ISSN 2395-1621

Harmonic Supression at the Point of Common Coupling

[1]Atul R. Pawar, [2]Vijay Harne

[#1]PG Scholar Department of Mechanical Engineering,S KNSinhgad Institute of Technology & Science, Lonavala, MaharashtraIndia

[#2]Assistant Prof. Department of Mechanical Engineering, SKN Sinhgad Institute of Technology & Science, Lonavala, MaharashtraIndia

ABSTRACT

Wind Farms (WF) engaged squirrel cage Induction generator (SCIG) directly connected to the distribution grid; represent a large rate of the wind energy conversion systems around the world. In facilities with moderated power generation, the WF is connected through medium voltage (MV) distribution lines. 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 harmonic & 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, aggravate (worsening) the Power Quality and WF stability. This situation can be improved using control methods at generator level, or compensation strategy 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 control & adjust 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 improvement of Power Quality and Wind Farm stability and harmonics present in grid to be suppressed by using UPQC circuit due to weak grid connection.

Key words – Wind farm, Weak grid, Voltage problem, Harmonic suppression, UPQC, Shunt controller and Series controller.

ARTICLE INFO

Article History

Received :29th February 2016

Received in revised form :

1st March 2016

Accepted : 4th March 2016

Published online :

6th March 2016

I. INTRODUCTION

The location of generation provision for wind energy is determined by wind energy resource availability, usually far from high voltage (HV) power transmission grids and major load or resource of consummation 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 characteristic of this type of connections is the increased voltage regulation sensitivity to changes in load condition [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, given the random nature of wind resources, the WF generates fluctuating & harmonic electric power. These fluctuations & harmonics 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], [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 usual one is to improve the power grid, increasing the short circuit power level at the point of common coupling PCC, thus minimizing the impact of power fluctuations and voltage regulation problems & harmonics in grid [5].

In last 5-10 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.

b) Improving 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 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 & Harmonics 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 UPQ device.

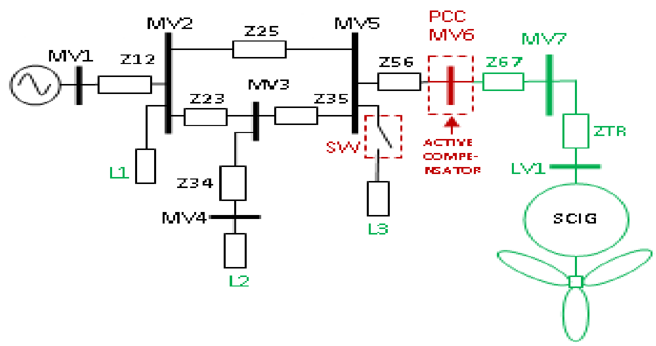


FIG (1): Study Case Power System

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, Harmonics 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 fixed reactive 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 power in 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.

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:

$PT = i = \sum 1 \ldots 36\, Pi$.------ (36 Wind turbine)

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].

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:

$PT = i = 1 \ldots 36\, Pi$ (2)

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

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.

