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IMPROVEMENT OF VOLTAGE REGULATION IN GRID INTEGRATED WIND FARM WITH CUSTOM POWER DEVICES

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Abstract. In this paper, a PQ based UPQC is proposed to mitigate the voltage regulation and fluctuations in the grid side when the grid is connected to wind farm. The wind farm is made by SCIG and it is directly connected to medium level voltage lines. But in this case, poor voltage regulation is occurred at PCC due to mismatching power capacity in between generation and transfer capacities. This problem is minimized with the help of PQ based UPQC. The internal controller scheme is mainly for power exchange between the series converter and shunt converter. With the help of these custom power devices, the sudden load changing effects also minimized. MATLAB/SIMULINK tools are used to execute this model.
Keywords: Point of Common Coupling, SCIG, Weak Grid, UPQC, Wind Farm.

I. INTRODUCTION

Power quality is defined as supplying pure sinusoidal waveform without any disturbances as well as voltage & frequency should be stable. In power quality problems generally, consider voltage must be stable because it affects the voltage regulation. Sometimes in the majority of the power quality issues voltage is the main concept when compared to current because of the controlling techniques. The power quality issue creates several problems technically but sometimes economical/financial problems are also created for various industries. For example, there are no semiconducting manufacturing industries in India because if any interruption caused in power supply or any power quality issues occurred it may surely damage manufacturing product. So on power quality issues, the industries are classified into three categories: 1. High cost, 2. Medium cost, and 3. Low cost. Various industries are listed under these three categories is shown in figure 1.

For more reliable and effective power transfer system IEEE defined the power quality standard's because of renewable energy power generation is integrated with the conventional grid system. For voltage stability, we have to improve voltage regulation.

What is the need for reactive power injection?

In WF formation we used squirrelcage induction generator it needs reactive power, so the reactive power is injected by a capacitor bank at each turbine. The CPD is used to compensate the reactive power but wind power is not constant because the wind speed is not constant in a day. So it leads to fluctuations in the voltage and power in WF output. The system is going to unstable by these fluctuations. So by using suitable CPD's both the power injections as well as voltage fluctuations compensation.DVR,D-STATCOM is only limited to point of connection but UPQC is used to control an area because of its internal structure i.e., series and shunt converter connected with a DC link. All the CPD's are useful to mitigate power quality issues but by providing UPQC there is no need for external DC bus link. If in case of D-STATCOM is used in this type of problems the external DC supply is most be provided. By this action zero average power is not possible and energy is stored in that CPD's. By this DVR the voltage regulation is improved but it is limited for large disturbances and not suitable for small disturbances aswell as for reactive power compensations.

When compared between D-STATCOM and DVR, DVR is most suitable for voltage regulation. If the comparisons between three CPD's D-STATCOM, DVR and UPQC, then UPQC is more accurately suitable for this type of problems. Because UPQC is to regulate voltage and acts as compensation for voltage sag problems. The DC link is a common point for series – shunt converter. The DC link provides power exchange between the series converter and shunt converter [4], [5].

II. DESIGN AND MODELING

In this paper, the wind farm is connected to the grid through a step-up transformer T1 and the wind farm is made by wind turbines with the reactive power compensation capacitor bank. To avoid poor voltage regulation custom power devices are used. D-STATCOM or UPQC is used to mitigate the voltage fluctuation and poor voltage regulation. The CPD is located at PCC to avoid poor voltage regulation. The UPQC is most suitable for this type of problems because in UPQC there is two series shunt converter with DC bus link. These two series shunt converters are voltage source inverters, CSI is not used due to DC bus losses. The UPQC is used mainly for grid side problems.

