International Conference on Renewable Energies and Power Quality (ICREPQ'13)
Bilbao (Spain), 20th to 22th March, 2013
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.11, March 2013

DGFACTS comparative in wind power to solve LVRT requirements

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Abstract. This article compares the results recorded in the connection of three types of DGFACTS (DSTATCOM, DVR, UPQC) to a wind farm equipped with wind turbines with squirrel-cage induction generators, in order to test the response to voltage dips due to single-phase short circuit and two phase short circuit, because this type of asymmetric faults is one of the most common to consider a power system. The results are compared with a previous work, dealing with symmetric (three phase) short circuits. For illustrative purposes, reference has been made to a standard wind farm in Spain, which has been subject to a fault of the type specified in Operating Procedure 12.3 in the Spanish Grid Code. The aforementioned options provide the wind farms with LVRT capability, in addition to catering for numerous other possibilities that have not been considered within this research.

Key words

DGFACTS, DSTATCOM, DVR, UPQC, LVRT, Grid Codes.

1. Introduction

The purpose of DGFACTS (Distributed Generation - Flexible Alternating Current Transmission Systems), which are also referred to as Custom Power Systems (CUPS), is to improve the quality of the supply in Distributed Generation grids through the integrated application of power electronic controllers, as a means for improving the quality of the electricity supply. This purpose becomes especially significant when dealing with the massive integration of renewable energy sources for power generation and distributed generation (DG) in power grids [1,2,3].

This paper focuses on this line of work, with the mounting of DGFACTS Power devices in a wind farm for facilitating the integration of wind energy into the electricity system. A comparison is made between the results recorded in the connection of three types of DGFACTS (DSTATCOM, DVR, UPQC) to a wind farm for resolving the issues of the low-voltage ride-though (LVRT) requirements of wind farms equipped with wind turbines with squirrel-cage induction generators. For illustrative purposes, reference has been made to a standard wind farm in Spain, which has been subject to a fault of the type specified in Operating Procedure 12.3 in the Spanish Grid Code. The aforementioned options provide the wind farms with LVRT capability, in addition to catering for numerous other possibilities that have not been included within this research. A previous work of the authors, dealing with symmetric (three phase) short circuits [3], the most dangerous fault, is used as basis of this work, which analyses the asymmetric short circuits (one and two phases).

2. Spanish grid code

The Spanish Grid Code, drafted by Spain's Grid Operator (Red Eléctrica Española), regarding the continuity of the supply lays down the requirements to be fulfilled by wind power facilities in order to ensure the uninterruptibility and quality of the supply in the event of network disturbances, pursuant to the text of additional provision four of Spain's Royal Decree 436/2004 [4].

According to the information from leading certification bodies (AENOR and, to a lesser extent, Germanischer Lloyd) substantially all of the wind farms have been certified to operate in the Spanish power system and meet its requirements [4].

The wind farms that have presented the most problems are the composed by generators with asynchronous squirrel cage. The difference between the installed and the certified power capacities in Spain is about 1418 MW. This is due to the exclusion of the certification procedure of a number of models of wind turbines, which either by age or by size, are not suitable to P.O.12.3 requirements. For these turbines, Verification Technical Committee (CTV) decided not to seek the adequacy and considered that the total power is very small and does not affect system security. In the future, certification will decrease because it would be only necessary to certify the new wind farms.

3. DGFACTS devices and power system description

The three DGFACTS devices compared are compensation devices [5]. These devices are connected to the load input to be protected and they are connected either in series or in shunt, or in a combination of the two, as shown in Fig. 3. The main feature of the three DGFACTS devices is that they are based on a multilevel voltage source converter (VSC) [6,7]. This type of inverter uses the Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage source with a typical chopping frequency of a few kilohertz. For a brief description of the characteristics of DSTATCOM, DVR, or UPQC see [3].

