owner, respectively. The AMSs considered are wind energy curtailment, coordinated on-load tap changer voltage control, and reactive power compensation [3].

Exploration of how the Distributed Generator (DG) hosting capacity of active distribution systems can be increased by means of network reconfiguration, both static, i.e., grid reconfiguration at planning stage, and dynamic, i.e., grid reconfiguration using remotely controlled switches as an active network management (ANM) scheme has been studied. The problem is formulated as a mixed-integer, nonlinear, multi-period optimal power flow (MP-OPF) which aims to maximize the DG hosting capacity under thermal and voltage constraints [4].

Hosting capacity of weak grids considering the interconnection of some types of electric machinery, as induction motor has been analyzed [5].

Although the works above have analyzed different aspects of hosting capacity, the effects that different types of wind turbines can to cause in the hosting capacity of unbalanced electrical distribution systems are not very clear in the literature. This paper uses a three-phase modeling of an electrical distribution system to obtain accurate results in a three-phase power flow software. Considering this fact, the analysis of the hosting capacity of IEEE 13 node test feeder will be performed. The paper is organized as follow: Firstly the concept of hosting capacity is reviewed. In section 3 the modeling of wind turbines type IV is shown. In section 4 the methodology of the work is explained. Lastly, in sections 5 and 6 relevant results are discussed and reported.

II. Hosting Capacity of Distribution Systems

Distributed generation is defined as the use of external sources of electrical power connected directly to an existing power distribution infrastructure. DGs are the smaller independent electrical sources that will be interconnected with the distribution infrastructure for economic and logistical reasons [6]. Distributed generation is closely related to the hosting capacity of the system.

The Hosting Capacity term was first used by André Even at the meeting of the EU-DEEP (European Distributed Energy Partnership) in 2004.

The hosting capacity is the maximum amount of generation that can be integrated into the power system, while still maintaining its performance within acceptable limits. The hosting capacity approach uses the existing power system as a starting point and considers the way in which distributed generation changes the performance of the system when no additional measures are taken. For this, a set of performance indicators is needed. This is a normal procedure in the power quality area, but not in other areas of power systems yet. [7]

According to [7], the power injected into the system through distributed generation generally tends to improve system performance (in general the electrical losses and voltage unbalance factor are decreased), while in other cases it may end up damaging the same (the voltages and the line loading and transformers loading are increased). These latter cases require greater attention.

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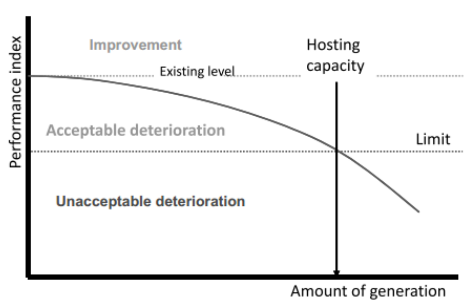

Figure 1. Hosting capacity approach; performance index is high in ideal case.

Observing Figure 1, from reference [7], it can be seen that the Hosting Capacity can also be defined as the upper limit of the power increase on the network that makes the performance of the system unacceptable to the established quality limits.

For example, excessive number and capacity of Distributed Generation may cause problems to distribution systems. To maintain existing protection coordination, the system can generally allow DG to be connected at a limited capacity. Widely understood that high level penetration of DG, can also increase feeder power loss. Moreover, it may cause system voltage profile to violate the required range [8].

III. Modeling Wind Turbines Type IV

Synchronous wind machines can be coupled to the electrical system in the following ways:

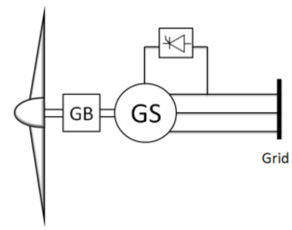

Figure 2 (a). Synchronous machine directly connected.

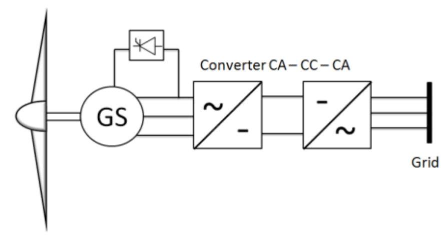

Figure 2 (b). Synchronous machine connected through frequency converter.

Wind machines of the type IV, also called synchronous machines, are responsible for generating most of the electricity produced in the world. These machines operate at a fixed and approximately constant speed Fig. 2 (a), in order to work in a predetermined frequency range. The structural simplicity and flexibility which are in constructive terms, to provide synchronous machines a huge advantage compared to the other with respect to the initial investment. Synchronous machines also can be connected with variable speed using a full converter as in Fig. 2 (b). These machines are important equipment in power systems. The external characteristics of synchronous generators are mainly concerned in the calculation of power flow [9].

