

Impact of the Use of FACTS to Increase Robustness of Operation in Grids with Large Scale Wind Generation

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Abstract — Increased penetration of wind power should not jeopardize power system robustness of operation. One of the critical issues is related with the possibility of the loss of large shares of wind power following a system disturbance. The propagation of voltage reduction that results from a short-circuit may provoke the disconnection of the wind generators, especially those that do not present ride through default capabilities.

The use of FACTS connected to the grid, nearby the large wind parks, may attenuate such a situation. In this work the effectiveness of such technical approach is addressed and discussed. Results obtained demonstrate that the use of FACTS increases grid robustness of operation by avoided the disconnection of part of the wind generation.

Index Terms — FACTS, Wind Generation, Ride through default, Grid Codes.

I. INTRODUCTION

The presence of large amounts of wind power generation in electrical networks requires that wind energy conversion systems should be kept in operation when disturbances occur. The loss of large amounts of this generation may lead to system instability problems or to overload of interconnection lines.

The capability of survival of these generation units to voltage dips that follow a short circuit in the grid is thus becoming a mandatory requirement in the Grid Codes of several countries. Wind generator manufacturers are developing systems capable of surviving to such voltage dips, complying with such Grid Code requirements. It also happens that the already installed wind generators are not capable of withstanding such grid disturbances, which requires the adoption of external measures like the installation of Flexible AC Transmission Systems (FACTS) devices. Such devices are capable of providing a support to voltage profiles, limiting the voltage deep during the short-circuit duration time. In these cases the issues of concern are: a) location of these devices and b) dimensioning of their capacity.

The research herein described tackles with such a problem, dealing with the Portuguese electric power system within an Iberian scenario (since 11GW of wind generation

are already in operation in the Iberian Peninsula). In this work different technologies associated with the already installed wind generators have been considered. The studies developed aimed to demonstrate that the use of FACTS allows a considerable reduction of the amount of wind production that is removed from operation, by the operation of under voltage protections, following a grid default.

Several operational scenarios have been considered in this study, however only results from the ones related with valley hours with small hydro generation and large wind penetration are described in this paper.

Simulations were performed using the PSS/E software and its conventional generation models to which a new set of models (developed in house) was added to describe the doubly fed induction generator (DFIG) and the variable speed synchronous generator (SIN). Also conventional wind induction generators (IG) were considered and modeled.

Valley hours scenarios correspond to a total production of 4600 MW, of which 1200 MW were considered to be of wind power origin. The three different wind generator technologies were distributed over the grid in 33 connection buses (considering the already installed wind farms, the ones presently under construction and those who have their projects already approved). The used network structure and data corresponds to the scenario defined for 2006, according to the investment plans of the Portuguese Transmission System Operator (TSO) for the period 2004-2009 (public information [3]). The wind generation scenario corresponds to a situation where 51% of the installed capacity is based on DFIG machines, 38% of SIN and 11% of IG (Fig. 1).

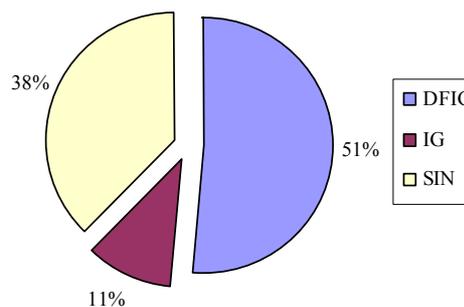


Fig. 1 – Portuguese technologies installed - National Total

The studies performed included the Spanish network and its interconnection with France and Morocco, assuming that in the simulated scenario about more 6000 MW of wind power was injected from the Spanish side of the grid. This generation consists of 60% of DFIG units and 40% of IG. Typical data regarding the wind generators was adopted to perform these studies. The corresponding wind parks were considered to be connected in 57 network buses.

Fig. 2 describes the location in the Iberian system of the buses with wind parks.