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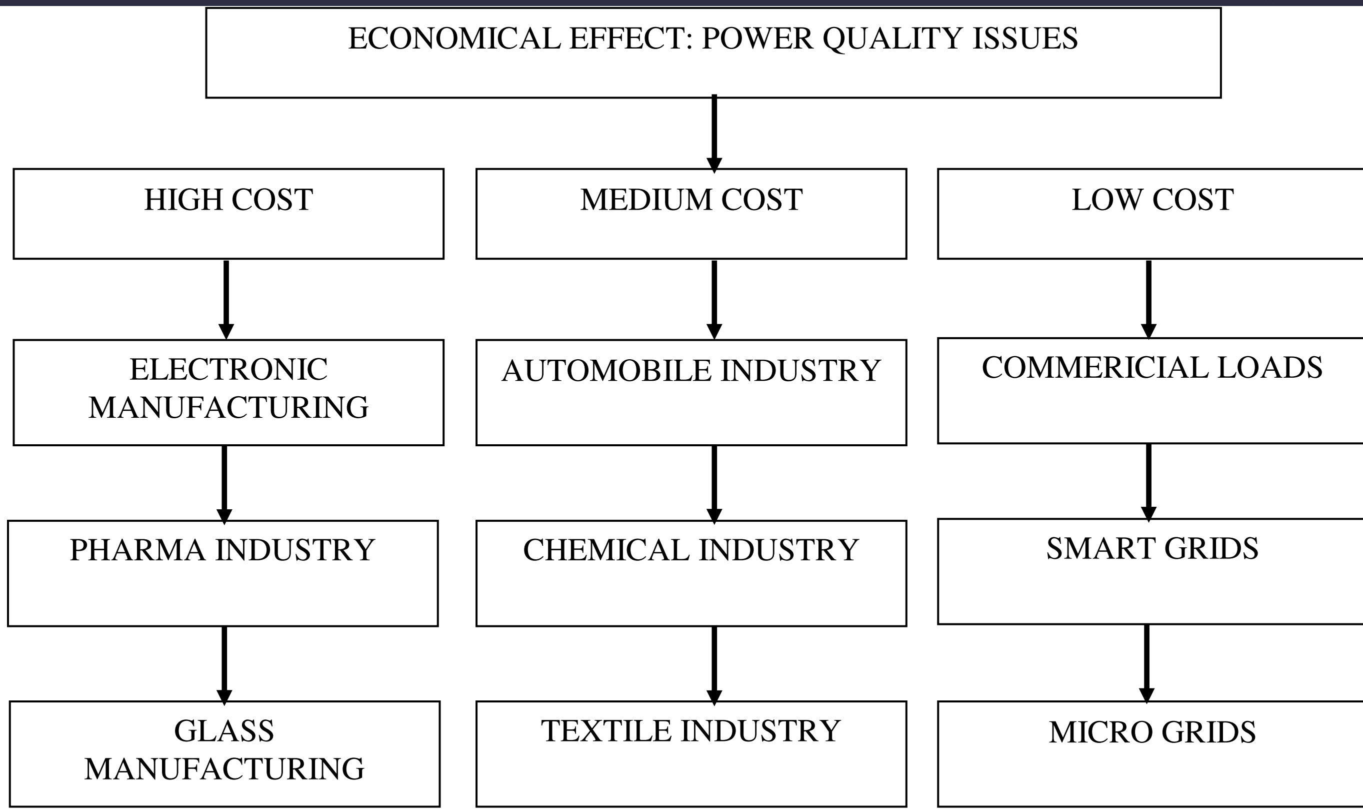

Figure 1: According to cost variations classification power quality affected industries.

With the help of UPQC, power quality issues are mitigated. The line voltage and voltage variations at PCC are compensated by series VSI converter and as well as voltage sags when sudden loading conditions. By this compensation with the presence of UPQC (series converter) helps to doesn't spread faults from the grid side to WF system. The shunt converter in UPQC will help to suppress the pulsations in active and reactive powers. The power which is injected into the grid from the WF system is completely free from pulsation of active and reactive powers which helps to maintain the system stability and power quality [2]. If the injected power is contained any faults/fluctuations the faults are spread over the grid side also and causes the voltage instability by the reactive power to unbalance. The wind energy is generated by wind farms, 36 squirrel cage induction generators are combined for wind farms. The total installed range is 22 MW. Each turbine has a reactive power compensation capacitor bank 175 KVAR and is connected to the power grid via 630KVA, 0.69/33 KV transformer. The concept of the weak grid is defined as "the ratio between short circuit power and rated wind farm power".

$$x = \frac{S_{sc}}{P_{WF}} = \frac{120}{22} = 5.45$$

The range of x is decided the whether the gird is weak or not. If the range is less than 20 it is called as "weak grid".

