Power Quality Improvement Using UPQC for Wind Farm Generation System

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Abstract- Normally the wind energy conversion system Wind Farms (WF) are employing squirrel cage induction generator (SCIG) and these are directly connected to the grid. In modern power system for convenience purpose the WF are connected through medium voltage (MV) distribution headlines. In this case a situation arises i.e. the power generated by WF is comparable to the transport capacity of the grid. This case is known as Wind Farm to Weak Grid Connection. Due to this poor voltage regulation problems are arise at the point of common coupling (PCC).The overall problems like weak grids ,wind power fluctuations and sudden load changes in system cause of this the power quality will be disturb. To overcome these problems a compensate technique will be use at pcc. In this technique using Custom Power devices technology (CUPS) efficiently regulates all problems. In this project propose a Unified Power Quality Compensator (UPQC) Custom power device. This device develop to regulate the Voltage in the WF terminals and to reduce voltage fluctuations at grid side. The internal control strategy is based on the management of active and reactive power in the series and shunt converters of the UPQC, and the exchange of power between converters through UPQC DC–Link. Simulations results show the effectiveness of the propose compensation strategy for the enhancement of Power Quality.

Keywords — Wind Energy, UPQC, voltage fluctuation, weak Grid

I. INTRODUCTION

The location of generation facilities for wind energy is determined by wind energy resource availability, often far from high voltage (HV) power transmission grids and major consumption centres [1].

In case of facilities with medium power ratings, the WF is connected through medium voltage (MV) distribution headlines. A situation commonly found in such scheme is that the power generated is comparable to the transport power capacity of the power grid to which the WF is connected, also known as weak grid connection. The main feature of this type of connections is the increased voltage regulation sensitivity to changes in load [2]. So, the system's ability to regulate voltage at the point of common coupling (PCC) to the electrical system is a key factor for the successful operation of the WF.

Also, is well known that given the random nature of wind resources, the WF generates fluctuating electric power. These fluctuations have a negative impact on stability and powerquality in electric power systems. [3]

Moreover, in exploitation of wind resources, turbines employing squirrel cage induction generators (SCIG) have been used since the beginnings. The operation of SCIG demands reactive power, usually provided from the mains and/or by local generation in capacitor banks [4], [5]. In the event that changes occur in its mechanical speed, i.e. due to wind disturbances, so will the WF active(reactive) power injected(demanded) into the power grid, leading to variations of WF terminal voltage because of system impedance. This power disturbance propagate into the power system, and can produce a phenomenon known as "flicker", which consists of fluctuations in the illumination level caused by voltage variations. Also, the normal operation of WF is impaired due to such disturbances. In particular for the case of "weak grids", the impact is even greater.

In order to reduce the voltage fluctuations that may cause "flicker", and improve WF terminal voltage regulation, several solutions have been posed. The most common one is toUpgrade the power grid, increasing the short circuit power level at the point of common coupling PCC, thus reducing the impact of power fluctuations and voltage regulation problems [5].

In recent years, the technological development of high power electronics devices has led to implementation of electronic equipment suited for electric power systems, with fast response comparedto the line frequency. These active compensatorsallowgreat flexibility in: a) controlling the power flow in transmission systems using

Flexible AC Transmission System(FACTS) devices, and b) enhancing the power quality in distribution systems employing Custom Power System (CUPS) devices [6] [9]. The use of these active compensators to improve integration of wind energy in weak grids is the approach adopted in this work.

In this paper we propose and analyse a compensation strategy using an UPQC, for the case of SCIG–based WF, connected to a weakdistribution power grid. This system istaken from a real case [7].
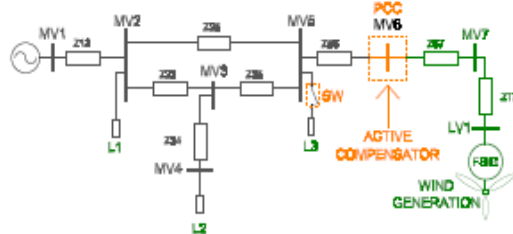

Fig1.study case power system

The UPQC is controlled to regulate the WF terminal voltage, and to mitigate voltage fluctuations at the point of common coupling (PCC), caused by system load changes and pulsating WF generated power, respectively. The voltage regulation at WF terminal is conducted using the UPQC series converter, by voltage injection "in phase" with PCC voltage.