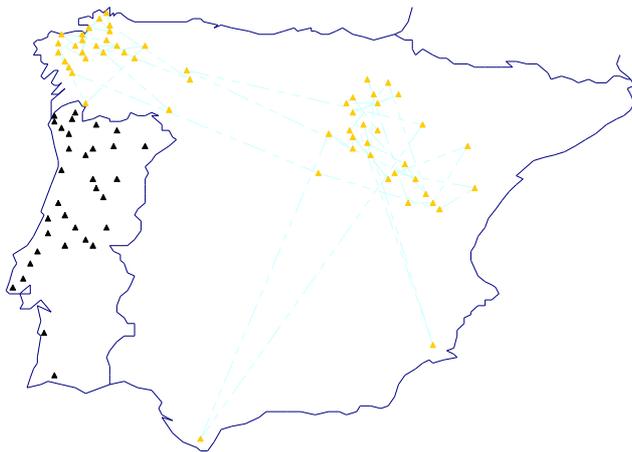


Fig. 2 – Approximate geographic location of the wind generation buses

II. MODELS

A. Generators models

DFIG Model

Figure 3 depicts the general scheme of the DFIG. A full description of the DFIG mathematical model as used in this research is given in [2].

A d-q voltage regulator is adopted for the control of the rotor-side converter, modeled as voltage source. To achieve active / reactive power control capabilities the rotor-side converter operates in a stator-flux d-q reference frame, controlling both active and reactive power outputs through v_{qr} and v_{dr} components, obtained from two separate sets of PI controllers. More details of this scheme are described in [12]. The PI controllers involve a cascade structure, where the outside PI blocks are used to regulate the reference rotor currents (i_{qr} and i_{dr}) and the inner side PI blocks are used to regulate the v_{qr} and v_{dr} components, respectively [2,12].

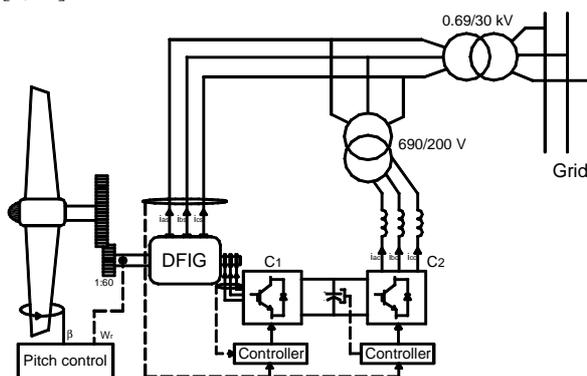


Fig. 3 – Physical configuration of the DFIG wind generator.

Through the rotor-side active power control loop the wind turbine is driven to operate with maximum power, once the active power reference input of the control system is set from a wind turbine operational optimal power curve

In this work, it was considered that the DFIG is controlled in order to supply: a) the active power from one curve of maximum power; b) reactive power defined from a specific set point [5]. The control philosophy adopted assumes that the converter of the rotor side is like a voltage controlled source and regulated from control tensions, in co-ordinated d-q, proceeding from controllers PI. These, in turn, configure in structure in cascade, whose external blocks of both meshes of control regulate reference chains (i_{qr} and i_{dr}) that v_{qr} and v_{dr} are injected in the internal blocks so that to regulate the control components, and therefore, the powers active and reactive of exit of the generator, respectively. Such boarding of control loop is described in detail in Fig. 4.

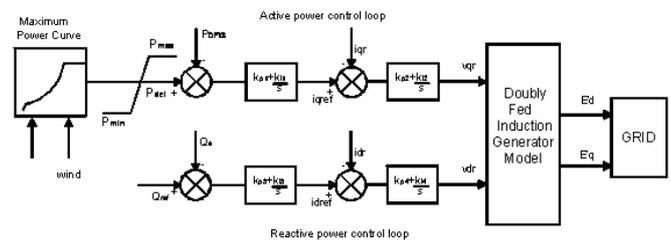


Fig. 4 – Control Loops for Active and Reactive Power of the DFIG.

IG Model

The model of the induction generator (IG) was derived after the Park equations, neglecting the fast stator transients [7]. Thus a third order model for this type of machine was adopted.

SIN Model

The synchronous variable speed generator was modelled through a simplified model where the mechanical part is neglected since the cascade of electronics converters filters mechanical interferences that could be passed to the grid.

The model adopted is a controllable source of active and reactive power, being its control loops described in detail in [7] and [8].

B. FACTS model

This section explains briefly the basic configuration of the Static Shunt Compensators (SVC) and Static VAR Compensators (STATCOM) exploited in this work [11].

