Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp496-502)

Large Scale Wind Power Integration into Power Networks Using SVS and Series Reactance

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Abstract: - The use of automatic reactive power compensation and series reactances as an adaptation mechanism for large scale wind power integration into power networks is discussed in this paper. The authors investigated the benefits of this mechanism aiming to avoid the usual large wind generation disconnections when a voltage dip occurs in power system due to faults in lines or other devices. The authors evaluated the impact in the critical clearing fault time in power system due to the insertion of the reactive compensation and series reactances in the wind park as a measure of the benefits achieved with the adaptation mechanism. The results demonstrated the convenience of this king of mechanism that can be used with conventional induction generators or doubly-fed induction generators. Even when the evaluation was made using the Venezuelan grip operation authority criteria, a sensibility evaluation was made using the low voltage ride through capability curve criteria, and the results in both cases confirmed that this mechanism could be a cheap solution in conventional wind park and for new ones as well, to avoid the wind generators disconnection when a voltage dip occurs in the power network.

Key-Words: Reactive Power Compensation, Large Wind Power Generation, Critical Clearing Fault Time, Series Reactance, Low Voltage Ride Through Capability Curve.

1 Introduction

Conventional squirrel cage induction generators and new technology generators, like rotor power converter controlled generators (doubly-fed induction generator), are expose to huge rotor current during large voltage dip caused by faults in the power networks. During the dip and some seconds after the fault is clear in the network, the conventional generators drain too much current in the rotor as a consequence of the slip increment droved by electric and mechanical energy unbalance. Similar effect is present in the doubly-fed generator because, to avoid the over dimension in the electronic circuitry of the converters, those power controllers are by-passed during the transient, converting those generators a simple conventional wound rotor induction generators (with the same performance than the squirrel cage ones).

During the transients, when the power system is trying to use all the reactive power reserve in the network for voltage support and fast recovery, the generator's inductive behavior are accentuated consuming reactive power from the network, making the restoration some times impossible and conducting the system to a voltage collapse.

Network operators usually prefer the disconnections of that kind of generators and their reconnection after the voltage has been recovered to normal values. This policy imposed in some regulations implies the use of low voltage relay that send the disconnection signal to the main breakers in the common coupling point, between wind parks and power networks, when a pre-set voltage dip value is reached. The disconnection it self does not mean a problem if the active power reserve are display according to this requirements, but have to be planned, dispatch and paid making the operation more expensive.

Nowadays, the wind power penetration and the relative importance of this generation during low demand daily period, make the disconnection somewhat impossible, unless an expensive reserve should be charged to service users. For this reason, this kind of investigation is very important because the goal is to find as much as possible technologic solutions to make the wind power a reliable source with the minimum constrains.

Under this idea, this paper shows the results obtained using a series reactance and a static voltage compensator as wind power park devices. The voltage compensator is used for wind generators voltage support, during and immediately after the fault, and the series reactance has the purpose to "separate" the power network and the electric wind power installations to reduce the consequences of network faults into the wind park and also, to reduce the reactive requirements from the static voltage compensator.

2 Main Design Considerations

2.1 Induction Generator used in Wind Power Applications

The most common induction generators used for wind purposes are the squirrel cage induction generator (SCIG) and the wound rotor induction generator (WRIG).

The first kind, SCIG, can be connected directly through the step up transformer to the medium voltage wind park installations, or using and electronic interface. This interface has the advantage that can controlled the electric and mechanical interaction between network and generator but, for large wind purposes this interface has to be sizing with the main generator capacity making it expensive and economically prohibited. The direct connection is the most common, cheap and widely used type of SCIG in the world. The SCIG, like any induction machine, has a strongly voltage and slip performance dependency (Fig. 1).