The network model consists of the connection arrangement of a wind farm connected to the electricity system on the 120 kV transmission grid through a step-up substation that receives the energy from the wind farm via a 25 km overhead line, at a nominal voltage of 25 kV[8]. The especifications of the system can be seen in [3]. The reason for focusing the study on wind farms equipped with squirrel-cage induction generators (SCIG) is their incapacity on their own to deal with the ever more demanding requirements made by the system operator [9,10,11], as we noted in section II.

4. Test system

The system represented in the simulation models is investigated by means of a simulation model using the SimPowerSystems library of SIMULINK/MATLAB™ software. The aim of the simulation is to verify the transient stability of the wind power generation system (network, wind farm and DGFACTS together with their appropriate controls) during a voltage dips at the connection point with the transmission network, according to the depth and duration specified in Operating Procedure 12.3 [12]. The two types of voltage dips are as shown in figure 4, corresponding to a one-phase dip in phase c and a two-phase dip in phases b and c. The dip starts when the system has reached steady-state operation (t = 4 sec.).

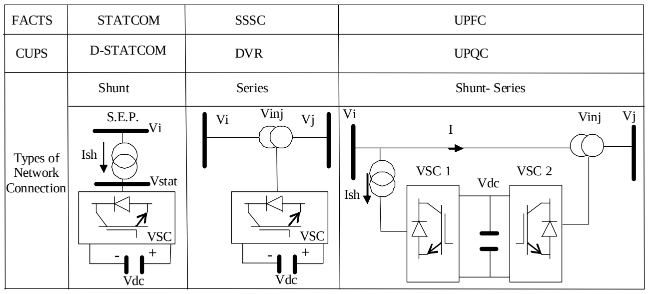


Fig. 3. Connected DGFACTS devices

In [3] the response of the DGFACTS devices to three-phase and two-phase voltage dips was studied, accordingly to the manual procedures for verification, validation and certification included in the PO 12.3 requirements for the response of the wind turbines during voltage dips. It states that test must be developed applying with the dip generator a three-phase and a two-phase isolated faults that cause a voltage dip in the affected phases whose characteristics are specified in the PO 12.3. In this article we will check the response to voltage dips due to short circuit faults monophasic and biphasic, as this type of asymmetric fault is the most common to be considered in a power system, apart from to its destructive character for both the system in general and for the devices involved.

The high cost of switching and protection equipment in high voltage networks, requires the calculation of short circuit currents with some accuracy, as the sizing of the equipment may be unacceptable from the economic standpoint. The correct determination of the performance of the equipment requires, in general, the study of various types of failure. Each of them represents different network imbalances which give rise to a different stress on the equipment in each case. Thus, for example, the maximum mechanical stress happens in the case of a short circuit three-phase, while for determining the inductive influence of leakage currents on the outside facilities monophasic and biphasic failures present more interest.

5. Simulation results

The comparative results are presented for the three DGFACTS studied, for the two cases of voltage dips directly linked to the presence of short-circuits correctly cleared that may occur in the electricity system, with these corresponding unbalanced faults (single-phase and two-phase) with the profiles of magnitude and duration specified in figures 4a and 4b, respectively.

A. Response to a one-phase dip

The rated values of the DGFACTS devices required for equipping the wind farm with fault ride-through capability for a voltage dip caused by a one-phase short circuit in properly solved in the high-voltage 120 kV are as shown in Table I.

TABLE I
ONE-PHASE DIP. RATING REQUIREMENTS

DGFACTS	Rated Power
DSTATCOM	5,5 MVA
DVR	6 MVA
UPQC	6 MVA

Figures 5-9 show the values recorded in the simulation of the bars in the wind farm substation. Figure 5 compares the active power values recorded by the three DGFACTS devices. Note should be taken of the consumption of active power by the UPFC derived by the shunt converter to supply the DC bus. The consumption of active power by the other two devices is almost zero. The lower variation in active power delivered during the dip recorded by the STATCOM as opposed to the other two (Pmin = 5.5 MW, Pmax = 10.5 MW).