SVC

Fig. 5 shows a schematic diagram of a SVC. The compensator normally includes a thyristor controlled reactor (TCR), thyristor-switched capacitors (TSC) and harmonic filters. It might also include mechanically switched shunt capacitors (MSC), and then the term static var system is used. The harmonic filters (for the TCR-produced harmonics) present a capacitive behavior at fundamental frequency. The TCR is typically larger than the TSC blocks so that a continuous control is performed. Other possibilities include fixed capacitors (FC), and thyristor switched

reactors (TSR). Usually a dedicated transformer is used to interface the MV side with HV connecting bus. The transmission side voltage is controlled and the MVar ratings are referred to the transmission side.

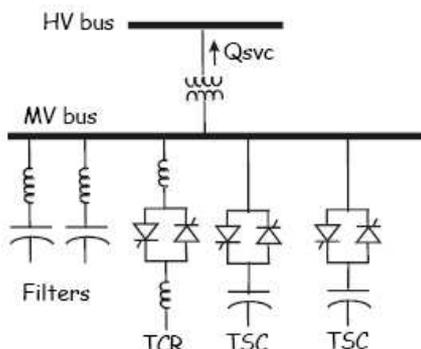


Fig. 5 - Schematic diagram of an SVC.

The rating of an SVC can be optimized to meet the required demand. The rating can be symmetric or asymmetric with respect to inductive and capacitive reactive power.

STATCOM

The voltage-sourced converter (VSC) is the basic electronic part of a STATCOM, which converts the dc voltage into a three-phase set of output voltages with desired amplitude, frequency, and phase. Fig. 6 shows the simplest implementation of a STATCOM.

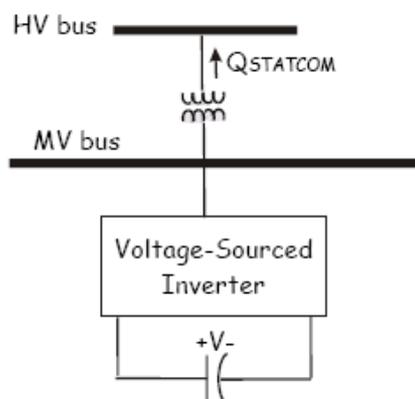


Fig. 6 – Schematic diagram of a basic STATCOM

There are different methods to implement a voltage-sourced converter. Pulse width modulation (PWM) control is used.

Inherently, STATCOM have a symmetrical rating with respect to inductive and capacitive reactive power. For example, the rating can be 100 MVar inductive and 100 MVar capacitive. For asymmetric rating, STATCOM need a complementary reactive power source.

III. INSTALLING FACTS - DEVELOPED APPROACH

In a first stage of the research it was assumed that the introduction of FACTS in the network would be of interest only in buses where wind generators would be installed.

The approach adopted involved the analysis of the dynamic behavior of the full system, following some specific

severe short circuits, including the monitoring of the wind generators behavior (and their under voltage protection) and the interconnection power flows.

The presence of FACTS and their controls leads to a grid injection of reactive power during the short circuit duration, sustaining voltage to drop largely and avoiding, in some cases, the tripping of wind generators. Both SVC and STATCOM were considered in these studies.

No ride through default capability was assumed to be already in operation in the wind generators installed. In fact, the situation in the Iberian system for the 2006 scenario is characterized by the lack of such capability in the large majority of the existing wind farms.

Accordingly, the research developed was divided in 3 different stages.

In a first one, FACTS were considered to be installed in each one of the 33 buses of the Portuguese transmission system that have wind parks connected, with capacity values of 0, 25, 50, 75 and 100MVar. In a second stage the same approach was tested but the FACTS capacity was defined as a percentage of the wind generation injected in each of these buses (0, 10, and 50%). Then in a third set of studies a reduction on the volume of FACTS was tested by trying to locate these devices (with capacities of 100, 120 and 150MVar) in the buses presenting the 3 larger short circuit levels of the all 33 wind power injection buses.

It should be mentioned that the first stage of these studies aimed at analyzing the behavior of the grid as a whole, while the second part the studies allowed the determination of an approximate value of the total capacity of the FACTS to be installed, using as criterion the reduction of the loss of wind generation that follows a grid disturbance. The main purpose of the 3rd stage was then to identify the location of the grid busses where it would be more effective to place FACTS, if one wants to avoid installing these devices in all wind farms.