On the other hand, the shunt converter is used to filter the WF generated power to prevent voltage fluctuations, requiring active and reactive power handling capability. The sharing of active power between converters are managed through the common DC link. Simulations were carried out to demonstrate the effectiveness of the proposed compensation approach.

II. SYSTEM DESCRIPTION AND MODELLING

A. System description

Fig.1 depicts the power system under consideration in this study.The WF is composed by 36 wind turbines using squirrel cage induction generators, adding up to 21.6MW electric power. Each turbine has attached fixed reactive compensation capacitor banks (175kVAr), and is connected to the power grid via 630KVA 0.69/33kV transformer. This system is taken from [7], and represents a real case.

The ratio between short circuit power and rated WF power, give us an idea of the "connection weakness". Thus considering that the value of shortcircuit power in MV6 is SSC $\simeq$120MV A this ratio can be calculated:

$$r = \frac{S_{SC}}{P_{WF}} \simeq 5.5$$

Values of r < 20 are considered as a "weak grid" connection [2].

B. Turbine rotor and associated disturbances model

The power that can be extracted from a wind turbine is determined by the following expression:

$$P = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot v^3 \cdot C_P$$

Where ρ is air density, R the radius of the swept area, v the wind speed, and CP the power coefficient. For the considered turbines (600kW) the values are R = 31.2 m,ρ= 1.225 kg/m3 and CP calculation is taken from [8].Then, a complete model of the WF is obtained by turbine aggregation; this implies that the whole WF can be modelledby only one equivalent wind turbine, whose power is the arithmeticsum of the power generated by each turbine accordingto the following equation:

$$P_T = \sum_{i=1\cdots36} P_i$$

Moreover, wind speed v in (1) can vary around its averagevalue due to disturbances in the wind flow. Such disturbancescan be classified as deterministic and random. The firstsare caused by the asymmetry in the wind flow "seen" bythe turbine blades due to "tower shadow" and/or due tothe atmospheric boundary layer, while the latter are randomchanges known as "turbulence". For our analysis, wind flowdisturbance due to support structure (tower) is considered, andmodelled by a sinusoidal modulation superimposed to the meanvalue of v.

The frequency for this modulation is 3· Nrotor forthe three–bladed wind turbine, while its amplitude depends onthe geometry of the tower. In our case we have considered a mean wind speed of 12m/s and the amplitude modulation of 15%.

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The effect of the boundary layer can be neglected compared to those produced by the shadow effect of the tower in most cases [3]. It should be noted that while the arithmeticsum ofperturbations occurs only when all turbines operate synchronously and in phase, this is the case that has the greatest impact on the power grid (worst case), since the powerPulsation has maximum amplitude. So, turbine aggregation method is valid.

C. Model of induction generator

For the squirrel cage induction generator the model available in Matlab/Simulink SimPower Systems libraries is used. It consists of a fourth–order state–space electrical model and a second–order mechanical model [5].

D. Dynamic compensator model

The dynamic compensation of voltage variations is performed by injecting voltage in series and active–reactive power in the MV6 (PCC) busbar; this is accomplished by usingan unified type compensator UPQC [9]. In Fig.2 we see the basic outline of this compensator; the busbars and impedances numbering is referred to Fig.1.

The operation is based on the generation of three phase voltages, using electronic converters either voltage source type(VSI–Voltage Source Inverter) or current source type (CSI–Current Source Inverter). VSI converters are preferred because of lower DC link losses and faster response in the systemthan CSI [9]. The shunt converter of UPQC is responsible for injecting current at PCC, while the series converter generates voltages between PCC and U1, as illustrated in the phasor diagram of Fig.3. An important feature of this compensator is the operation of both VSI converters (series and shunt) sharing the same DC–bus, which enables the active power exchange between them.
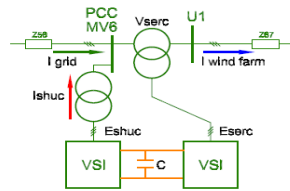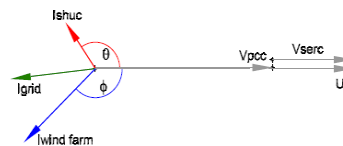