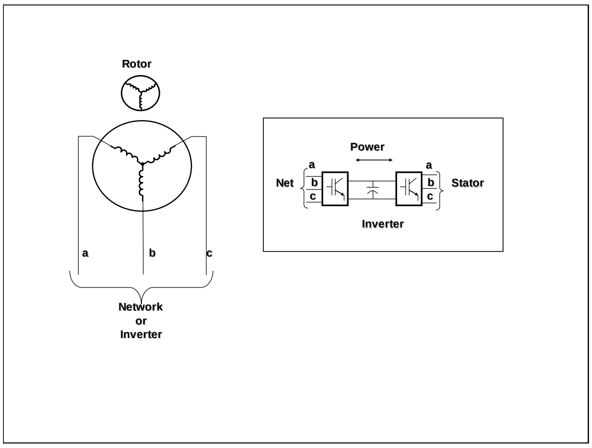

Fig 1. SCIG

The WRIG is nowadays spread and commonly used in new installation with a rotor power controlled device connected to the same wind park electric installation. The most common rotor controllers are the Rotor Load Variable Control (RLVC) and the Pulse Width Modulation Inverter (PWMI). The most used is the PWMI commonly refer as a doubly-fed induction generator. Stator is directly connected to the step up transformer and the rotor is also connected to the same incoming electric installation using another transformer for appropriate voltage range in the controller. Generator torque and slip is controlled with the rotor electronic interface and, one of the most important advantages, it is possible to control the reactive consumption making possible no reactive power interchange with the network (Fig. 2).

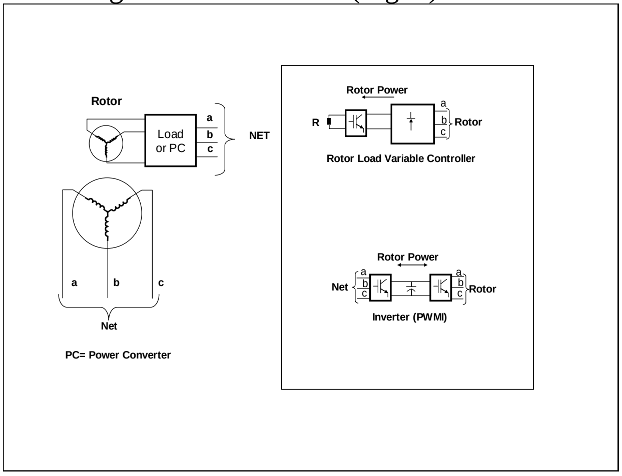

Fig 2. WRIG

2.2 The Power Unbalance during Fault Conditions and the Restoration Process

When the power system at normal condition, the mechanical power in fed by prime mover equals (power conversion losses neglected) the electric power generated in all generators. In induction generators the most critical variable, the slip, is at nominal value (i.e. -0,4 p.u. for a typical 2MW wind generator). A suddenly fault occurs in the power system and the power balance is not maintain any longer in any generators. In the wind generators, the results will be an important slip increment and when the fault is clear, those generators, like any others, most recover its normal operation in such a way that a power interchange take place during some seconds before a new condition is achieved. During and after the fault is cleared, all generators move one against other, and the wind generators are not an exception.

The slip increment in wind generator boost the inductive behavior of this machines, and rotor and stator currents are so high that a thermal delay disconnection occurs as a protection strategy. In WRIG generators, before the disconnections, a controller by-pass occurs to reduce the thermal stress over such devices, avoiding an uneconomical controller over sizing design. During the by-pass this generators becomes like a SCIG because rotor are short-circuited. So, during the fault and some seconds after it has been cleared, both kinds of wind generators behave most likely from the power interactions and physical phenomenon point of view.

During the fault and some seconds after the fault is cleared the induction generators are acting like an inductive load, consuming a large amount of reactive power form the system. During this time, a restoration process take place in the system where the reactive power is needed for voltage recovery support. But, with the inductive consumption from the wind park, the restoration could be, some times, impossible due to voltage collapse.

This period of time is commonly studied using the swing motion equations that involve all generators. In the case of wind generator those equations could be written as:

$$2H_t\frac{dw_t}{dt} = T_t - K_s{*}\theta_{tg} - D_s(w_t - w_g) \qquad (1)$$

$$2H_g\frac{dw_g}{dt} = T_g - Te \qquad (2)$$

Equation (1) is for turbine and generator interaction and equation (2) is for system and generator interaction.