Short-circuit simulations have been carried out, taking place in 3 buses of the Portuguese transmission grid: Valdigem (North of Portugal - 220kV), Rio Maior (Centre of Portugal - 220kV) and Portimão (in the South - 150 kV).

IV. ANALYSIS OF THE RESULTS

Due to the large concentration of wind power generation in the north of Portugal, short circuits simulated in center and in the south of the grid have smaller impact than the ones that occur in the north part of the system.

It was also observed that it is not effective to place SVC/STATCOM in all buses. Namely in places where the grid is weaker (i.e. smaller short circuit power), no real benefits are obtained with the use of these devices regarding the minimization of the loss of wind generation.

A. Analysis of the Wind Generation Loss Amount

In the studies performed in the second stage of this research, it was observed that the most significant gains are obtained when the total FACTS capacity is of the order of 10% of the wind power generation, i.e. 120MVar. With this value, is this possible to avoid that 195 MW of wind generation would be removed from the system (Fig. 7).

A good solution would then be the introduction of SVC/STATCOMs with a capacity of 10% of the injected generation in each wind generation bus. As it can be observed from next figure, this solution is a good technical option. As already described, one decided to study also the best possible system location as function of the short circuit power, considering that a total power of 120 MVar would be the solution in terms of capacity to be installed. The 3 buses with largest short circuit power where wind parks are connected were selected to receive 3 FACTS of 40 MVar each. However this solution has not provided good results.

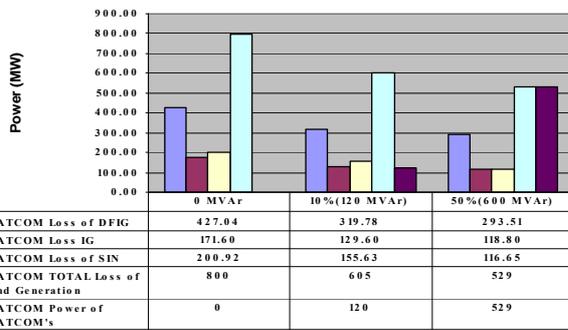


Fig. 7. Loss of wind generation per technology, following a short circuit in Valdigem (300ms), considering different STATCOM capacities.

B. Dynamic Behavior

Short circuit in Valdigem bus

From the performed analysis, different dynamic behaviors were identified when using SVC and STATCOM. STATCOM do have faster response, as we can see in Fig 8.

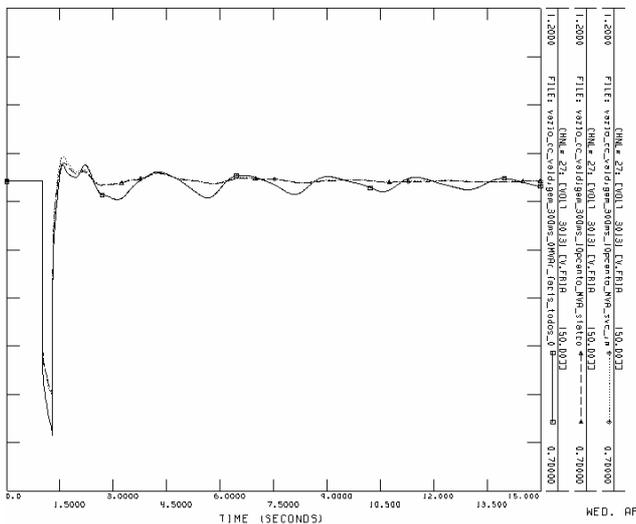


Fig. 8. Bus Voltage in Vila Fria - Short circuit in Valdigem (300ms), considering no FACTS, 10% SVC(120MVar) and 10% STATCOM(120MVar).

When comparing results regarding the loss of wind generation, using of both FACTS technologies, only small differences were identified. The wind generation loss amount is roughly the same, with slightly better results for the case of the STATCOM. Only small differences in what concerns power flows in the interconnection lines between Portugal and Spain, as well as small differences in terms of the voltage profiles in the different wind generation buses

were verified. The obtained results also demonstrate a very close dynamic response when comparing SVC and STATCOM solutions.

In the next figure it can be observed that the use of STATCOM devices avoids the disconnection of some wind farms due to their minimum voltage protection operation.