Fig2. block diagram of UPQC   Fig3. Phasor diagram of UPQC

We have developed a simulation model for the UPQC based on the ideas taken from [10]. Since switching control of converters is out of the scope of this work, and considering that higher order harmonics generated by VSI converters are outside the bandwidth of significance in the simulation study, the converters are modelled using ideal controlled voltage sources. Fig.4 shows the adopted model of power side of UPQC.
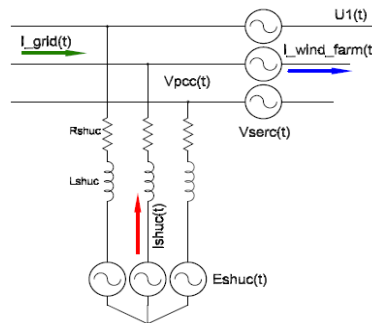

Fig4. power stage compensator model, AC side

The control of the UPQC, will be implemented in a rotating frame dq0 using Park's transformation (eq.3-4)

$$T = \frac{2}{3} \cdot \begin{bmatrix} \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} = T \cdot \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (4)$$

Wherefi=a,b,crepresents either phase voltage or currents, and fi=d,q,0 represents that magnitudes transformed to the dqo space.

This transformation allows the alignment of a rotating reference frame with the positive sequence of the PCC voltages space vector. To accomplish this,a reference angle synchronized with the PCC positive sequence fundamental voltage space vector is calculated using a Phase Locked Loop (PLL) system. In this work, an "instantaneous power theory" based PLL has been implemented [11].

Under balance steady-state conditions, voltage and currents vectors in this synchronous referenceframe are constantquantities. This feature is useful for analysis and decoupled control.

III. UPQC CONTROL STRATEGY

The UPQC serial converter is controlled to maintain the WFterminal voltage at nominal value (see U1 bus-bar in Fig.4), thus compensating the PCC voltage variations. In this way, the voltage disturbances coming from the grid cannot spread to the WF facilities. As a side effect, this control action may increase the low voltage ride–through (LVRT) capability inthe occurrence of voltage sags in the WF terminals [4], [9].
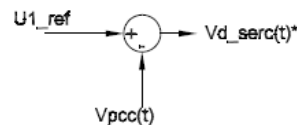

Fig5. Series compensator controller

Fig.5 shows a block diagram of the series converter controller. The injected voltage is obtained subtracting the PCC voltage from the reference voltage, and is phase–aligned withthe PCC voltage (see Fig.3).

On the other hand, the shunt converter of UPQC is used to filter the active and reactive power pulsations generated by the WF. Thus, the power injected into the grid from the WF compensator set will be free from pulsations, which are the origin of voltage fluctuation that can propagate into the system. This task is achieved by appropriate electrical currentsinjection in PCC. Also, the regulation of the DC bus voltage has been assigned to this converter.

Fig.6 shows a block diagram of the shunt converter controller. This controller generates both voltages commands Ed shuC∗and Eq shuC∗based on power fluctuations ΔP andΔQ, respectively. Such deviations are calculated subtracting the mean power from the instantaneous power measured in PCC.
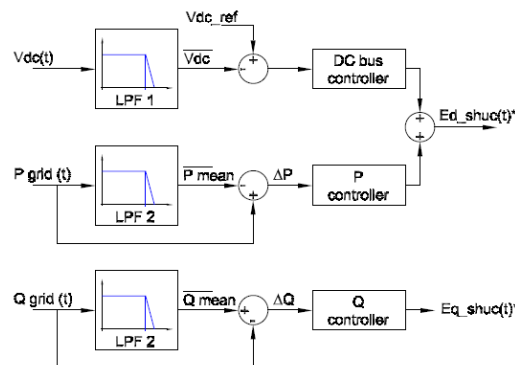

Fig6. Shunt compensator controller

The mean values of active and reactive power are obtained by low–pass filtering, and the bandwidth of such filters are chosen so that the power fluctuation components selected forcompensation, fall into the flicker band as stated in IEC61000- 4-15 standard.

In turn, Ed shuC∗also contains the control action for theDC–bus voltage loop. This control loop will not interact withthe fluctuating power compensation, because its componentsare lower in frequency than the flicker–band .