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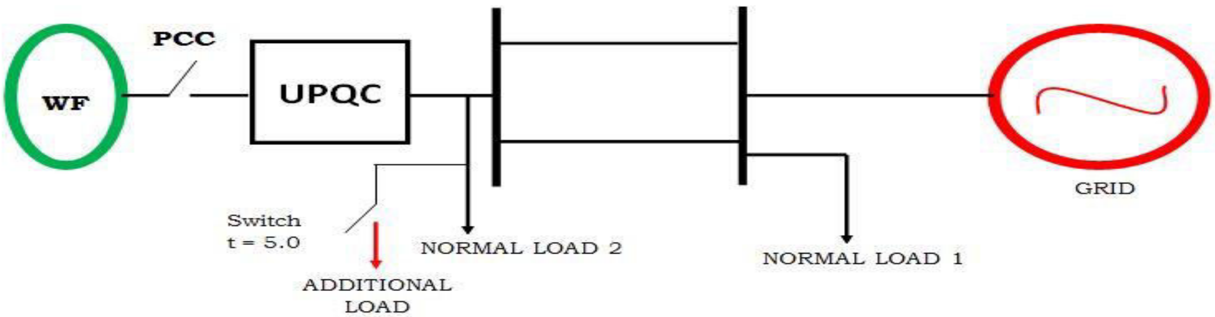

Figure2: Representation of Grid Integrated Wind Farm in Single Line Diagram.

$$i_d = \sqrt{\frac{2}{3}}\left\{i_a * \cos\theta - i_b * \cos\left(\theta + \frac{2\pi}{3}\right) - i_c * \cos\left(\theta - \frac{2\pi}{3}\right)\right\} \tag{1}$$

$$i_q = \sqrt{\frac{2}{3}}\left\{i_a * \sin\theta - i_b * \sin\left(\theta + \frac{2\pi}{3}\right) - i_c * \sin\left(\theta - \frac{2\pi}{3}\right)\right\} \tag{2}$$

$$i_o = \frac{1}{\sqrt{3}}\{i_a + i_b + i_c\} \tag{3}$$

$$v_d = \sqrt{\frac{2}{3}}\left\{v_a * \cos\theta - v_b * \cos\left(\theta + \frac{2\pi}{3}\right) - v_c * \cos\left(\theta - \frac{2\pi}{3}\right)\right\} \tag{4}$$

$$v_q = \sqrt{\frac{2}{3}}\left\{v_a * \sin\theta - v_b * \sin\left(\theta + \frac{2\pi}{3}\right) - v_c * \sin\left(\theta - \frac{2\pi}{3}\right)\right\} \tag{5}$$

$$v_o = \frac{1}{3}\{v_a + v_b + v_c\} \tag{6}$$

$$\begin{bmatrix} i_o \\ i_d \\ i_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \cos\theta & \cos\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{7}$$

In matrix form, it can be represented as (8)

$$\boldsymbol{I_{dqo} = P * I_{abc}}$$

Similarly (9)

$$\begin{bmatrix} v_o \\ v_d \\ v_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \cos\theta & \cos(\theta + 2\pi/3) & \cos(\theta - 2\pi/3) \\ \sin\theta & \sin(\theta + 2\pi/3) & \sin(\theta - 2\pi/3) \end{bmatrix} \times \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

In matrix form, it can be represented as (10)

$$\boldsymbol{v_{dqo} = P * v_{abc}}$$

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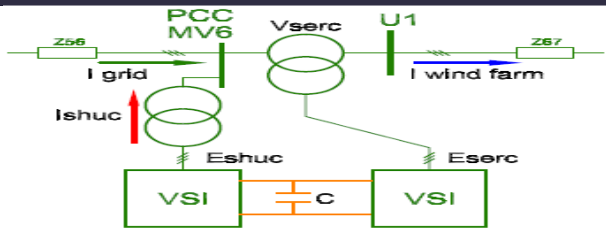

Figure 3: Line diagram of wind farm connected grid system with UPQC.