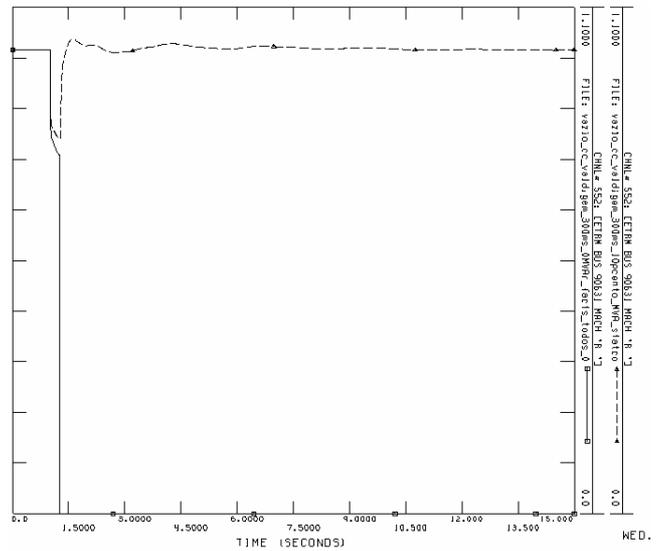


Fig. 9 - Loss of wind generation – Vila Fria, following a short circuit in Valdigem (300ms), considering different STATCOM’s capacities installed (0 and 10% (120MVar)).

The simulated disturbance is a short circuit with the duration of 300ms. Three distinct situations were compared: installation of 0, 10% (120MVar) and 50% (600 MVar) STATCOM capacities. Figures 10, 11 and 12 show the injected reactive power of the 3 STATCOM solutions.

Short circuits with 500ms of duration also have also been simulated leading to instability phenomena in the Iberian grid due to actuation of minimum voltage relays of some wind parks situated in Spanish territory. Such situation results from the propagation of the voltage drop provoked by the short circuits in Portugal.

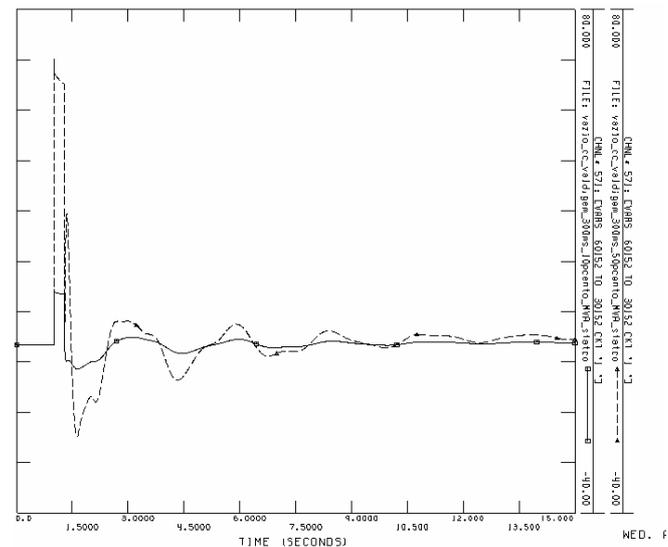


Fig. 10 – Pedralva bus (150kV): STATCOM Injected reactive power following a short circuit in Valdigem (300ms), considering the two different STATCOM capacities installed (10% and 50%).

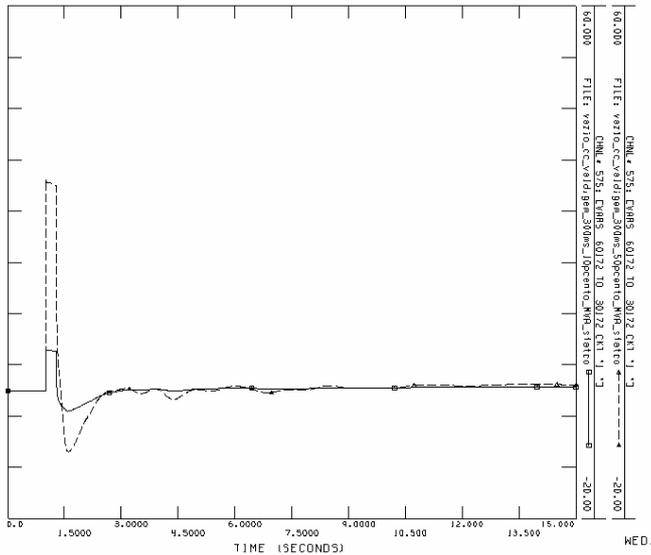


Fig.11 – C. Branco bus (220kV): STATCOM Injected reactive power following a short circuit in Valdigem (300ms), considering the 2 different STATCOM capacities installed (10% and 50%).