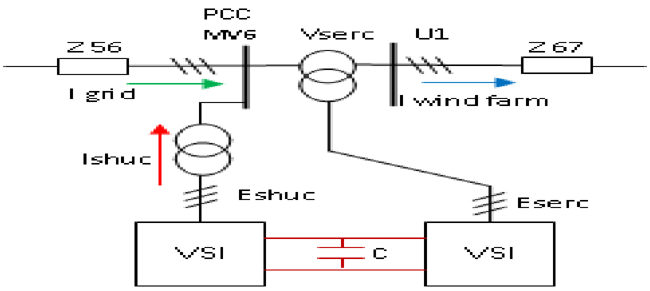


Fig (2): Block diagram of UPQC

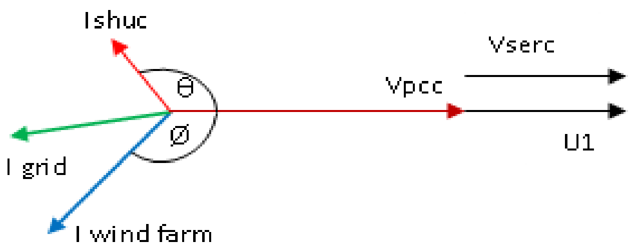
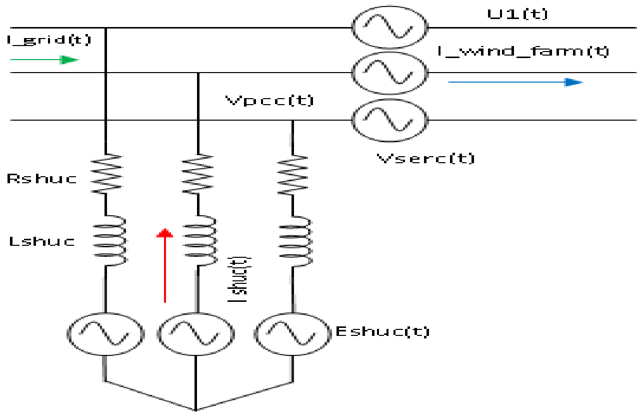


Figure 3. Phasor diagram of UPQC

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.



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

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

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

--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 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 [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 Figure 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. 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 modeled using ideal controlled voltage sources. Figure 4 shows the adopted model of power side of UPQC. The control of the UPQC, will be implemented in a rotating frame dq0 using Park's transformation (eq.3-4).

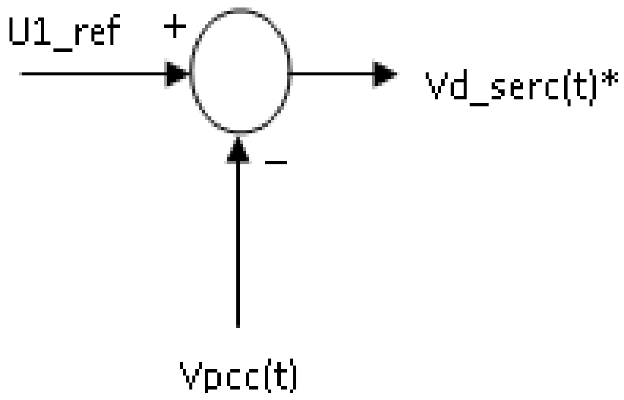


Figure 5. Series compensator controller

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.

3.0 UPQC 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 bursar 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].

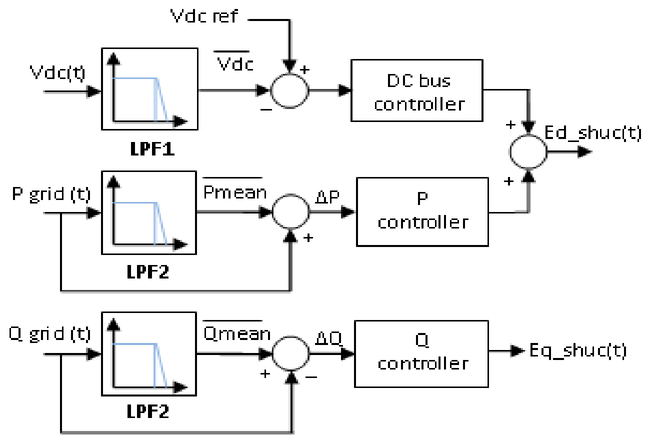


Figure 6. Shunt compensator controller

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

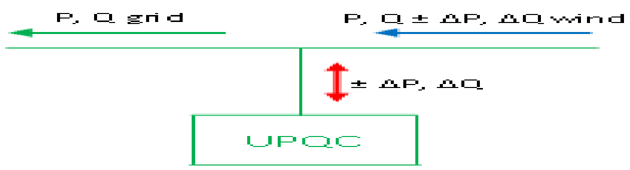


Figure 7. Power buffer concept

UPQC can be seen as a "power buffer", leveling the power injected into the power system grid i.e, Acive & reactive power compensation at standard value.

