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Analysis of UPQC for Voltage Sag Compensation in Wind Farms to Weak Grid Connections

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Abstract:

Wind Farms (WF) employing squirrel cage Induction generator (SCIG) directly connected to the grid; represent a large percentage of the wind energy conversion systems around the world. In facilities with moderated power generation, the WF is connected through medium voltage (MV) distribution headlines. In this scheme, the power generated is comparable to the transport capacity of the grid. This case is known as Wind Farm to Weak Grid Connection, and its main problem is the poor voltage regulation at the point of common coupling (PCC). Thus, the combination of weak grids, wind power fluctuation and system load changes produce disturbances in the PCC voltage, worsening the Power Quality and WF stability. This situation can be improved using control methods at generator level, or compensation techniques at PCC. In case of wind farms based on SCIG directly connected to the grid, is necessary to employ the last alternative. Custom power devices technology (CUPS) results are very useful for this kind of application. In this paper is proposed a compensation strategy based on a particular CUPS device, the Unified Power Quality Compensator (UPQC). A customized internal control scheme of the UPQC device was developed to regulate the voltage in the WF terminals, and to mitigate 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. This approach increases the compensation capability of the UPQC with respect to other custom strategies that use reactive power only. MATLAB/Simulink ® Simulations results show the effectiveness of the proposed compensation strategy for the enhancement of Power Quality and Wind Farm stability.

***Keywords* — Wind farm, Weak grid, UPQC, Shuntcontroller and Series controller.**

1. 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 centers [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 power quality 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], 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 to upgrade 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 compared to the line frequency. These active compensators allow great 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].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 analyze a compensation strategy using an UPQC, for the case of SCIG–based WF, connected to a weak distribution power grid. This system is taken from a real case [7]. 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 is managed through the common DC link. Simulations were carried out to demonstrate the effectiveness of the proposed compensation approach.

1. **A) Cause of Harmonics at PCC:**

- The combination of weak grids
- Wind power fluctuation
- System load changes
- Harmonic Polluting Loads :
- 1.Computers
- 2.Computer controlled machine tools
- Photo-copying machines
- Various digital controllers
- Adjustable speed drives

  Uncontrolled or phase controlled rectifiers

1. **B) Effect of Harmonics on Wind Farms:**

   -Disturbances in the PCC voltage
   -Worsening the Power Quality
   -Worsening the Wind Farms stability

2. System description& Modeling

2.1 System description:: The WF is composed by 36 wind turbines using squirrel cage induction generators, adding up to 21.6MW electric power. Each turbine has attached fixedreactive compensation capacitor banks (175 kVAr), and is connected to the power grid via 630KVA 0.69/33 kV transformer. The ratio between short circuit power and rated WF power, give us an idea of the “connection weakness”. Thus considering that the value of short circuit powerin MV6 is SSC ≃ 120 MVA this ratio can be calculated:

$r = SSC/PWF \cong 5.5$--- Values of $r < 20$ are considered as a “weak grid” connection.

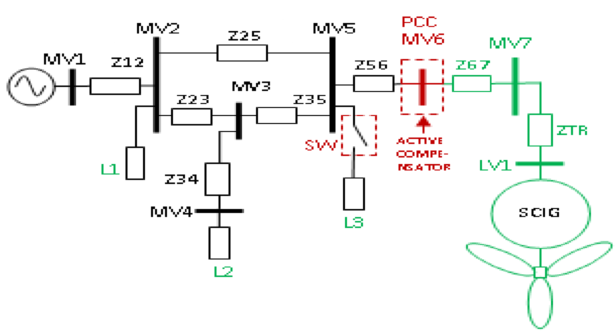

FIG (1): Study Case Power System

2.2. Turbine rotor and associated disturbances Model:

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

$P = 1/2\rho \cdot \pi \cdot R^2 \cdot v^3 \cdot CP$

Where ρ is air density, R is the radius of the swept area, v the wind speed, and CP the power coefficient. For the considered turbines (600 kW) the values are R= 31.2 m, ρ = 1.225 kg/m3 and CP calculation is taken from [8].

Power is the arithmetic sum of the power generated by each turbine according to the following equation:

$PT = i = \sum 1\ldots36\ Pi.$

For the considered turbines (600 kW) the values are $R = 31.2\ m$, $\rho = 1.225\ kg/m_3$ and C_P 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 modeled by only one equivalent wind turbine, whose power is the arithmetic sum of the power generated by each turbine according to the following equation:

$P_T = {}_{i=1\ldots36} P_i$ (2)

Moreover, wind speed v in (1) can vary around its average value due to disturbances in the wind flow.