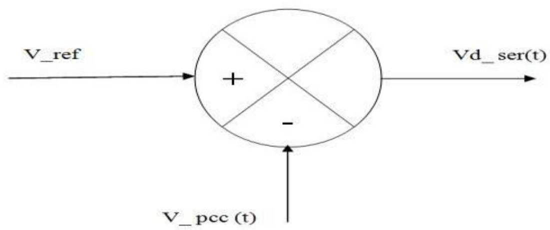

Figure 4: Internal structure of voltage compensator in UPQC.

Series compensator: the series compensator is designed to get the voltage of two-axis system i.e., park's transformation. The bus bar voltage will be considered as reference and it connected to the summation of the voltage at PCC. If these errors/any unwanted quantities are generated & it is named $\mathbf{V_{d\_ser}}$&$\mathbf{V_{q\_ser}}$. With the help of a low pass filter, the mean values of active and reactive powers are calculated & it connected to a summation point of grid active & reactive powers to eliminate the unwanted frequency terms. These actions, the fluctuated P & Q are calculated and named as ΔP & ΔQ. These two quantities are helpful for calculation of $\mathbf{V_{d\_ser}}$&$\mathbf{V_{q\_ser}}$ as well as $\mathbf{V_{d\_err}}$[7]-[9].

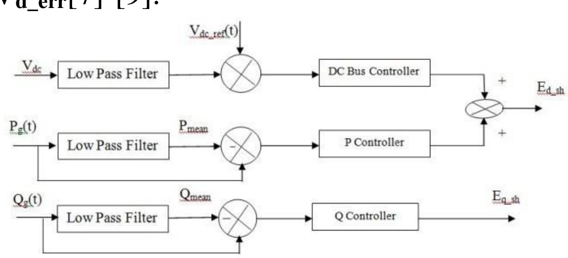

Figure 5: Internal structure of internal structure of Shunt controller UPQC.

For calculation of $\mathbf{V_{d\_shc}}$, the $\mathbf{V_{d\_err}}$& ΔP are processed to DC bus controller & P controller respectively. The error in $\mathbf{V_{dc}}$ is calculated by comparing the $\mathbf{V_{dc\_ref}}$&$\mathbf{V_{dc}}$ processed by a low pass filter [1].

III. SIMULATION RESULTS

Testing condition on grid-connected wind system with and without UPQC

a. At t = 0, the simulation starts with series converter and DC link voltage controllers in operation.

b. At t = 0.5, the effect of tower shadow starts.

c. At t = 3.0, the P & Q control loops are enable.

d. At t = 5.0, the load is additionally added to the system in large amount.

e. At t = 8.0, the additional load is removed from the wind integrated grid system.

Figure 6 represents active and reactive power responses at the grid side under the tower shadow effect up to 0.5 sec. from 0.5 seconds onwards all wind turbines are synchronized and it minimizes the effect of tower shadow problem. But due to wind input variations, the wind farm output also fluctuating and can be controlled by the onlyactivation of UPQC. UPQC comes into operation at 3 sec and it clearly indicates by reducing peak over shots/fluctuations.Figure 7, 8 represents the voltage response at point of common coupling and voltage response of wind farm, when the UPQC comes to operation the voltage variations are settled down, voltage variations are caused due to wind input is not constant in day or in any particular period, so compensation is required to settle down the variations. At 3

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sec onwards UPQC enables the loop control and the variations are settling down. We can observe the voltage response of DC link from 3 sec onwards in figure 12.