Even when it could be possible that the generator could withstand the high currents, most operators prefer the disconnection of the wind generator because it could be possible to better support the voltage recovery process. That was a common practice in the past but not any longer since the relative weight of wind generation during the base or low daily load profile, make this generation very important in the generation share units commitment.

In these cases, when the disconnection occurs during these load profile conditions, the system must have enough spin generation reserved connected to support the power imbalance or to have and adequate interconnection with other systems, to support the imbalance through an increase in the transmission interflow. In both cases the reasonably priced unit dispatch and selling/buying contracts moved something away form the optimal point, and that represent more cost for users.

To avoid this, a whole regulation rules have been changing to command the permissible conditions in witch this kind of generator can be disconnected. In this way, the technology investigations are aim to find cheaper solutions to improve the wind generators performance during faults in the power network.

For this purpose, this investigation was carried on using the static voltage compensation and series reactance to create an "adaptation mechanism" that improve the voltage response of wind park during fault conditions in power networks.

2.3 Basic Design Considerations

To develop the study an imaginary wind generation was created in which design was considered a real network located in some place of Venezuela (Isla de Margarita) where the wind assessment indicates a reasonable feasibility for one wind park with 90 MW of capacity. So, the design included a wind park prototype with 45 units (VESTAS V-80) with 2 MW of capacity each one. An array of 5 x 9 units were considered where each 5 units where connected to the same 13,8 kV circuit as indicated in figure 3.

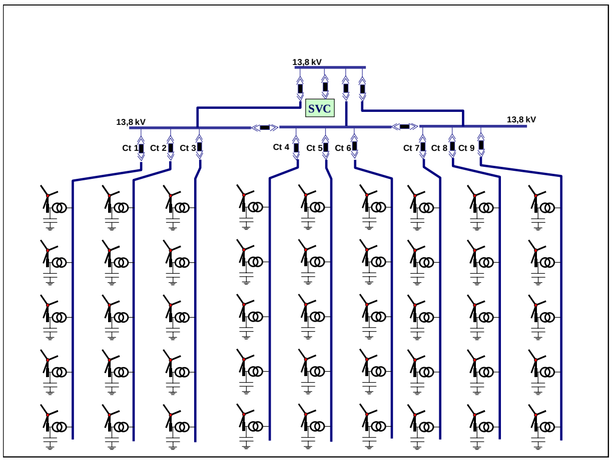

Fig. 3 . Wind Park Array

The collector substation was considered with 3 main busbars with longitudinal breakers and 1 busbar with the static voltage compensator (SVC). The primary voltage of the collector system is 13,8 kV and the generator voltage is 690 V. SCIG generator was considered and each unit was capacitor compensated in the primary side for 100% power factor correction in only one step.

The generator compensation was design under the no load criteria, so the capacitor are connected in only one step when the generator is connected to the main circuit as soon as the wind blows over 4,5 m/s. Under this condition, all busses must remain under 1.05 p.u. voltage with minimum generation in all units. To fulfill this requirement the svc must have an inductive range to compensate the high capacitive load under low generation conditions.

The common coupling point between wind park collector system and power network is done through a 115 kV busbar which is connected the collector system with 2 autotransformers 115/13,8 kV. Figure 4 shows the detail of this arrangement.