The reactive power in the UPFC (figure 6) does not record major variations either during the dip or after the fault has been cleared, whereas the other two devices record a sharp peak of reactive power delivered to the network both when there is a voltage dip in the STATCOM and when the dip has been cleared in the DVR.

The input voltage to the wind farm substation is very well compensated with STATCOM (figure 7), while the best compensation at the outlet of DGFACTS is made with UPQC, which keeps the voltage constant in the load. This means that the variation in the speed of the rotor on the turbine (figure 9) in this latter case is hardly noticeable. In the cases of connection of STATCOM and of the DVR, the rotor speed records a sudden increase from 1,005 to 1,023 pU in half a second (in the case of the DVR).

The highest current peak is recorded with STATCOM when the voltage dip appears, but it presents the best performance regarding the delivery of reactive current to the network. By contrast, the lowest delivery of reactive current is made in DVR, which at times even needs to draw it from the network (figure 8).

B. Response to a two-phase dip

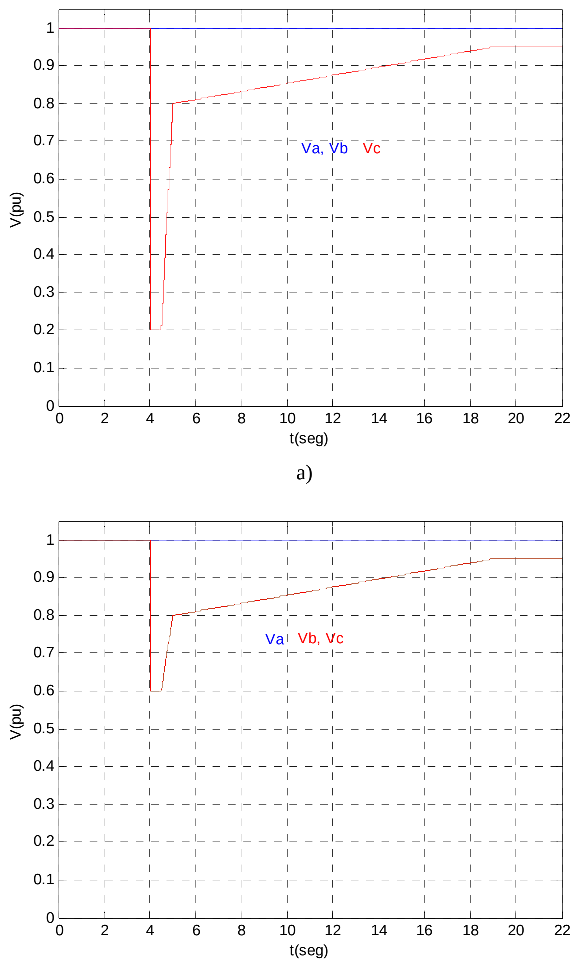
The disturbance which is simulated is the corresponding to a unbalanced short circuit corresponding to a two-phase fault in the phases b and c. The sizing that is needed by DGFACTS devices, shown in Table II, is slightly greater than in the previous case, more marked in the case of DVR.

TABLE II
TWO-PHASE DIP. RATING REQUIREMENTS

DGFACTS	Rated Power
DSTATCOM	6 MVA
DVR	9 MVA
UPQC	7 MVA

This analysis of the response to a two-phase dip does not present the graphs obtained (similar to the case of a response to a three-phase dip) simply for reasons of lack of space in this paper.

