METHODOLOGY FOR ANALYSIS OF ANGLE STABILITY IN DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION

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ABSTRACT

Brazil is going through a moment of change in the power generation paradigm. Renewable sources are expanding their market share and the connection in distribution networks is inevitable. Customers will exchange energy freely with the power utilities, inconsistently and without predictability. The distribution systems, so far supplying radial feeders, with linear electric loads, with low short-circuit power and predominance of unidirectional power flow. This condition was drastically changed to a topology with multiple generations, distributed and with uncertain operation. This paper investigates the angular stability of distribution systems, with multiple synchronous and asynchronous generating machines, with penetration level increasing of distributed generation such as wind and photovoltaic. A methodology to develop a reduced equivalent dynamic model, as well as a stability analysis of distribution systems is proposed considering varied operative conditions and the characteristics of the traditional distribution systems.

INTRODUCTION

The Brazilian energy matrix diversification comes to meet a global trend of increasing the share of renewable sources in the electricity production. Although Brazil has a share of 45.3% of its production from sources such as water, biomass and ethanol [1], in addition to wind and solar energy, the public policies stimulate the net metering, this is, the energy exchange between customers and power utilities.

Another relevant characteristic in this scenario is the peculiarity of the distribution systems with unbalanced loads, from single-phase connections, two-phase and three-phase and with increasing non-linear portion.

In this context, there is an immense field for research on the impacts of this Distributed Generation (DG) expansion, since the distribution systems were not designed for this new reality.

The high penetration of DG raises questions about the behavior of networks considering the disturbances and load variations, and large variation in generations levels at short intervals of time. In addition, power system stability assessment concepts and the most simulation software used, are made for a different reality of the lived for distribution, where the unbalanced loads, the large systems extensions and the low power short-circuit are the reality.

This paper investigates the transient stability of distribution systems, with multiple synchronous and asynchronous generating machines, and increasing penetration of DG such as wind and photovoltaic.

PROBLEM FORMULATION

The use of small water potentials as well as the expansion of electricity production by consumer, leads us to questions about the operational impact and the influence on the electricity quality, in this new operating profile in the distribution systems. The current distribution networks have limited control elements, basically: voltage control have the AVR (Automatic Voltage Regulators) in substations, capacitor banks and automatic voltage regulators over the feeders. The protection network, in general, has the automatic circuit reclosers and fuses only.

These conditions, combined with abrupt changes of wind generation and voltaic sources, brings the question of how to behave the dynamics and hence that we have quality in distribution systems with this diversity of sources. Protection of distribution systems is also a relevant factor in the analysis, since in higher voltage networks, we have a more sophisticated protection system and to a lesser extent. In distribution systems, usually have some automatic reclosers in substations and at relevant points and numerous keys fuses protecting leads and specific loads. These keys are characterized by thermal fuses principle for switching short-circuits currents, which decreases the accuracy in working times and hence should be considered in the analysis. Another relevant point is the current methods for analyzing, devoted to transmission systems, but questionable for this new condition. Using the Simulight [2] simulator, this paper presents the evaluation of a distributed generation connected to a weak distribution system, showing the dynamics and effects on the quality of supply.

MODEL GENERATORS AND CONTROLS

In this paper the models of used machinery and regulators were:

Synchronous generator - Small Hydro Power Plant (SHP)

The SHP generates through synchronous generators, has

a nominal power 1 MVA and dispatches 0,4 MW. For being a small generation, typically operating in constant power mode and in this case, with unity power factor.
Synchronous machines can be represented by three models:
• Classic model, consisting of a constant voltage source behind the direct-axis transient reactance;
• Model for salient-pole generators;
• Model for generators with flat rotor.
The model used for machine was the MD03 [3].