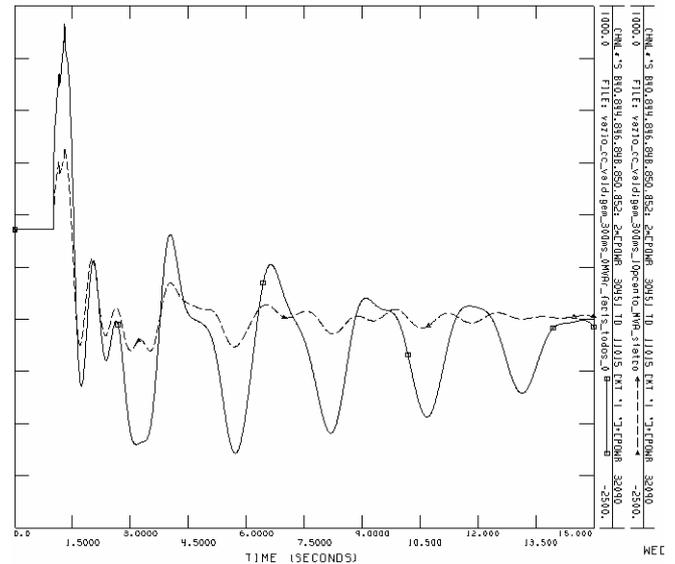


Fig.13. – Active power flow in the interconnections (Initial area exchange of 500MW) following a short circuit in Valdigem bus (300ms) – without STATCOM and with STATCOM (10%).

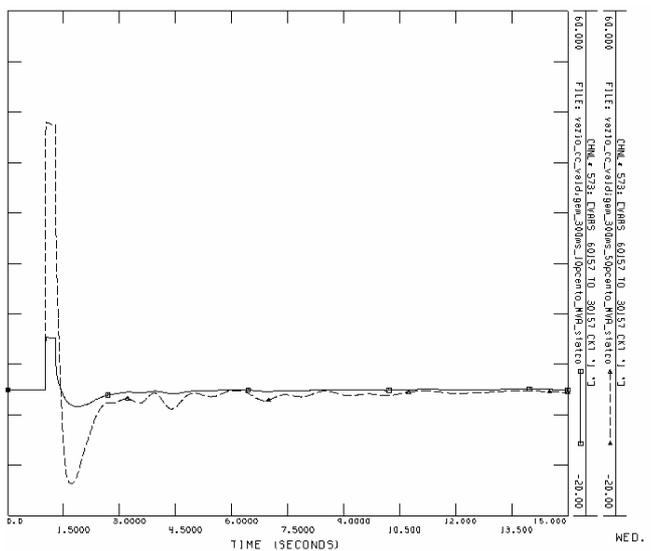


Fig. 12 – Falagueira bus (150 kV): STATCOM Injected reactive power following a short circuit in Valdigem (300ms), considering the 2 different STATCOM capacities installed (10% and 50%).

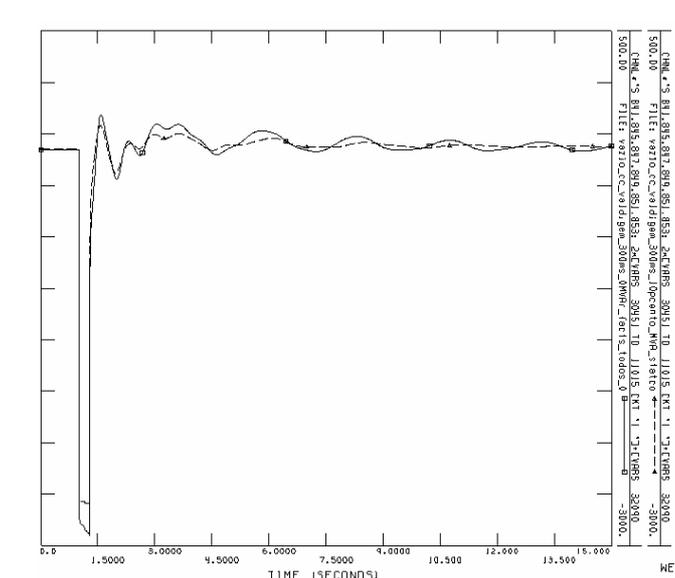


Fig. 14 – Reactive power flow in the interconnections (Initial area exchange 500MW) following a short circuit in Valdigem bus (300ms) – without STATCOM and with STATCOM (10%).