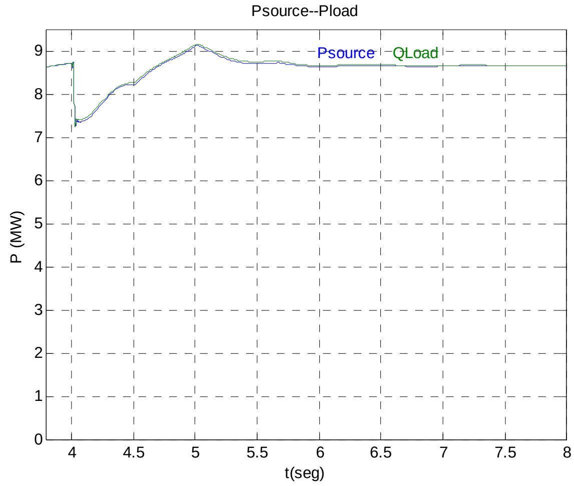
The DVR device is the one that most reactive power demands from the grid during and after the failure. The best voltage compensation is performed by UPQC device that delivers the output voltage of the device with little disturbance. This device absorbs more quickly and with less variation the current delivered to the network. The response of the speed of the turbine rotor to a biphasic voltage dip is different depending on the type of DGFACTS device employed; for instance, when UPQC is connected, the rotor speed is reduced as a result of the compensation performed in maintaining tension above the nominal in two phases, while in the two other cases the speed increases above the nominal until the stabilization of the system.



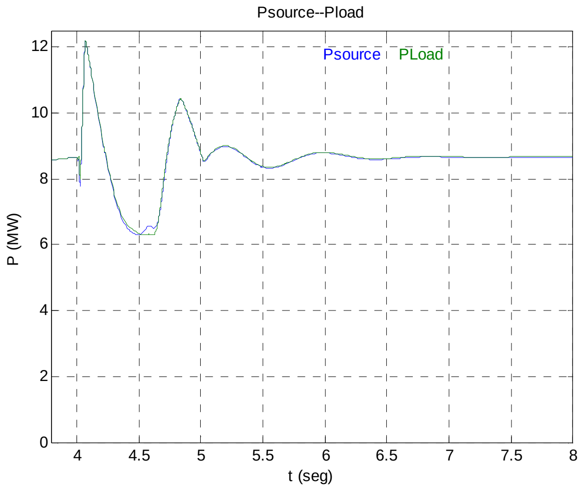
a)

b)

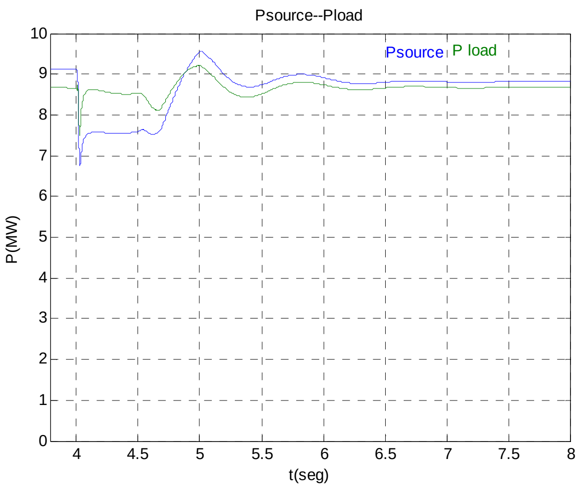
Fig. 4. Voltage-Time curve a) One-phase dip b) two-phase dip