Such disturbances can be classified as deterministic and random. The firsts are caused by the asymmetry in the wind flow “seen” by the turbine blades due to “tower shadow” and/or due to the atmospheric boundary layer, while the latter are random changes known as “turbulence”. For our analysis, wind flow disturbance due to support structure (tower) is considered, and modeled by a sinusoidal modulation superimposed to the mean value of v. The frequency for this modulation is 3.

Nrotor for the three–bladed wind turbine, its amplitude depends on the geometry of the tower. In our case we have considered a mean wind speed of 12 m/s and the amplitude modulation of 15%.

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 arithmetic sum of perturbations 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 power pulsation has maximum amplitude. So, turbine aggregation method is valid.

2.3 Dynamic compensator model:

The dynamic compensation of voltage variations is performed by injecting voltage in series and active–reactive power in the MV6 (PCC) bus bar; this is accomplished by using a unified type compensator UPQC.

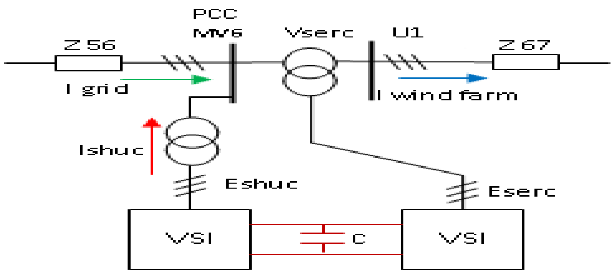

Fig (2): Block diagram of UPQC

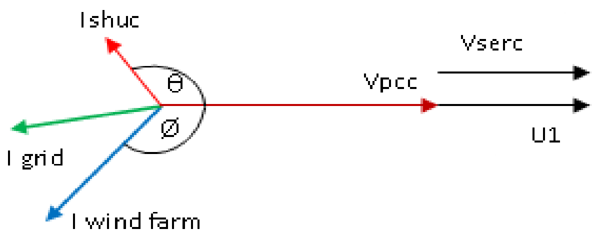

Figure 3. Phasor diagram of UPQC

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 converter is preferred because of lower DC link losses and faster response in the system than CSI. 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.

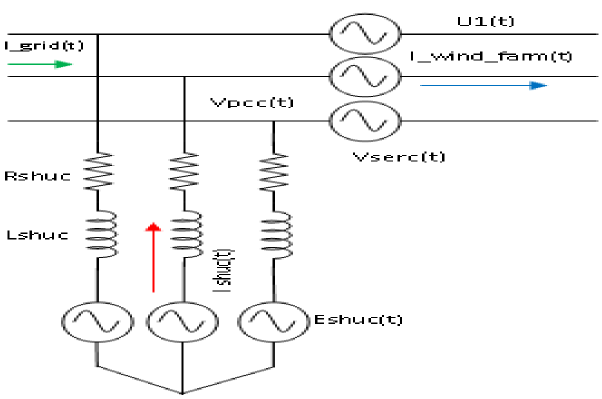

Figure 4. Power stage compensator model. AC side

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

$$T = 2/3 \begin{pmatrix} \sin\theta & (\sin\theta - 2\pi/3) & (\sin\theta + 2\pi/3) \\ \cos\theta & (\cos\theta - 2\pi/3) & (\cos\theta - 2\pi/3) \\ ½ & ½ & ½ \end{pmatrix} \quad \text{----(3)}$$

$$\begin{pmatrix} fd \\ fq \\ f0 \end{pmatrix} = T \begin{pmatrix} fa \\ fb \\ fc \end{pmatrix} \quad \text{----(4)}$$

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

The operation is based on the generation of threephase voltages, using electronic converters eithervoltage source type (VSI–Voltage Source Inverter) orcurrent source type (CSI–Current Source Inverter).VSI converter is preferred because of lower DC linklosses and faster response in the system than CSI [9].The shunt converter of UPQC is responsible forinjecting current at PCC, while the series convertergenerates voltages between PCC and U1, as illustratedin the phasor diagram of Figure 3. An importantfeature of this compensator is the operation of bothVSI converters (series and shunt) sharing the sameDC–bus, which enables the active power exchange between them.We have developed a simulation model for theUPQC based on the ideas taken from [10]. Sinceswitching control of converters is out of the scope ofthis work, and considering that higher order harmonicsgenerated by VSI converters are outside the bandwidthof significance in the simulation study, the convertersare modeled using ideal controlled voltage sources.Figure 4 shows the adopted model of power side ofUPQC. The control of the UPQC, will be implementedin a rotating frame dq0 using Park's transformation(eq.3-4).