A. Type IV Wind turbines directly connected

Mathematical modeling of synchronous machine connection to the electrical system of the IEEE distribution is based on the work of Chen [10], the model aims to demonstrate the turbine's connection behavior to the system bus. Thus, this section is based on their work on the study of distributed generation in distribution systems. All system components are modeled with their equivalent circuits in terms of inductance, capacitance, resistance and injected current.

Works on voltage control systems with wind generators using synchronous machines have been performed. Results reported that synchronous generators are not controlled to maintain constant voltage, but the power, and the power factor constants. These parameters are pre-set by the system operators. As a result, synchronous generators in power generation mode may be represented approximately as a constant power device in the power flow studies, that is, are represented as PQ devices.

The synchronous generator is modeled with an internal voltage "EI" and its own reactance X_d. In the figure there is shown a Thévenin equivalent circuit for a synchronous generator as a direct network connection mode. This model differs from traditional load flow model in a generation bus (PV bus) on which the power is specified for a given voltage level.

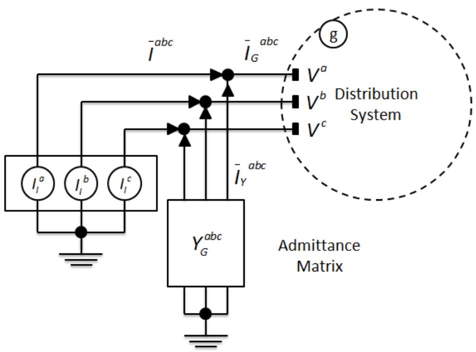

Figure 3. Norton equivalent circuit of an wind turbine generator directly connected.

For the model of the synchronous machine connected to the grid without inverter system as shown in Figure 3, the line current is calculated by:

$$I_I = \frac{(P_T - jQ_T) + \left[V_g^{abc}\right]^{*t}\left[Y_G\right]\left[V_g^{abc}\right]}{(V_g^a + a_s^2 V_g^b + a_s V_g^c)^*} \tag{1}$$

Using the vector below, we can obtain the vector of currents injected for each phase:

$$I_I^{abc} = \begin{bmatrix} 1 \\ a_s^2 \\ a_s \end{bmatrix} I_I \tag{2}$$

Where:

$a_s = 1\angle 120^o$ is the numerical operator of symmetrical components matrix.

P_T is the three-phase active power of the generator

Q_T is the three-phase reactive power of the generator

Y_G is the admittance matrix of the generator

V_g^i is the line-to-ground voltage of phase i

B. Wind turbines connected through frequency converter

The concept of analysis of the synchronous machine coupled to the distribution system through the frequency converter has been developed in [11]. To control the drive, it is considered that only the positive sequence current is injected into the system by the converter, the reason is that for a four-wire system and unbalanced, the converter can determine the negative sequence current and zero as way to offset the imbalance caused due to system connection point downstream. This current form injected by the synchronous machine per phase is given by:

$$I^1 = \frac{(-S_{Synchronous\_Generator} / 3)^*}{(V^1)^*} \tag{3}$$

For the current control in the positive sequence.

$$I^{0,2} = 0 \tag{4}$$

For the current control in the negative and zero sequences.

Where:

$S_{Synchronous\_Generator}$ is the apparent three-phase power of the wind generator

$I^{0,1,2}$ is the current in symmetrical components, injected by the wind energy control system

$V^{0,1,2}$ is the voltage line-to-ground at the PCC in symmetrical components (Point of Common Coupling)

IV. METHODOLOGY

This article will address the simulation of load flow of a distribution system with wind generation integrated in different ways. In the first situation will be analyzed the hosting capacity of type IV machines connected without frequency converter, while in the latter case, the wind turbines connected through frequency converter will be considered. Factors will be analyzed as: Degree of voltage unbalance in the system and specifically at PCC (point of common coupling), the profile of bus voltages and total electrical losses in the lines for different power factor values of the synchronous machine.

The number of machines is varied from 1 to 10 to thereby ascertain the influence of different power injected in the 680 bus of IEEE 13 bus test feeder. Thus, the power is increased to 37.3kVA (50HP – nominal power of one wind turbine generator) in each simulation step. The power factors analyzed are 0.9 inductive, 1 and 0.9 capacitive.