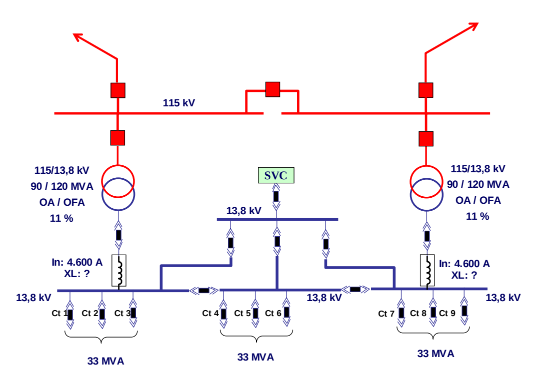

Fig 4. Substation arrangement

In figure 4 it can be pointed out the presence of one svc and two series reactances with a thermal capacity similar to the power transformers but unknown impedance because that value must be design with the svc to optimize the ranges. The series inductance has the purpose to “electrically move away” the network and the collector system, in order to minimize the network fault consequences over the wind generators and to reduce the svc requirements.

2.4 SVS and Series Reactance correlation

Figure 5 shows the design model used to compute the power reactive and series inductance calculation. Vc and Vg was maintained fix at 1.0 pu.u and the Vs was change to simulate a voltage dip from 1.0 pu. To 0.5 p.u. in steps of 5%. The calculations were made using the PSS/E power flow program.

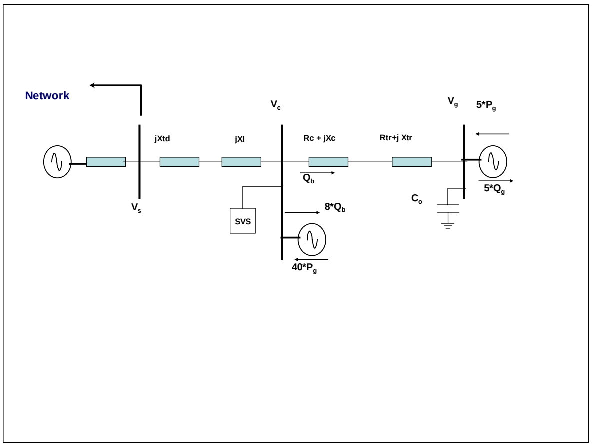

Fig 5. Design Model

The generator was simulated in the middle of the primary collector circuit to represent the mean behavior of all 5 generators connected along each primary circuit. Other 40 generators were simulated as one generator with the adequate power generation. Only one power transformer and one series reactance was considered because the design assumed n-1 criteria for the main substation.

Figure 6 and 7 shows the relationship between the svc reactive generation and the inductance for different voltage dip. In figure 6 a 1 MW of generation in each unit was considered and in figure 7 a 2 MW was considered.