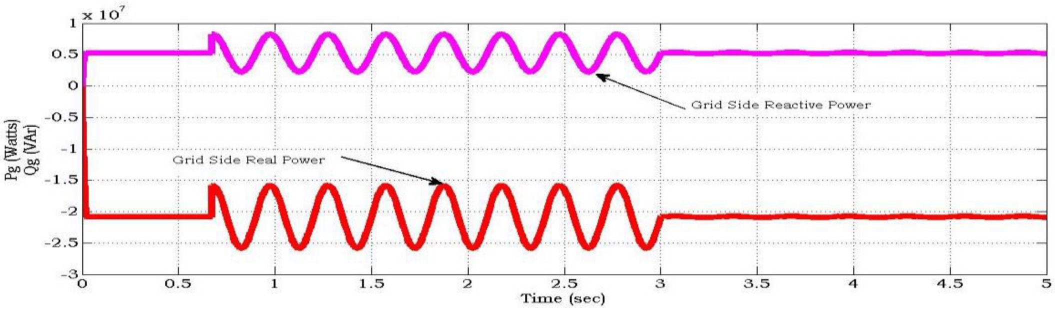

Figure 6: active and reactive power response at the grid side.

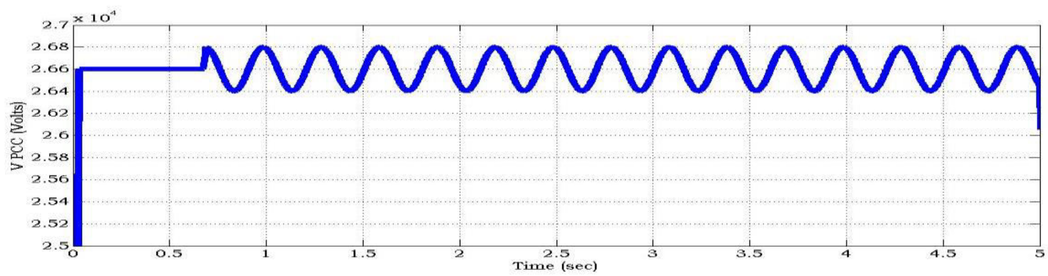

Figure 7: Voltage response at the point of common coupling without UPQC.

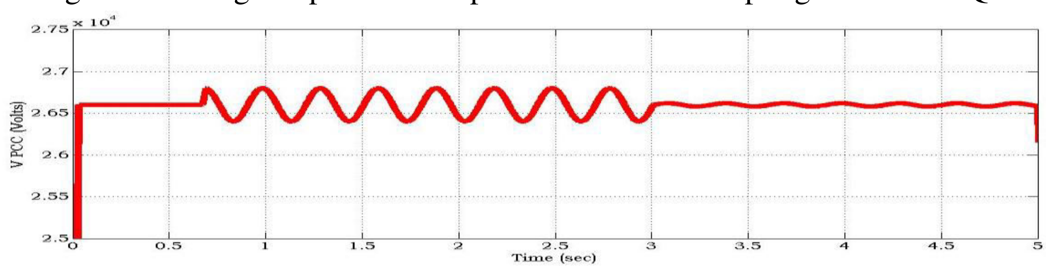

Figure 8: voltage response at the point of common coupling.