Voltage Control

The basic function of an excitation system is to provide direct current to the field winding of the synchronous machine. In addition, the excitation control system performs basic functions and protection for the satisfactory performance of a power system by controlling the voltage applied to the field winding and therefore the field current itself. The control functions include control of the terminal voltage and reactive power generation, in addition to own functions to increase the stability of the system [4]. The voltage regulator used was the IEEE DC1 type, as shown in Figure 1.

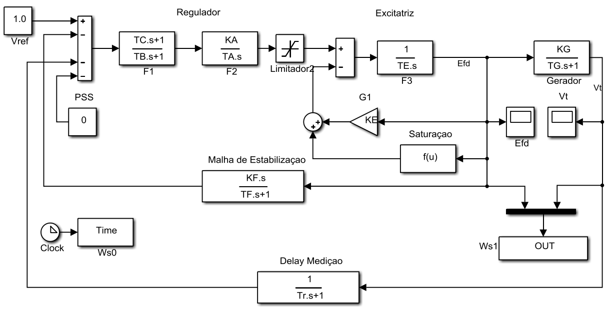

Figure 1 – DC1 IEEE.

Speed Governor

The primary regulation aims to maintain the frequency offsets within minimum values without loss of stability. Thus, the speed regulators are control systems used in this task. The speed automatic adjustment does act to increase or decrease the power of the generator when the frequency deviates from the nominal value (60 Hz in the Brazil).The speed regulator used was the IEEE HYGOV2 [5], [6] as shown in the Figure 2..

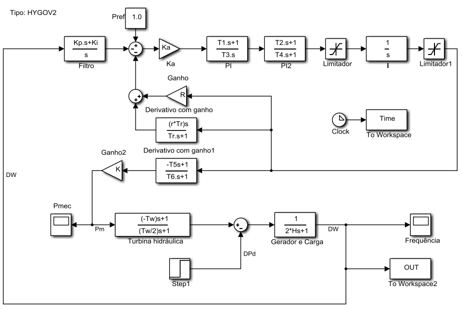

Figure 2 – Speed governor – HYGOV2.

Wind Generator

The wind generator chosen was the Squirrel Cage, Induction Generator directly connected (GIDC), because it was the most used on the principle of expansion of wind generation and display characteristics that can affect quality of supply. Figure 3 shows a simplified schematic of a GIDC connection to an electric system.

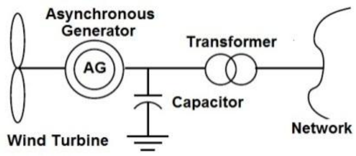

Figure 3 - Induction generator, squirrel cage (GIDC).

The induction machine may behave both as a motor and as a generator, and this alternating behavior is through the rotor rotating speed compared to the synchronous speed of the machine. When the rotor rotates at a speed less than the synchronous speed, the machine acts as a motor, and the faster the machine works like a generator. The induction machine connected to the network and powered by a faster speed synchronous, generates a voltage that has the same amplitude and frequency of the network to which it is connected. The induction generator is connected to the wind turbine through of gearboxes (with the function of increasing the angular velocity of the induction machine spindle by these operate at high speeds with a reduced number of poles) [7].

PROPOSED METHODOLOGY

As a way to evaluate the effects of the DG in Distribution Systems, are proposed the sequence illustrated in Figure 4, to analyze the Transient Stability of generic circuits.

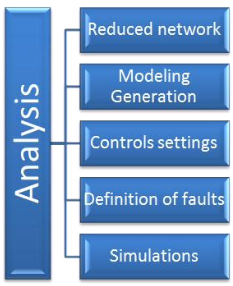

Figure 4 – Flowchart of methodology.