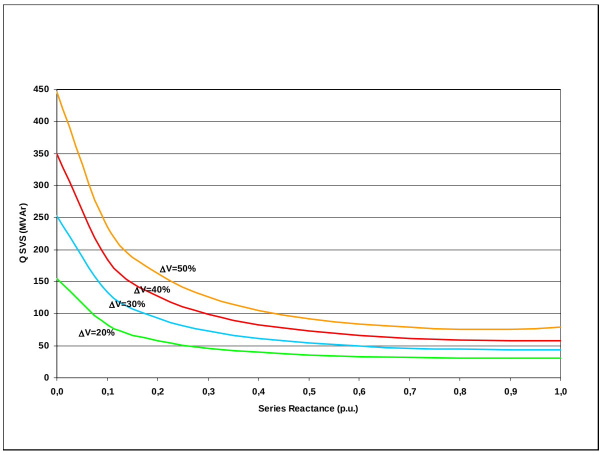

Fig. 6. SVC and series reactance relationship for 1MW

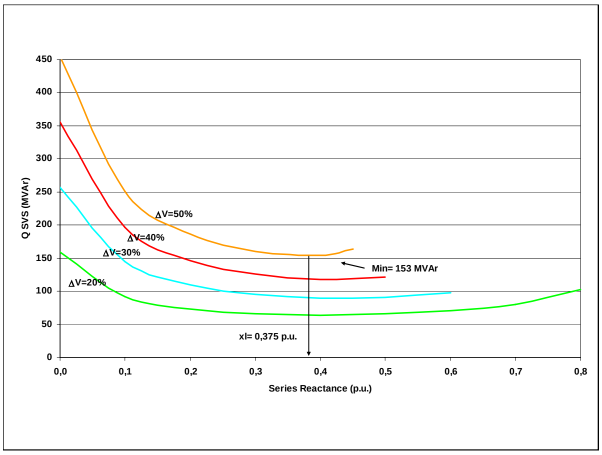

Fig. 7. SVC and series reactance relationship for 2 MW

The results show that for a maximum generation of 90 MW in the wind park, the maximum reactive power requirement is achieve. And the maximum, of course, is required for the maximum voltage dip. It can be seen that the series reactance reduce the reactive power requirements in the SVC. A minimum of 153 MVAr is required for the svc and correspond to 0,375 p.u. of series reactance.

An optimization process was considered including investment consideration. A new curve was developed in fig 8 were the economic optimal value for the svc is 160 MVAr and a series reactance of 0,3 p.u.

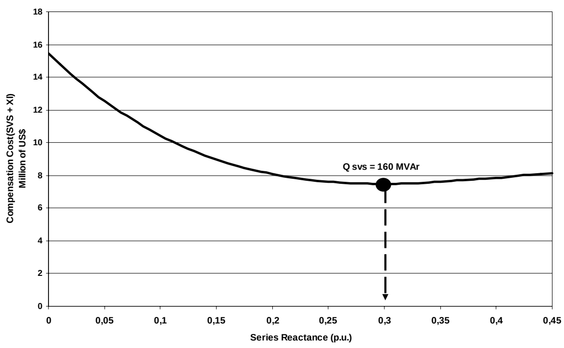

Fig. 8. Economic Optimization

The SVC was also required to have an inductive range to maintain a 5% maximum voltage range over the nominal values.

3 Power System Simulations

3.1 Power Flow Results

The simulation were done representing the network shown in figure 9, were there are two main power sources besides the wind park: a thermal power plant with 220 MW of installed capacity and a cable interconnection with main land (115 kV).

Fig. 9.The power system of Margarita Island

The wind park model used in power flow program is show in figure 10, were each machine group represent 5 generation units.

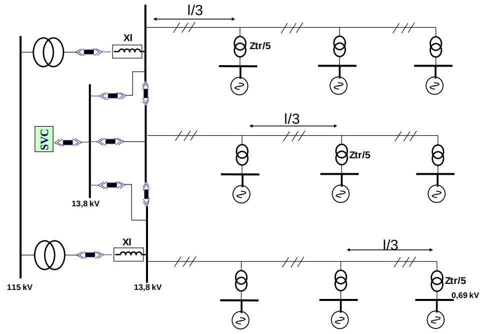

Fig. 10. The wind park representation

The simulations were done for three wind generation conditions related to its capacity: 100%, 70%, 40% and 3%. The system response was very successful and no voltage violations were fund at any buses for any single contingency applied. The 40 MVAr of inductive range in the SVC was correctly dimensioned and was checked under the low generation condition simulated. Also, no mayor reactive power is interchanged between the network and the collector system was found.

3.2 Dynamic Results: Critical Clearing Fault Time

For dynamic simulations a flux linkage model for induction generator was used to represent the wind generators. The turbines and generators were simulated as one mass and no mechanical power was considered constant during the run time. The main machines characteristics use in the simulation were:

H= 5 s	T’’= 0,1 s	T’= 1,53 s
X= 4 p.u.	X’= 0,3 p.u.	X’’= 0,2 p.u.
Xl= 0,1 p.u.		

The simulations were done using the same software used for load flow analysis. The thermal units in the network were represented in detail using the current data of generators, governors and excitations models. The mainland system was considered as an infinite bus.

The goal in these simulations was to evaluate the critical clearing time (CCT) for any fault in the network comparing the wind park with and without the compensation mechanism. Figure 11 shows the result of critical clearing time without the compensation mechanism.