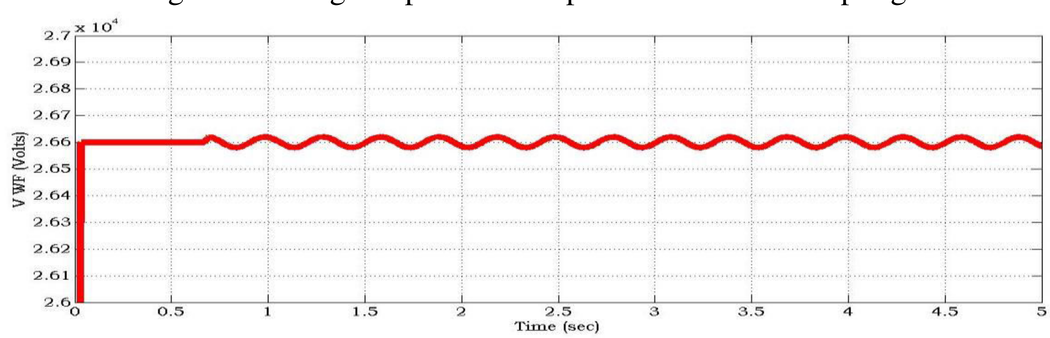

Figure 9: wind farm voltage response without UPQC

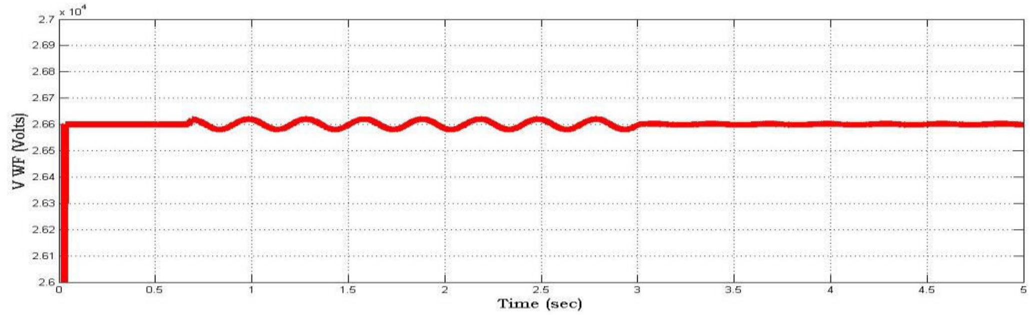

Figure 10: wind farm voltage response.

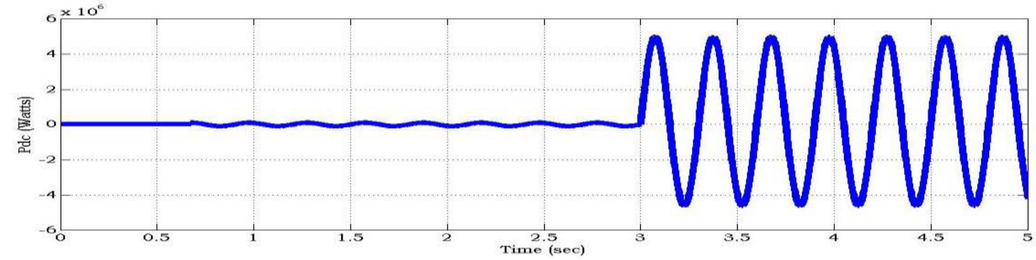

Figure 11: Real Power output response from UPQC.

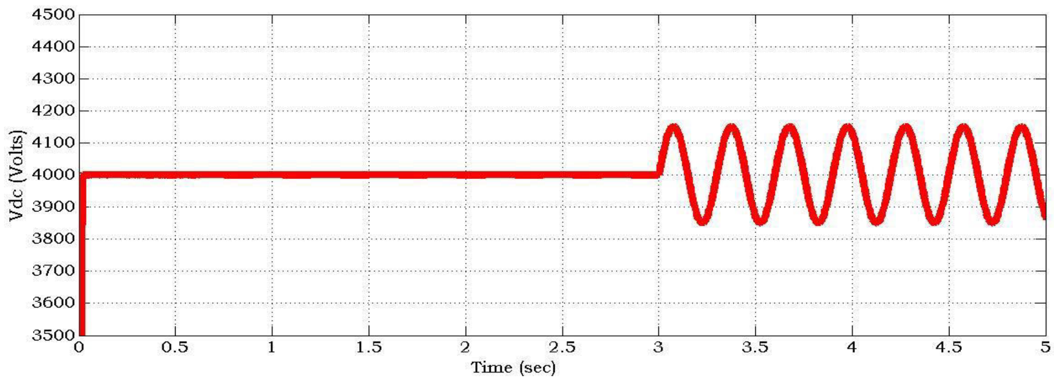

Figure 12: DC bus link Voltage response.