a) STATCOM

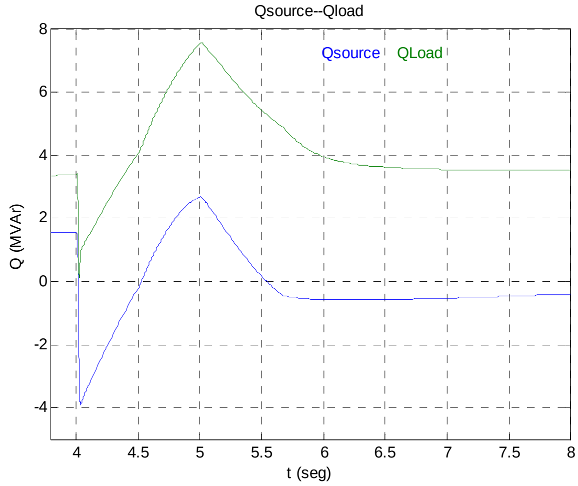


b) DVR

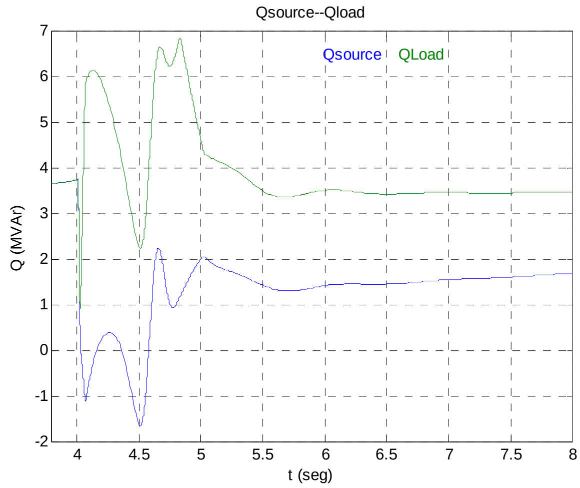


c) UPQC

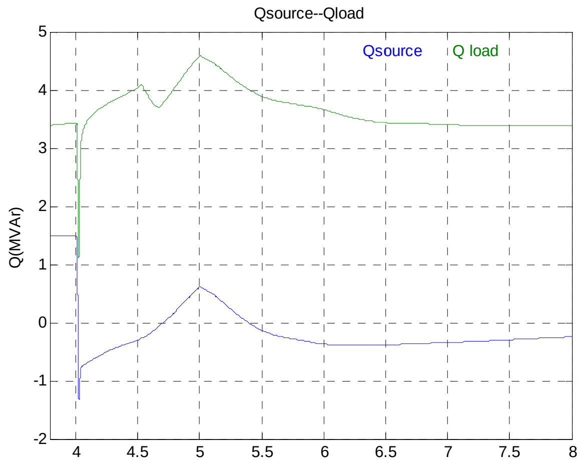
Fig. 5. Active Power-Time



a) STATCOM

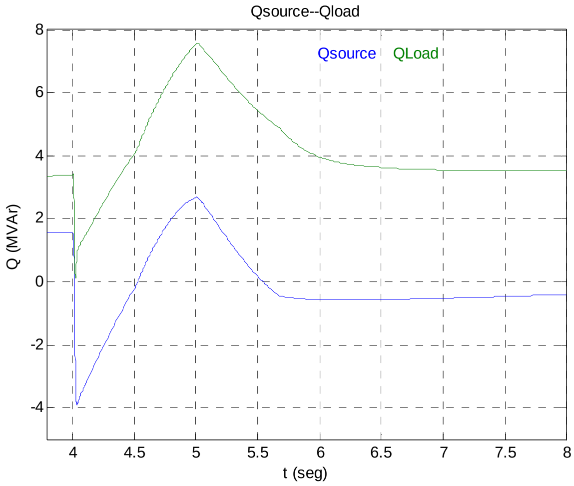


b) DVR

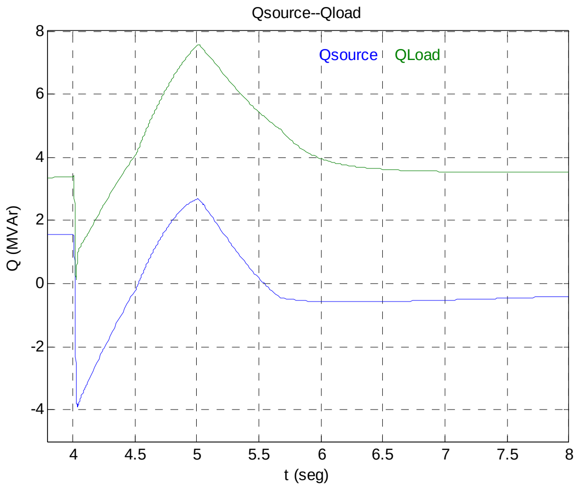


c) UPQC

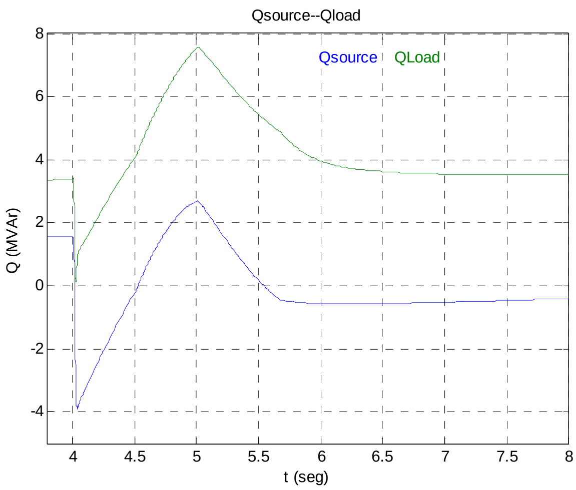
Fig. 6. Reactive Power-Time



a) STATCOM

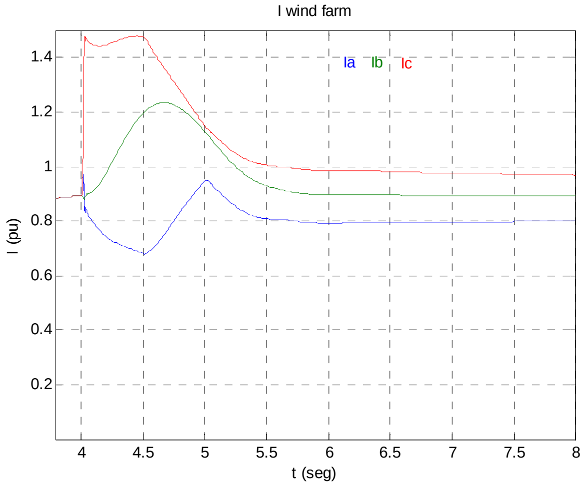


b) DVR

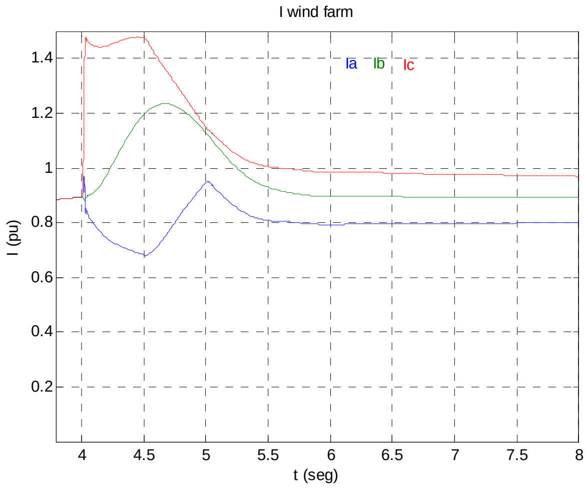


c) UPQC

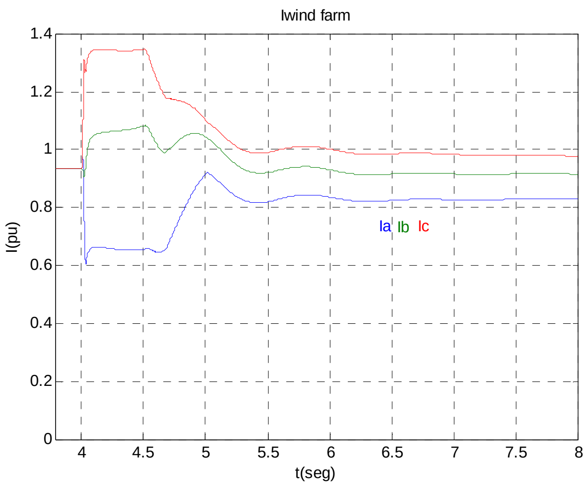
Fig. 7. Voltage-Time



a) STATCOM

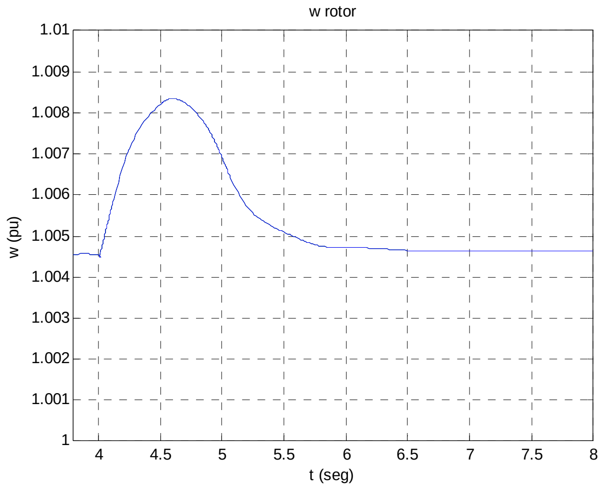