All the features like load lines, voltage profiles in each bus, etc., are set in document provided by the IEEE, called IEEE 13 Node Test Feeder, which are considered as reference data for the system in its condition, so that they can be compared with the data resulting from the simulations that contain the wind synchronous machine included.

V. NUMERICAL RESULTS

The numerical results were obtained simulating the wind turbines at IEEE 13 node test feeder using ANAREDGEE software.

IEEE 13 bus system is shown in Figure 4, which is a radial distribution network provided with a voltage regulator at the source, a transformer between the buses 633 and 634 and a sectioning between 671 and 692 buses.

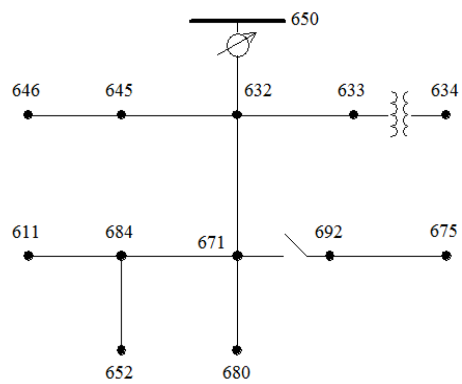

Figure 4. IEEE 13 Bus Test Feeder

ANAREDGEE is a program used to perform the simulation of the three-phase load flow (Backward/Forward Sweep algorithm). All the computational modeling involved and implemented in the program provided a high reliability of the results for the distribution system, based on the three-phase load flow models developed and adapted largely by Professor William H. Kersting [12] the University of Las Cruces in New Mexico, USA. These results were acquired in ANAREDGEE and validated with own results of the IEEE.

A. Case Study 1

Figure 5 illustrates the study developed.

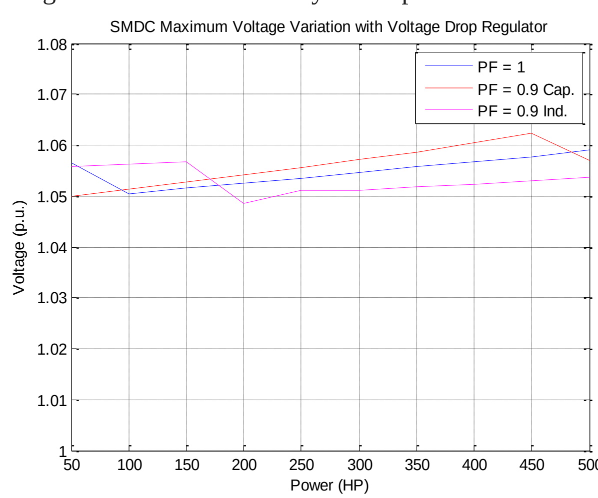

Figure 5. SMDC maximum voltage variation with voltage drop regulator

Figure 5 shows the non-linear variation of the maximum voltage in the system, when directly connected machine and the voltage drop regulator are present in the substation. In this case the hosting capacity is achieved for the three power factors types, except for 200HP and 0.9 inductive power factor.

The degree of voltage unbalance for this study is shown in Figure 6. It is observed that there is a considerable reduction in the degree of disequilibrium when the system is equipped with a voltage regulator at source, allowing allowable values before the rules in force in Brazil. For the inductive power factor, it is noticed a singular behavior before the other power factor values. Up to 150HP, inductive power factor showed high results when compared to the others, while for powers above 200HP the inductive power factor presented much more satisfactory results.

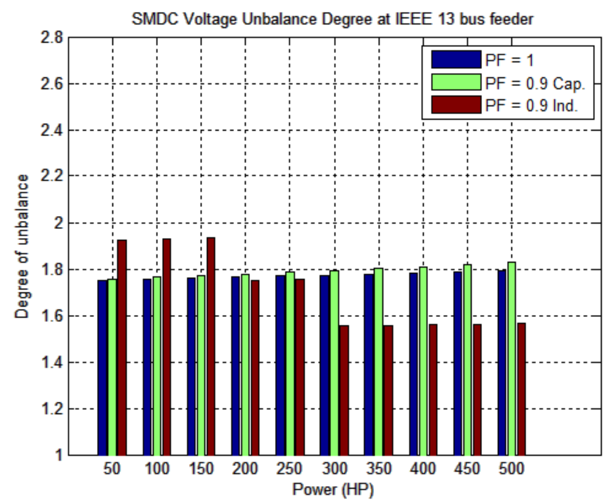

Figure 6. SMDC Degree of voltage unbalance

In case 1, it is also observed a reduction in the total losses of the system gradually to the extent that the power injected into the system through the machine increases (figure 7).