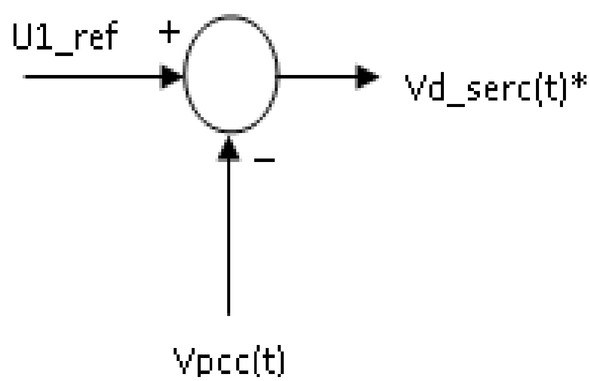

Figure 5. Series compensator controller

A block diagram in fig (5) of the series converter controller. The injected voltage is obtained subtracting the PCC voltage from the reference voltage, and is phase–aligned with the PCC voltage.

3.0UPQC Control strategy: The combination of series &parallel active filters is called the unified power quality compensator.

Use of UPQC in this scheme :A customized internal control scheme of the UPQC device was developed to regulate the voltage in the Wind Farm terminals and to mitigate voltage fluctuations at grid side.

The UPQC serial converter is controlled to maintain the WF terminal voltage at nominal value (see U1 busbar in Figure 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 in the occurrence of voltage sags in the WF terminals [4], [9].

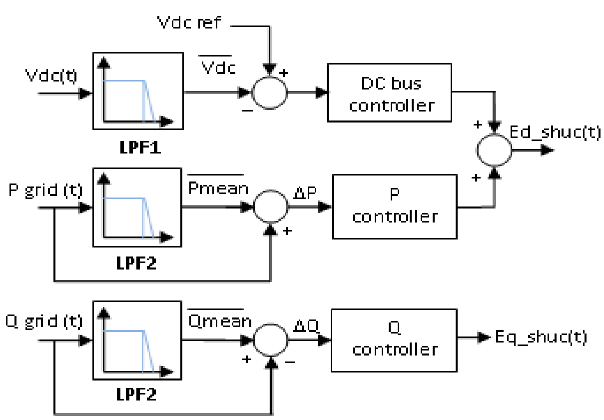

Figure 6. Shunt compensator controller

Figure 6 shows a block diagram of the shunt converter controller. This controller generates both voltagescommands Ed_shuC∗ and Eq_shuC∗ based on powerfluctuations ΔP and ΔQ, respectively.

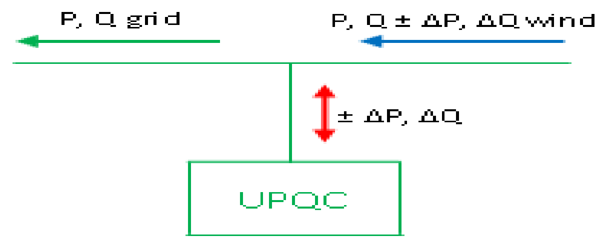

Figure 7. Power buffer concept

UPQC can be seen as a "power buffer", leveling the power injected into the power system grid.

4.0Circuit construction, Simulation results and Discussion:

Numerical simulations were performed to determine and then compensate voltage fluctuation due to wind power variation, and voltage regulation problems due to a sudden load connection. The simulation was conducted with the following chronology:

- at t = 0.0″ the simulation starts with the series converter and the DC–bus voltage controllers in operation.
- at t = 0.5″ the tower shadow effect starts;
- at t = 3.0″ Q and P control loops (see Figure 6) are enabled;
- at t = 6.0″ L3 load is connected.
- at t = 6.0″ L3 load is disconnected

5.0 Result analysis Compensation of Harmonics:

Simulation results for 0 < t < 6: At t = 0.5" begins the cyclical power pulsation produced by the tower shadow effect. As was mentioned, the tower shadow produces variation in torque, and hence in the active and reactive WF generated power. For nominal wind speed condition,the power fluctuation frequency is f = 3.4Hz, and the amplitude of the resulting voltage variation at PCC, expressed as a percentage is:**$\Delta U/U_{rated}$= 1.50 %.**