b) DVR

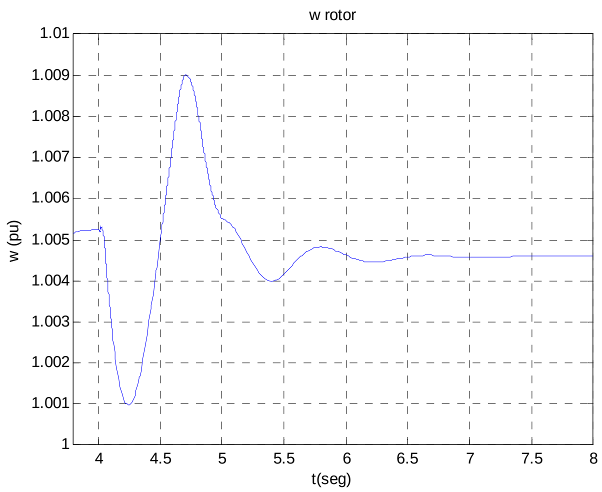


c) UPQC

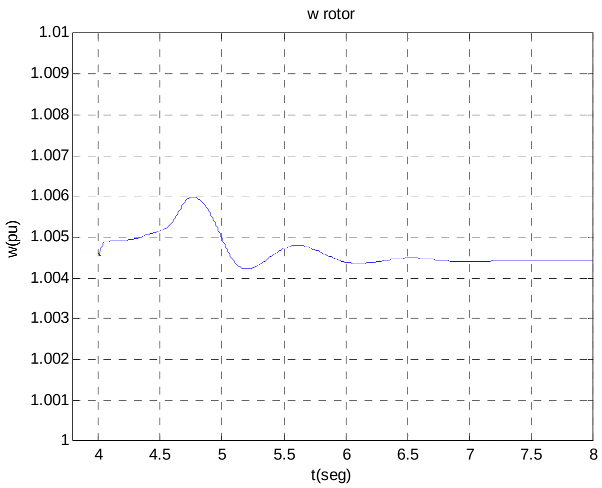
Fig. 8. Current-Time



a) STATCOM



b) DVR



c) UPQC

Fig. 9. Speed of the rotor-Time

6. Conclusions

Any of the three DGFACTS devices employees can ensure the protection of a wind farm consisting of wind turbine type SCIG, from voltage dips produced by asymmetric faults generated in the network, and they can provide those parks with LVRT capability. The DSTATCOM and UPFC devices are the ones that need a smaller sizing of the VSC inverter rated power, with 6 and 7 (3+4) MVA respectively. The sum of the selected DGFACT power can be connected to the input of the wind park (park substation) or divided into several modules connected in each turbine. The latter option is often cheaper and more viable.

When looking for the best response to the requirements of the system operator, the UPQC device would be the best option. If what is sought is the cheaper DGFACTS that permits that the wind farm meets the "low voltage ride through" (LVRT) requirements, the best option might be the DSTATCOM, a device that turns out to be simpler in structure and control.

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