The behaviour of the sum of the flows of active and reactive power (it includes all the interconnections with Spain) is presented in figures 13 and 14 respectively, showing the impact that the short circuit provokes. It can be observed that the installation of the STATCOM devices, besides avoiding the disconnection of some wind farms, also contributes clearly for an improvement of a fast damping of the interconnection power flows.

From the studies performed it was also possible to understand that an increase in the capacity of the STATCOM to be installed is not providing a corresponding improvement in system dynamic behaviour.

The importance of the STATCOM can also be verified in the next plots (Fig. 15). STATCOM collaborate effectively to keep in the nominal levels and fast stabilizing the voltage following the short circuits. This is a very important contribution for the increase of the global robustness of operation.

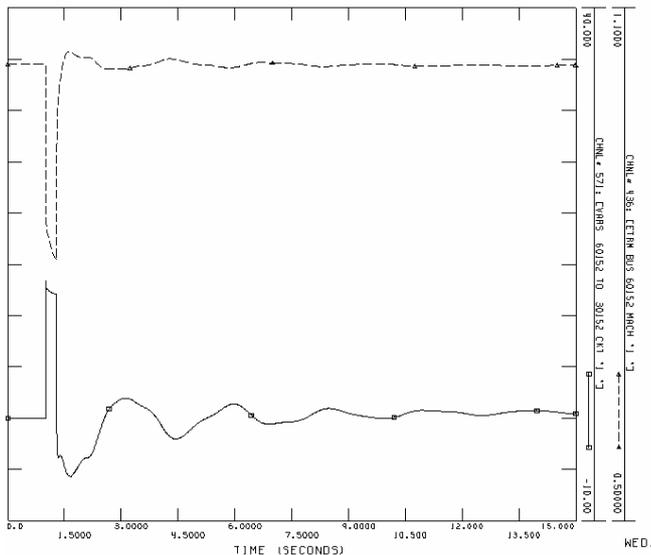


Fig. 15 – Pedralva bus (150kV): STATCOM Injected reactive power / bus voltage.

Short circuit in Rio Maior and Portimão buses

The occurrence of a short circuit in Rio Maior (center of Portugal) shows less impact concerning the loss of wind production when compared with the effects resulting from the short circuit in the Valdigem bus. Again it was also verified that STATCOM were able to improve globally voltage profiles (fast damping voltage oscillations), namely in buses with wind generation, avoiding that the minimum settings of the minimum voltage relays would be reached. For the cases related with short circuits in the South of Portugal, the impact in the grid is even smaller than the one that results from short-circuits in the area of the Rio Maior bus.

V. CONCLUSION

From the preliminary results obtained in the Portuguese / Spanish system, one can conclude that it will be beneficial to install FACTS in strategic buses of the Portuguese transmission network in order to mitigate the impact of short circuits that may occur in the grid and that may lead to the disconnection of large amounts of wind generators due the tripping of their under voltage protection relays.

With the introduction of FACTS, significant reduction in the minimum values of voltage drops were obtained in most of the wind farm buses, avoiding the disconnection of wind generation for short-circuits situated around the network area with largest concentration of connection of wind farms.

An important reduction on the amount of the loss of wind generation can be obtained specially for the cases where no ride through default requirements were adopted. Such requirements only now are becoming mandatory and the adoption of an approach similar to the one described in this paper can contribute to increase the robustness of operation.

The main difference between SVC and STATCOM performance lies on the system induced dynamic behavior, as STATCOM improves faster the voltage profiles comparatively with SVC. However, and in what concerns the loss of wind generation, they provide similar results. Tuning of the control parameters of these FACTS still needs

to be investigated.

ACKNOWLEDGMENT

Authors want to thank Ana Estanqueiro / National Institute of Industrial Engineering and Technology (INETI) to provide data to wind park locations.

Tank to PRODEPIII – 1065004/2004 to financial support.

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