4.0 Circuit 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 caused 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.

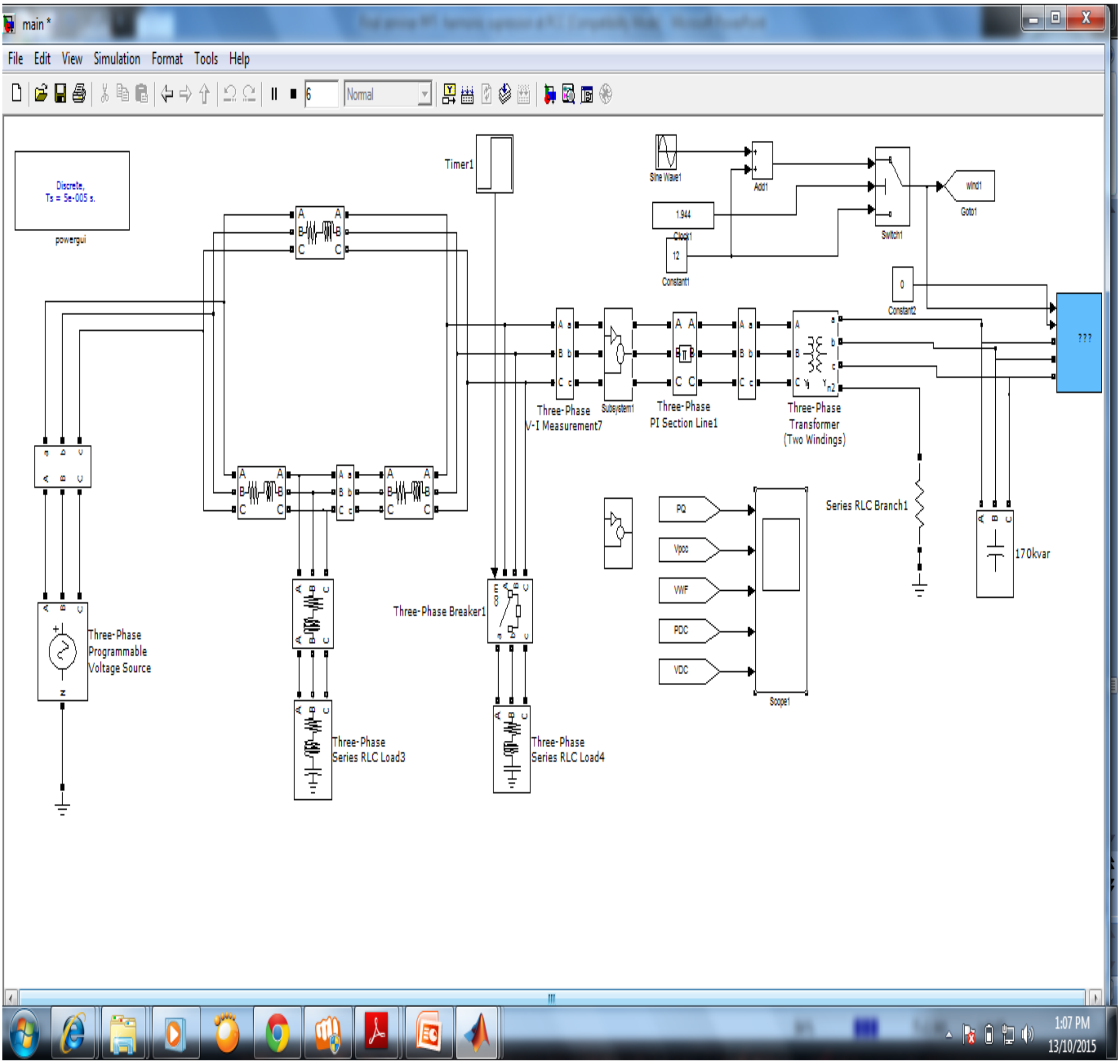
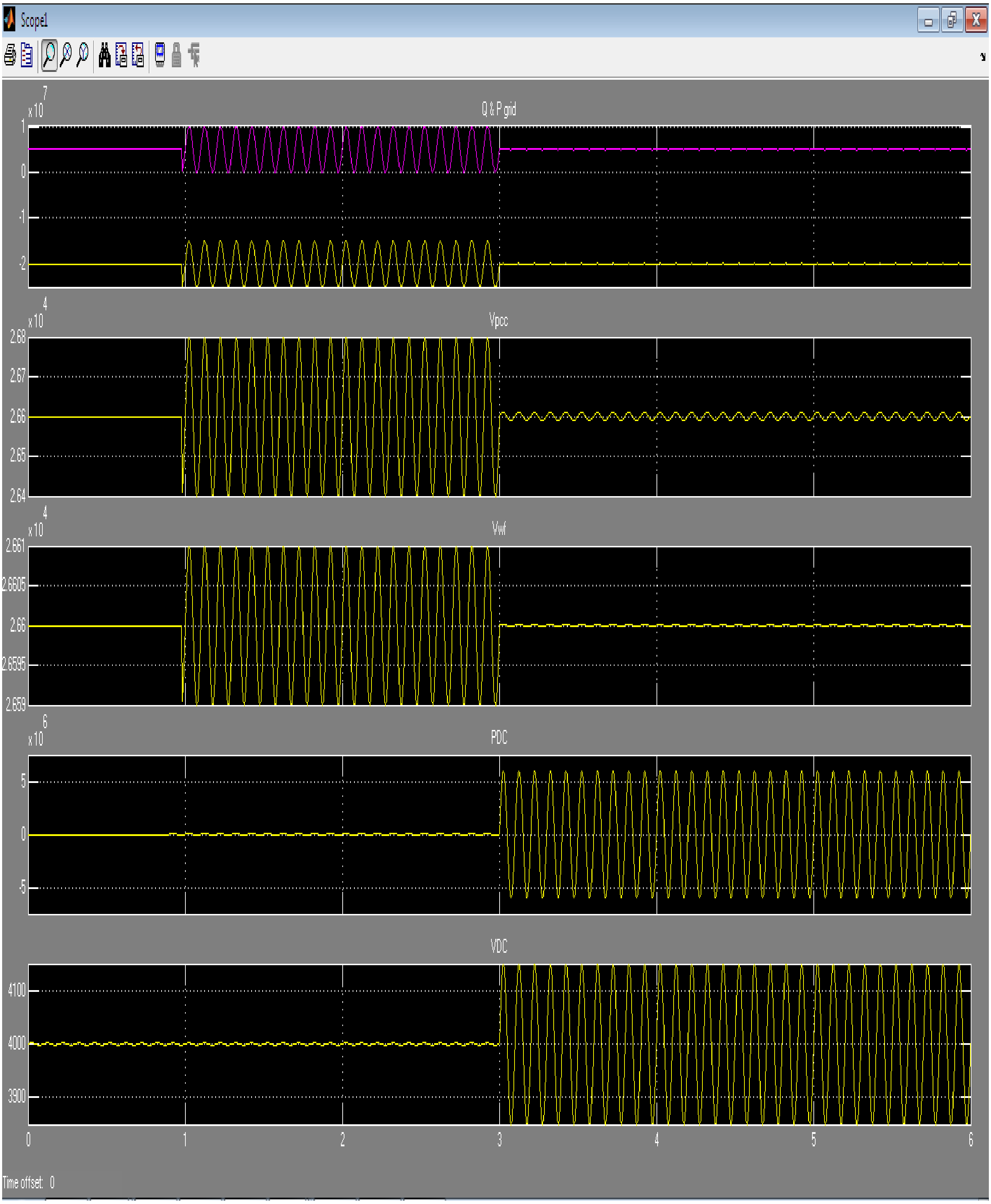