The powers PshuC and QshuC are calculated in the rotatingreference frame, as follows:

$$P_{shuC}(t) = 3/2 \cdot V_{PCCd}(t) \cdot I_{shuCd}(t)$$

$$Q_{shuC}(t) = -3/2 \cdot V_{PCCd}(t) \cdot I_{shuCq}(t) \qquad (5)$$

Ignoring PCC voltage variation, these equations can bewritten as follows.

$$P_{shuC}(t) = k'_p \cdot I_{d\,shuC}(t)$$

$$Q_{shuC}(t) = k'_q \cdot I_{q\,shuC}(t) \qquad (6)$$

Taking in consideration that the shunt converter is based on a VSI, we need to generate adequate voltages to obtain thecurrents in (6). This is achieved using the VSI model proposed

in [10], leading to a linear relationship between the generatedpower and the controller voltages. The resultant equations are:

$$P_{shuC}(t) = k''p \cdot E_{d\ shuC}(t)$$

$$Q_{shuC}(t) = k''q \cdot E_{q\ shuC}(t) \qquad\qquad (7)$$

P and Q control loops comprise proportional controllers,while DC–bus loop, a PI controller.
In summary, in the proposed strategy the UPQC can be seenas a ''power buffer'', levelling the power injected into the power system grid. The Fig.7 illustrates a conceptual diagram of thismode of operation.
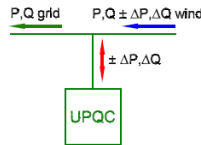

Fig7. Power buffer concept

It must be remarked that the absence of an external DCsource in the UPQC bus, forces to maintain zero–averagepower in the storage element installed in that bus. This is accomplished by a proper design of DC voltage controller.
Also, it is necessary to note that the proposed strategy cannotbe implemented using other CUPS devices like D–Statcomor DVR. The power buffer concept may be implementedusing a DStatcom, but not using a DVR. On the other hand, voltage regulation during relatively large disturbances cannotbe easily coped using reactive power only from DStatcom; inthis case, a DVR device is more suitable.

IV. SIMULATION RESULTS AND DISCUSSION

The model of the power system scheme illustrated in Fig.1, including the controllers with the control strategy detailedin section III, was implemented using Matlab/Simulinksoftware. Numerical simulations were performed to determineand then compensate voltage fluctuation due to wind powervariation, and voltage regulation problems due to a suddenload connection.
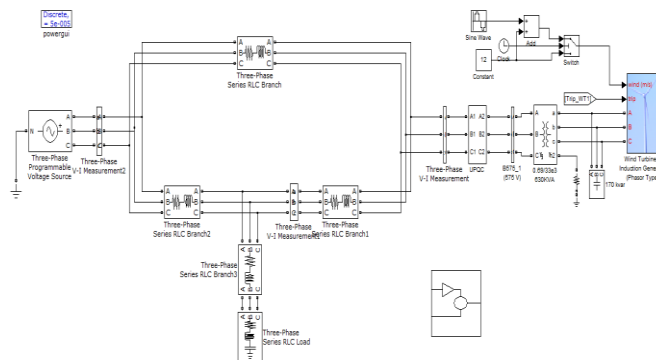
A. Compensation of voltage fluctuation

Fig.8 Simulation model of power system with wind disturbance

Simulation results for $0 < t < 4$ are shown in Fig.9.(a,b,c).At $t = 0.5''$ begins the cyclical power pulsation producedby the tower shadow effect. As was mentioned, the towershadow produces variation in torque, and hence in the activeand reactive WF generated power. For nominal wind speedcondition, the power fluctuation frequency is f = 3.4Hz,and the amplitude of the resulting voltage variation at PCC,expressed as a percentage is:

$$\frac{\Delta U}{U_{rated}} = 1.50\ \%$$

This voltage fluctuation is seen in middle curve of Fig.8 for$0.5 < t < 3$.
The fluctuation value is higher than the maximum allowedby the IEC61000-4-15 standard [12]. This means that even in normal operation, the WF impacts negatively on the SystemPower Quality.
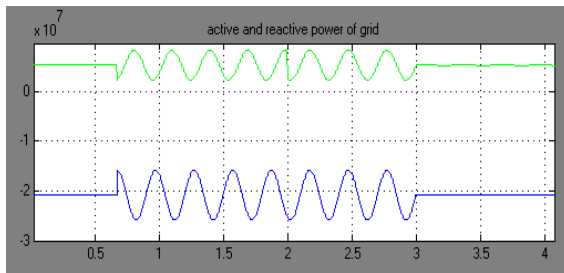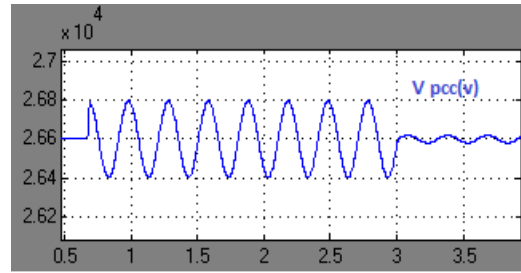
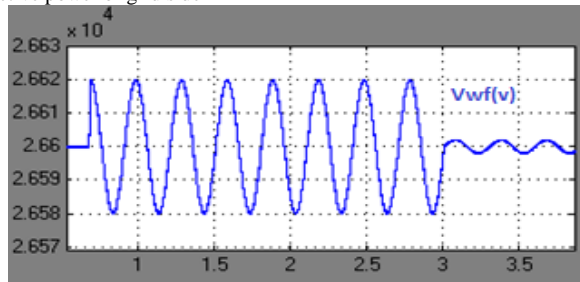Fig. 9(a) Active and reactive power of grid side   Fig.9(b) PCC voltage

Fig. 9(c) WF terminal voltage

At t = 3.0″ the active and reactive power pulsations are attenuated because the P and Q controllers come into action.

The amplitude of the PCC voltage fluctuation is reduced fromits original value of 1.6% (without compensation) to this newvalue:

$$\frac{\Delta U}{U_{rated}} = 0.18 \%$$

This value agrees with IEC standard [12], since is lowerthan the specified permissible maximum limit, 0.5% at 3.4Hz.

In the lower curve of Fig.8, WF terminal voltage behaviour is shown; the series converter action maintains WF terminalvoltage constant, regardless of the PCC voltage behaviour.The pulsation of active power and voltage at the UPQCDC–side, are shown in Fig.10 (a,b).

As can be observed in the upper curve, the series converterrequires negligible power to operate, while the shunt converterdemands a high instantaneous power level from the capacitorwhen compensating active power fluctuation. Compensation ofreactive powers has no influence on the DC side power [13].
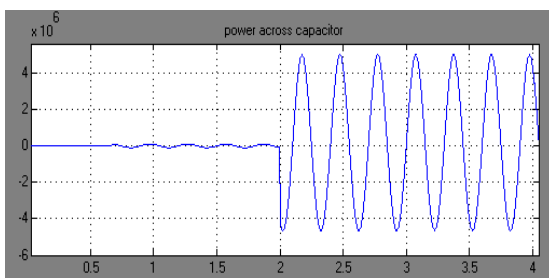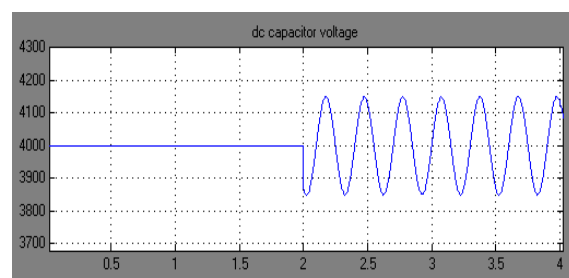

Fig. 10 (a) Power of capacitor in the DC-link   Fig. 10 (b)Voltage of capacitor in the DC-link

The DC-bus has voltage level limitations in accordancewith the VSI's operational characteristics. As the fluctuatingactive power is handled by the capacitor, its value needs to beselected so that the "ripple" in the DC voltage is kept withina narrow range.In our case, we have considered a capacitor size C = 0.42 F.This high value can be easily obtained by using emergingtechnologies based capacitors, such as double–layer capacitors,also known as ultra-capacitors.