Distribution networks are large, with many branches and distributed loads. The use of time domain simulation brings the need to circuit size reduction, without losing the dynamic representation of the original circuit. In the first step is created this simplified model and validated by comparing to original values in steady state. The second step is DG allocations, which are made according to the perspective of the planner, either by appointment or by analysis of the situation. The controls used in each DG should be modeled and have the settings optimized, with

actual or typical values. The fourth step is to define the contingency which must be small changes in load, so as to assess the small-signal dynamic also sets up great contingencies (short-circuits), in order to evaluate the transient stability. In the case of distribution systems, small contingencies represents a disconnected branch , while major events are three-phase bolted fault in the main trunk feeder.
The last step is to analyze the responses of the machines and the torque effect on the generator shaft, as well as frequency and voltages.
The criterion for the torsion stress in Simulight is based on active power difference generated immediately before and after the switching (Ap) which is given by:

$$\Delta P = Pe_{(0-)} - Pe_{(0+)} \leq 0.5 \qquad [1]$$

where:
Pe_((0-)) is the active power generated immediately before switching. Pe_((0+)) is the active power generated immediately after switching; 0,5 pu is calculated based on the rated apparent power of the generator.

This criterion was proposed by a Working Group of the IEEE [8] empirically to safeguard the axis of the generator-turbine systems due to switching in electric network [4]. To analyze the simulation results, it is desired that the values contained in Table 3 are met.

Table 1 – Acceptable limits.

Variable	Acceptable value	Description
α	≤ 90°	Steady state rotor angle
ΔP	≤ 0.5	Torsion stress
Vrp	0.95 ≤ Vrp ≤ 1.03	Steady state voltage
Frp	59.9Hz ≤ Vrp ≤ 60.1Hz	Steady state frequency
Ft	59.5Hz ≤ Vrp ≤ 60.1Hz max	Transient regime frequency (30 s)

EXPERIMENTAL RESULTS

As a study case, a real feeder was chosen, with 22 km of main trunk feeder and a 1.859 MW demand. This circuit was reduced to 12 bar system as shown in Figure 5.

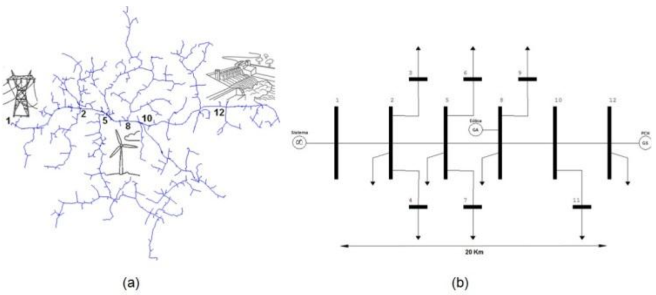

Figure 5 - (a) Real network. (b) Reduced network in the Simulight.

The circuit chosen for study, had the most significant we preserved, those with a greater extent or larger accumulated charge. Loads of branches and main trunk feeder were concentrated and losses distributed.
The power flow flowing from the reference bus to the original circuit without DG, is S = 1.859 + j0.215 MVA.

With the connection of DGs, the flow in the original network switches to S = 1.327 + j0.448 MVA.
The objective is to evaluate the impact of varied connection kind GD simultaneously in an actual distribution network, so as to realize the topology change and the change in the accessed network power quality.
In this study the wind generation is located approximately 50% of the main trunk feeder, while the SHP it is farthest point. This example is intended to simulate a case that illustrates the effects of the DG penetration in a relatively weak distribution network. The hydroelectric generation, a SHP, was connected in the farthest bus, injecting 0.4 + j0 MVA. In the intermediate bar, the insertion of a wind generation was simulated, directly connected type, generating 0.12-j0,27MVA. We therefore have a total j0.27 0.52 MVA DG, which corresponds to a penetration rate of 30.66%.
Analysis of the system was based on three simulations: Just disconnecting a branch, turning off a system load, being evaluated the stability for small signals. A short circuit in a branch, with triggering the protection, removing the fault and, finally, a short circuit in the main trunk feeder with automatic reclosing of the substation.
The distribution system under analysis has two connected DGs, a wind, GIDC type, and other hydro with synchronous generator. Will assess the impact on power quality, caused by power variations of these DGs, upon the occurrence of disturbances in the system. The generations connected will be assessed for the availability and operating conditions.
On the first two events it is desired that the SHP remain in synchronism and that wind does not consume too reactive. It is also expected that the voltage levels do not exceed the adequate limits. For the third event the current regulations of the power utilities requires disconnection of generation during the reclose interval. These conditions will be analyzed, observing the system voltage levels. The simulations were developed using the software Simulight Coppe [4].