Figure 8. Model of power system scheme



Fig(9) Results with UPQC device

The UPQC is also operated to maintain the WF terminal voltage constant, rejecting PCC voltage variations, due to events like sudden connection/disconnection of loads, power system faults, etc. A sudden connection of load is performed at t = 6", by closing L3 switch (SW) in
Figure10. This load is rated at PL3 = 9.2 MW and QL3 =9.25 MW

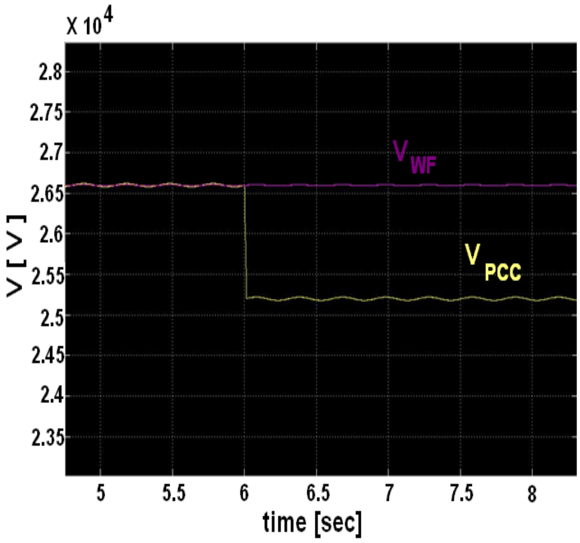


Fig 10. Voltage at WF, at PCC

Figure 10 shows the PCC and WF terminal voltages, and series injected voltage at "a" phase. In this figure is clearly seen a sudden change in PCC voltage, while WF terminal voltage remains almost constant due to series converter action.

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.

REFERENCES

[1] M.P. P´alsson, K. Uhlen, J.O.G. Tande. "Large-scale Wind Power Integration and Voltage Stability Limits in Regional Networks"; IEEE 2002. pp. 762–769

[2] P. Ledesma, J. Usaola, J.L. Rodriguez "Transient stability of a fixed speed wind farm" Renewable Energy 28, 2003 pp.1341–1355

[3] P. Rosas "Dynamic influences of wind power on the power system". Technical report RISØR-1408. Ørsted Institute. March 2003

[4] R.C. Dugan, M.F. McGranahan, S. Santoso, H.W. Beaty "Electrical Power Systems Quality" 2nd Edition[5] Wind Turbine Generating System—Part 21, International standard-IEC 61400-21, 2001

[5] P. Kundur "Power System Stability and Control" McGraw-Hill, 1994.ISBN 0-07-035958-X

[6] N. G. Hingorani y L. Gyugyi. "Understanding FACTS". IEEE Press;2000

[7] Z. Saad-Saoud, M.L. Lisboa, J.B. Ekanayake, N. Jenkins and G. Strbac "Application of STATCOM's to wind farms" IEE Proc. Gen. Trans. Distrib. vol. 145, No. 5; Sept. 1998

[8] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi "Wind Energy Handbook" John Wiley & Sons, 2001. ISBN 0- 471-48997-2

[9] A. Ghosh, G. Ledwich "Power Quality Enhancement Using Custom Power Devices" Kluwer Academic

[10] C. Schauder, H. Mehta "Vector analysis and control of advanced static VAR compensators " Publisher, 2002. ISBN 1-4020-7180-9" IEE

[11] E.M. Sasso, G.G. Sotelo, A.A. Ferreira, E.H. Watanabe, PROCEEDINGS-C, Vol.140, No.4, July 1993.

[12]International Electro technical Commission INTERNATIONAL STANDARD IEC 61000-4-15: Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques Section 15: Flickermeter Functional and design specifications." Edition 1.1 2003.