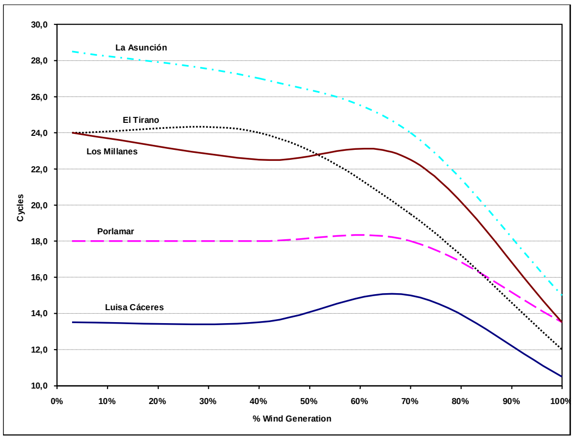

Fig. 11. CCT without compensation mechanism

The worst wind generation condition to define the critical clearing time is 100%. This restriction is first located in Luisa Cáceres and El Tirano substations. This result is expectable because for this condition of wind generation, both substations represents the voltage support nodes in this power systems, so it is expectable that faults in these substations are more restrictive than in others. The statement is verified when wind generations comes less import in proportion to the thermal and main land power source. When no wind generation is presented, Luis Cáceres is more representative for clearing time purposes. Figure 12 shows the same evaluations but considering the "adaptation mechanism".

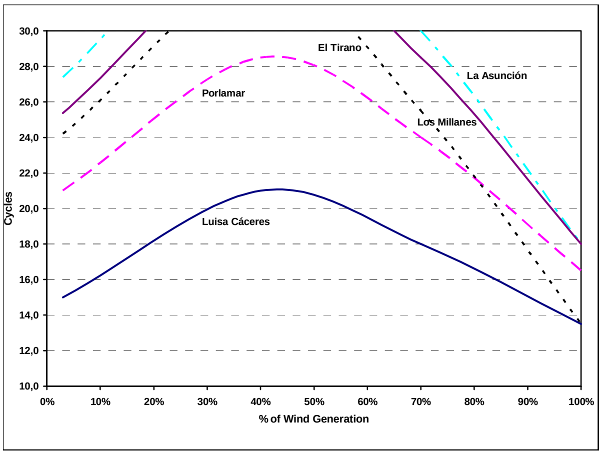

Fig. 12. CCT with compensation mechanism

As can be seen, the critical clearing times in all substations have increased considerably. Here, like in the previous cases analyzed, the Luisa Cáceres substation represents the most critical case and it is presented for a 100% of wind generation. El Tirano substation shows a similar condition in this case, it has the same critical clearing time like in Luisa Cáceres. The reason is due to in this case, both substation represents the most important nodes from the voltage regulation point of view. Unlike the previous case, the presence of an SVS gives more importance to this substation for voltage support purposes.

For the Luisa Cáceres substation, the critical clearing time is 18% bigger with the compensation than in the case where no compensation was considered. Similarly, for the El Tirano substations the difference (for 100% of wind generation) is around 13%.

The best measure of the gain achieved with the compensation is represented in figure 13, where both cases are shown for the main voltage support substations: Luisa Cáceres and El Tirano.

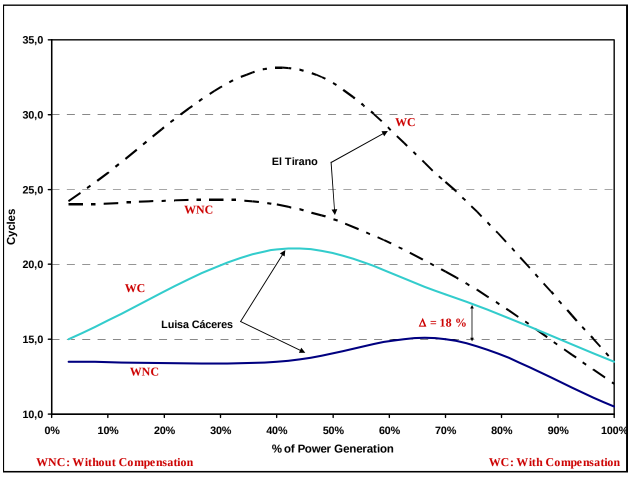

Fig. 13. CCT comparison

It could be notice that the maximum benefit achieved by the compensation is presented around 75% of the wind power generation level. But the minimum clearing times are for the 100% of the wind generation.