Load disconnect

As a first event we have a load disconnect, located in the bus 3. This bus was chosen because it has the largest concentrated load on a system extension. We can see in Figure 6 and Figure 7, respectively, the rotor angle and frequency of the SHP, as evidenced timing after the event.

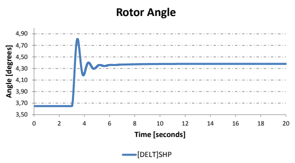

Figure 6 – Rotor Angle - SHP.

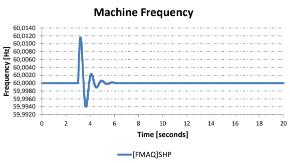

Figure 7 – Generator frequency.

The Figure 8 shows the reactive power consumption of the Wind Generator. Realize a transient increase in the consumption of reactive around 7%, and the rapid stabilization in over 4% of the original value.

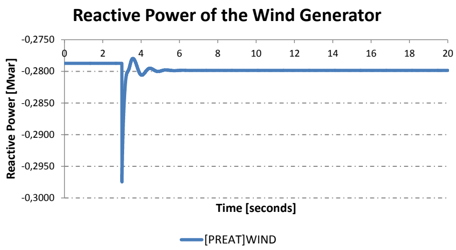

Figure 8 – Reactive Power – Wind Generator.

We have seen in Figures 9 and Figure 10 that profile voltage have a transient and permanent elevation. The torsional effect on the axis of the SHP is within the expected limits.

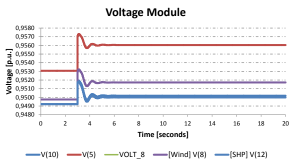

Figure 9 – Bus Voltage.

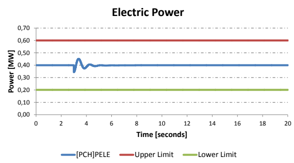

Figure 10 – The generator shaft torsional.

Short-circuit on Branch with triggering the protection

To evaluate the performance of SHP during a short circuit in a branch, where it is want that the generator remains synchronized after fault clearing has been simulated an event on the bus 11, with operation of two typical distribution fuse, 15K and 25K. The clearing times for the event are respectively 130 ms and 250 ms. For the fuse 15 K, response time 130 ms, seen in Figure 11 and Figure 12, that the SHP keeps the synchronism, but the frequency limits, that is 60,1 Hz is exceeded.

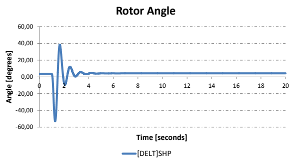

Figure 11 - Rotor Angle - SHP.

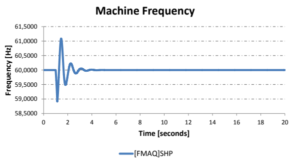

Figure 12 - Generator frequency.

However, we have a significant sag, reaching 0.2 pu on the bus 10, seen in Figure 13. SHP bus, the module voltage gets to 0.21 pu and is expected operate under voltage relays. We can also see in Figure 14 that a large torsional effect on axis generator, which reduces the lifetime of the machine.

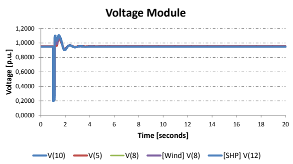

Figure 13 - Bus Voltage.

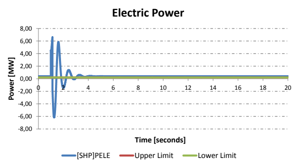

Figure 14 - The generator shaft torsional.