Voltage fluctuation for 0.5 < t < 3. The fluctuation value is higher. This means that even in normal operation, the WF impacts negatively on the System Power Quality. 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 from its original value of 1.6% (without compensation) to this new value:

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

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

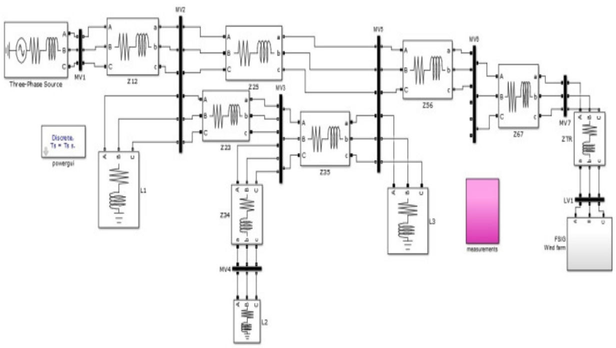

Figure 8. Model of power system without UPQC

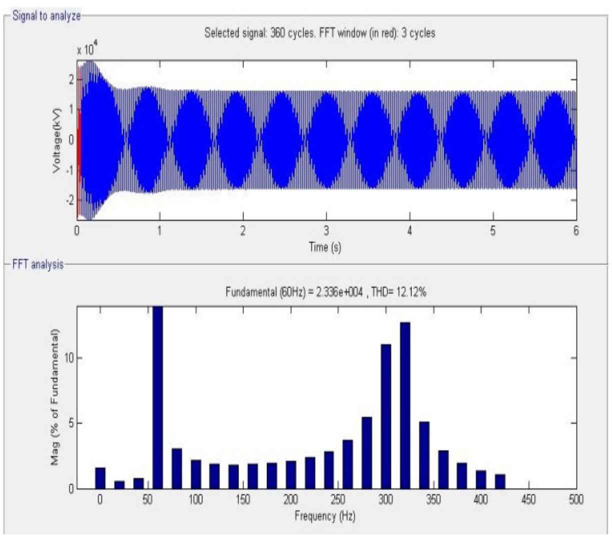

Fig.9. Result Of power system without UPQC

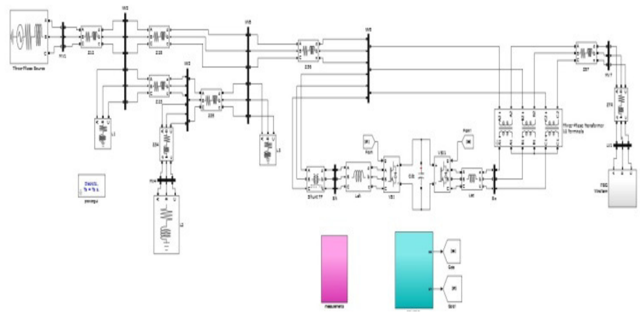

Figure 10. Model of power system scheme with UPQC

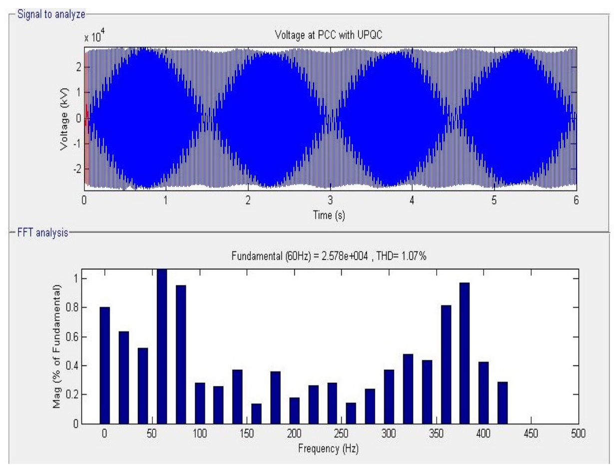

Fig.11. Result Of power system with UPQC

6.0 Conclusion:

Using an UPQC type compensator was presented, to connect SCIG based wind farms to weak distribution power grid. The proposed compensation scheme enhances the system power quality& reduces harmonics at PCC (point of common coupling) , exploiting fully DC–bus energy storage and active power sharing between UPQC converters, features not present in DVR and D–Statcom compensators. Active compensators to improve integration of wind energy in weak grids are the approach adopted in this Scheme. The simulation results show a good performance in the rejection of power fluctuation due to "tower shadow effect" and the regulation of voltage due to a sudden load connection. So, the effectiveness of the proposed compensation approach is demonstrated in the study case. In future work, performance comparison between different compensator types will be made.

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