It is very important to point out that those results are based on the dynamic power system performance criteria used by the Venezuelan operator. In few cases, the critical times were defined by lost of synchronism in the induction generator, and in most cases the transient voltages performance were the restrictions that defined the critical clearing fault time.

3.3 Dynamic Results: Low Voltage Ride Through Capability Curve

As a sensitivity investigation, both cases were analyzed using the low voltage ride through capability curve (LVRTCC) criteria used in some European operators. Figures 14 and 15 show some results from the analysis.

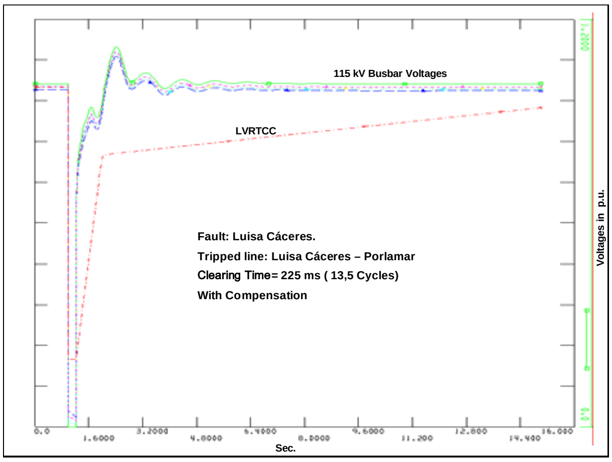

Fig. 14. CCT using LVRTCC

In figure 14 the critical clearing fault time is the same for the case using the Venezuelan operator criteria. As can be seen, the LVRTCC would give more time for the clearing process because voltages are over the curve and no long term lost of synchronism (a typical behavior present in induction generator) is present.

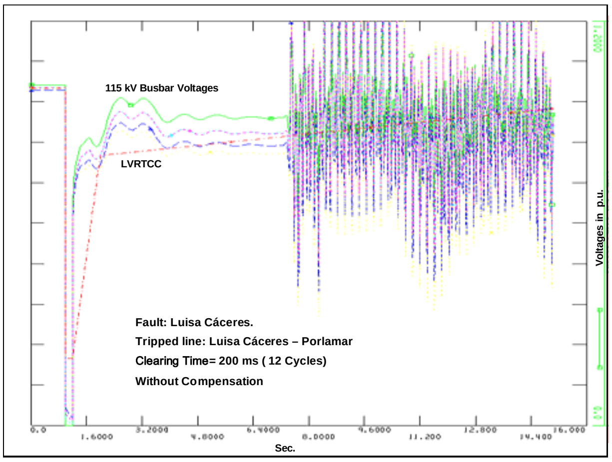

Fig. 15. CCT using LVRTCC

In this case, without compensation, the critical clearing fault time is reduced because it can be seen that the long term lost of synchronism phenomena is present.

4 Conclusion

The load flow and dynamic analysis shown that the compensation mechanism using an SVS and a series reactance is a technological solution that can be use to minimize the problems presented in the large scale wind power integration to power networks.

In a large scale wind power integration cases, the critical clearing times and may be some other parameters most be evaluated for many wind power generation level, because the system do not shown the same behavior over the whole range of generation.

The mechanism proposed in this paper could be used in new or in existing wind power installations where regulations prohibited the disconnections of induction generators when a voltage dip occurs in the power network.

More detailed analysis must be done for any practical case and can be found that the compensation mechanism gives some advantages for the whole network and in such case, some economical compensation could be obtained from the market attachable to the wind park profits.

Better performance and cheap compensation schemes could be obtained in case where the wind generators compensation capacitors can be divided in switchable steps. Also, the mechanism could be improved when the wind park uses doubly-fed induction generators.

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