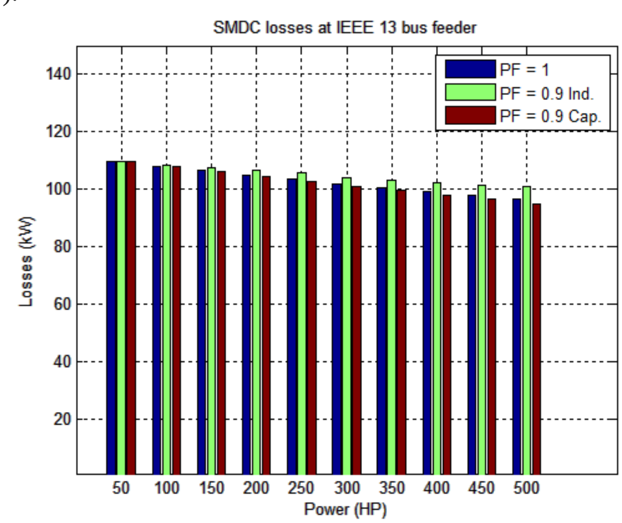

Figure 7. SMDC losses at IEEE 13 node test feeder

In the situation of figure 8 for all power factors, the loading is 80% for a power of 50 HP. It can be observed that the loading of the line between the source and the bus 632 is lower for a capacitive power factor of the wind turbines.

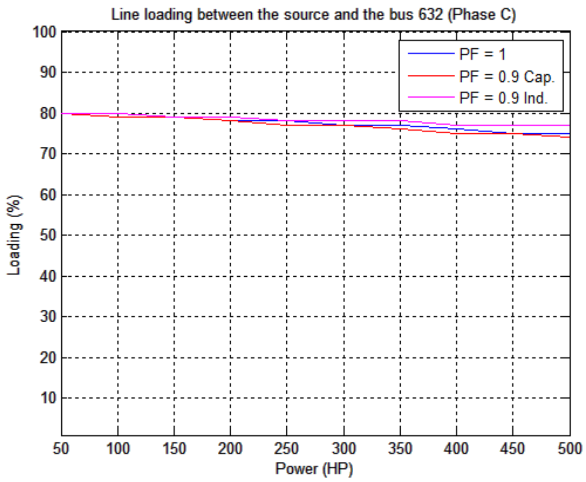

Figure 8. Line loading (source-632 phase C)

B. Case Study 2

With the system voltage regulator, the same study of the case 1 is repeated in the case 2, however the machine connection is made via the frequency converter. Figure 9 illustrates the study developed.

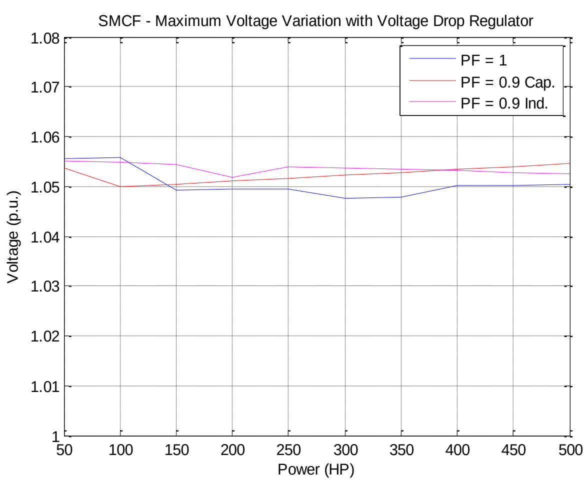

Figure 9. SMFC maximum voltage variation with voltage drop regulator

Figure 9 shows that the voltage variation of maximum value of the IEEE 13 bus system was caused by the connection of the synchronous machine with frequency converter. The hosting capacity is not exceeded to powers from the 150HP, considering the unitary power factor. For the power of 200HP, the results for the three power factors are very close and the hosting capacity is slightly violated for leading and lagging power factors. As noted in case 1, here too there was a reduction in the degree of voltage unbalance due to the use of a voltage regulator at the source, as can be seen in Figure 10. However, the inductive power factor shows the highest degree of unbalance values for power ranges up to 150HP. For larger injected power levels, setting the unity power factor in machine offers better results in relation to the degree of voltage unbalance in the generator connection bus.