The reactive power absorbed by the induction generator, can be seen in Figure 15, there being a transient increase of 4 times of order, which contributes significantly to the system voltage sag.

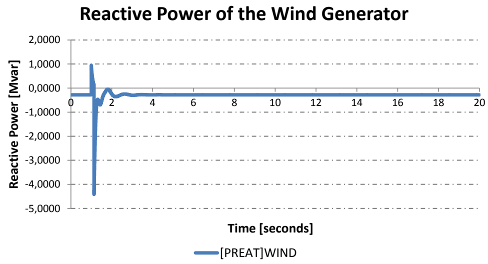

Figure 15 - Reactive Power – Wind Generator.

For the fuse 25K with 250 ms operating time, seen in Figure 16 and Figure 17, the SHP does not maintain synchronization and be disconnected from the system.

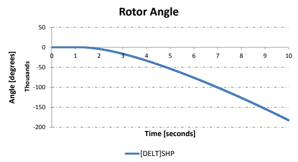

Figure 16 - Rotor Angle - SHP.

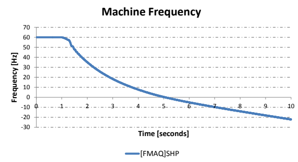

Figure 17 - Generator frequency.

In this event the absorption of reactive power by wind generator is not different from that in the previous simulation, with 15K fuse.

The answer to this type of defect and its operating time is undesirable because the events with the possibility of insulation shall not affect the operation of Distributed Generation. Note that the evaluation is very important events adjacent to the main trunk feeder.

Short-circuit on the main trunk feeder with reclosing on recloser

This event evaluates a typical Distribution Systems situation where during the automatic reclosing of the substation, the DGs are removed. A three-phase short circuit is applied on the bus 5, with substation protection operation in 500 ms. It is observed severe voltage variation and a large frequency deviation, respectively shown in Figure 18 and Figure 19.

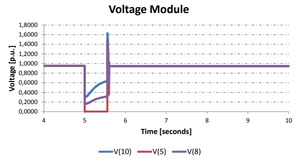

Figure 18 - Bus Voltage.

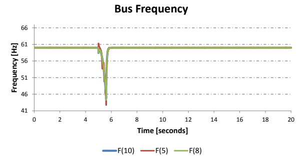

Figure 19 - Generator frequency.

With the generations disconnection there is a large generation loss which, for this GD level penetration and these control settings, certainly results in disconnection of the whole system, because in practice the protections will not allow such violation of voltage and frequency.

As the automatic reclosing in distribution networks, mainly serving rural areas, is essential to the quality of supply, it is evident the need for a deeper evaluation of each case, as in systems where GD is significant, this strategy disconnecting the generations during the timing of the action of protection, it is reckless to the stability and quality of supply of the system under analysis.

CONCLUSIONS

This paper seeks to highlight the need for careful evaluation in distributed generation connection in Distribution Systems. The inherent characteristic of R >> X, especially in rural feeders, even in systems with low index of distributed generation penetration, stability is compromised and reflections in the power quality can be enhanced. The proposed methodology indicates the need to represent the large distribution systems through smaller equivalent networks, representing significant extensions in load and impedance. The application of the methodology in a real system confirmed the need to evaluate the critical events in the feeder trunk, but also the peripheral events, evaluating the operating times of the protection fuses. With Distributed Generation increase the distribution systems should receive investments in order to increase their short-circuit power, extend the protection of feeders and evaluate the possibility of operating with islanding and monopolar reclosing. It is evident the need for Distributed Generation contributing reactive power support, in order to optimize voltage levels, especially during contingencies. Finally, protection studies should include trying to keep the same Distributed Generation with automatic reclosing in order to ensure the stability and quality of electricity supply in multi-machine systems.

ACKNOWLEDGMENTS

The authors would like to thank the technical and financial support of Cooperativa Regional de Energia Taquari Jacui (CERTAJA ENERGIA), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundacão de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

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