B. Voltage regulation

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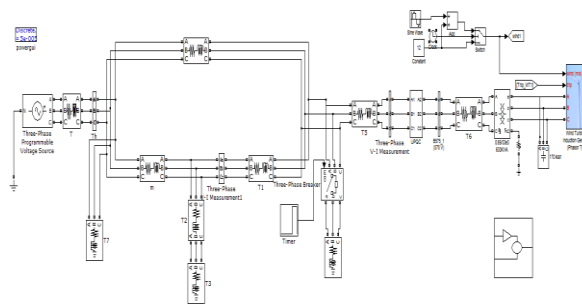*Vol. 1, Issue 6, December 2012*

Fig.11. Simulation model of power system with sudden load change

Simulation results for 0 < t <8 are shown in Fig.12.(a,b,c,d),the UPQC is also operatedto maintain the WF terminal voltage constant, rejectingPCC voltage variations, due to events like sudden connection or disconnection of loads, power system faults, etc. A suddenconnection of load is performed at t = 5″, by closing L3switch (SW) in Fig.11. This load is rated at PL3 = 9.2MW andQL3 = 9.25MW. Such load is then disconnected at t = 7″.Fig.11 shows the PCC and WF terminal voltages, and seriesinjected voltage at "a" phase. In this figure is clearly seen asudden change in PCC voltage, while WF terminal voltageremains almost constant due to series converter action.
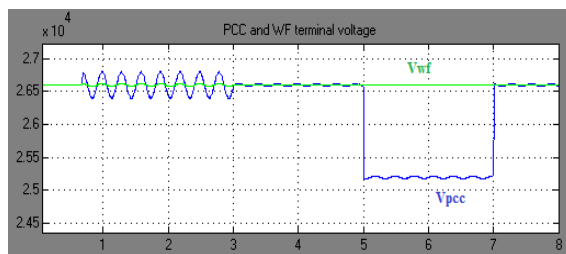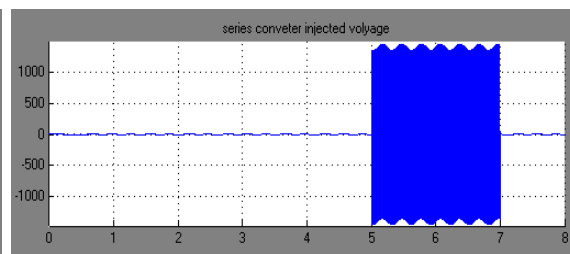

Fig. 12(a) Voltage at wind terminal and PCC
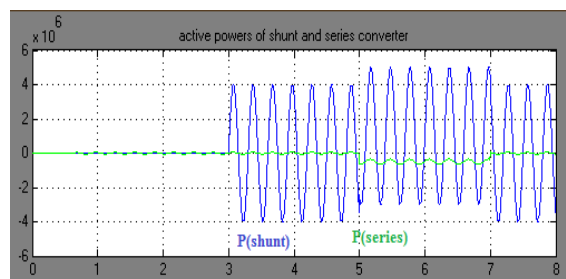

Fig. 12(b)Series injected voltage at "a" phase
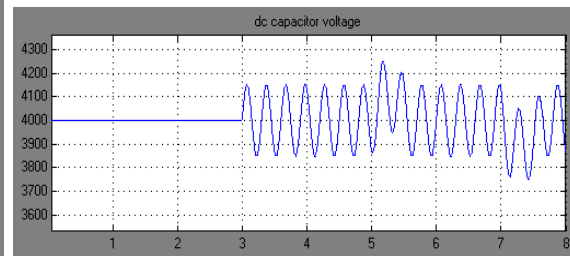

Fig.12(c) Shunt and series converter active power

Fig. 12(d) DC-bus voltage

In the upper curve of Fig.12 (a,b) is seen shunt and seriesconverter active–power behaviour.
The mean power injected (absorbed) by series converter isabsorbed (injected) by shunt converter, because of DC voltageregulation loop action (Fig.6). So, the step in series converteractive power is the same butopposite sign that shunt converterpower. Fig.12 (c,d) also shows DC–bus voltage, and is clearlyseen the V_{DC} control action. V_{DC} mean value is maintained at its reference level, whileripple is not rejected.

V. CONCLUSION

In this paper, a new compensation strategy implementusing an UPQC type compensator is present to connectSCIG based wind farms to weak distribution power grid. Theproposed compensation scheme enhances the system powerquality, exploiting fully DC–bus energy storage and activepower sharing between UPQC converters, features not presentin DVR and D–Statcom compensators. The simulation results show a good performance in the rejection of power fluctuationdue to "tower shadow effect" and the regulation of voltagedue to a sudden load connection. So, the effectiveness of the proposed compensation approach is demonstrated in the study case. In future work, performance comparison betweendifferent compensator types will be made.

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