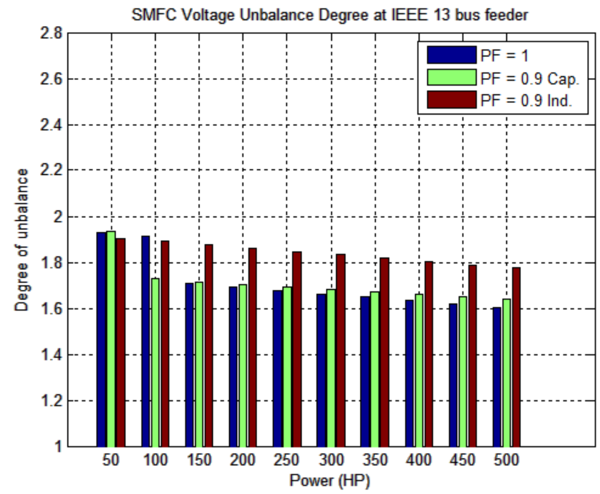

Figure 10. SMFC Degree of Voltage Unbalance

The system losses in case 2 are shown below:

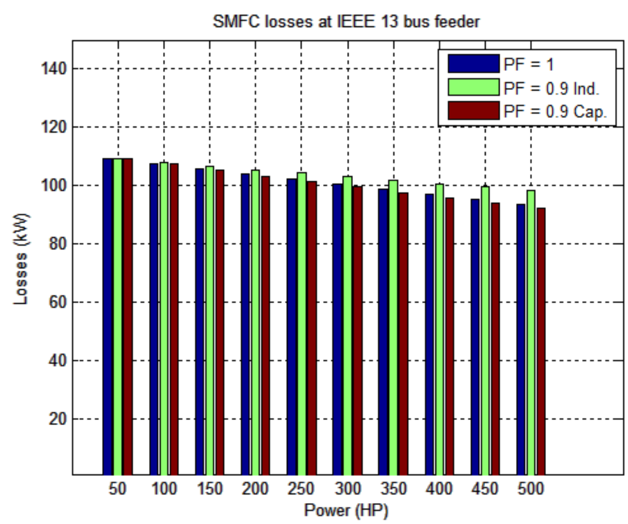

Figure 11. SMFC losses at IEEE 13 node test feeder

Although the graphic behavior is similar to the other cases, this configuration were found the lowest losses of the system for all power factors analyzed, showing that the voltage regulator's presence in the source along with the coupling of the machine to the system by frequency converter provide better results for the total losses of the network (Figure 11).

Regarding the loading of the line between the source and the bus 632, again found the best results when the synchronous machine is coupled to the system by frequency converter. With the power increase, there may be a reduction in the loading of up to 7% if the machine works with capacitive power factor. For unitary power factor and inductive, there was a decrease of 6% and 4%, respectively (Figure 12).

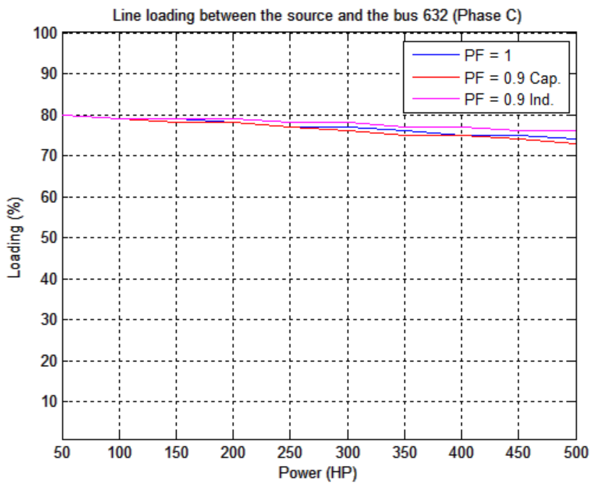

Figure 12. Line loading (source-632 phase C)

VI. Conclusions

This paper presented and discussed some important results for the operation of wind energy systems with directly connected synchronous machines and synchronous machines connected through frequency converter. Among the key findings analyzed is quoted: 1) When the voltage regulator is connected to the substation, voltages change in a non-uniform way, and therefore the hosting capacity can be violated to a smaller injected power and not violated to a higher power injected 2) Directly connected machine causes, in general, greater losses than connected through the frequency converter. The losses decrease the extent that a certain amount of injected power is present to the extent that the injected power increases; and there is a difference between the losses of different power factors. That is, the capacitive power factor causes smaller losses compared with the unitary and followed finally inductive power factor. 3) With voltage regulator, the voltage unbalance degree of the bus 680 varies non-uniformly. 4) Voltage unbalance degree is lower in general with the machine connected through the frequency converter. 5) Directly connected machine, because it is cheaper, is indicated only for a system designed for your connection, once again, that the violation of permissible limits in the system is more likely. If the system is not properly designed to withstand a direct connection to their machines, or for a system with a high degree of voltage unbalance, a connection through the frequency converter is advisable.

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