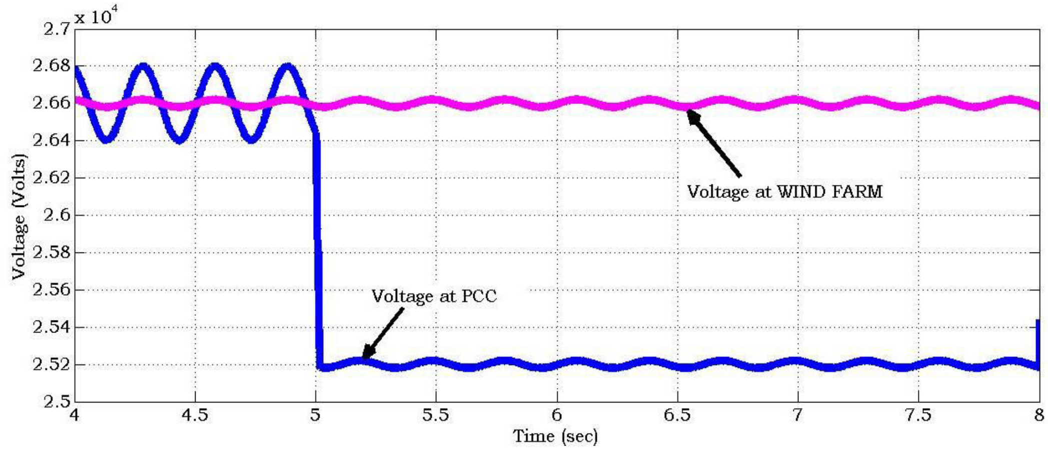

Figure 13: Voltage response at both point of common coupling and wind farm during load changes without UPQC.

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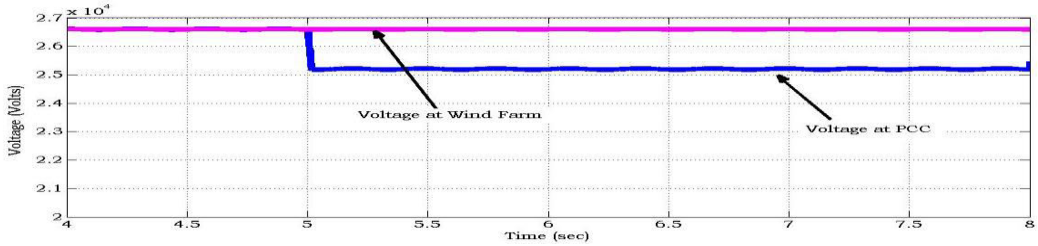

Figure 14: Voltage response at both point of common coupling and wind farm during load changes.

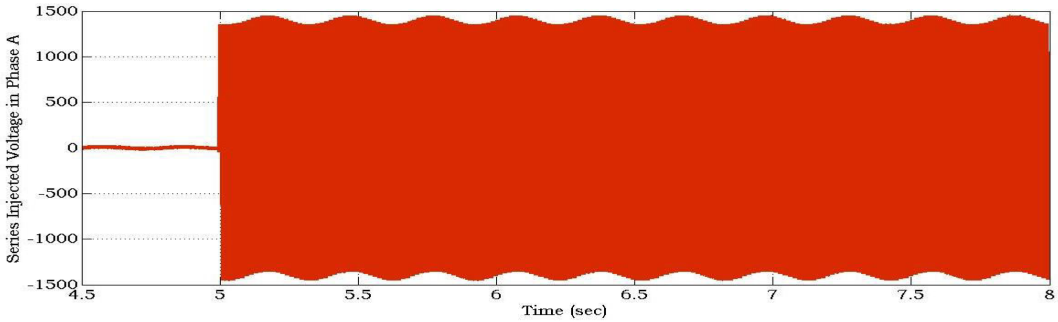

Figure 15: response of injected voltage by the series converter at load varying situation.

Figure 11 and 12 shows the response of active power and DC Bus voltage from T = 0 – 5, this period divides into two different cases. First one is 0<T<3 in this period UPQC is not under the operativecondition and gives the constant response. The second one is 3<T<5, in this period UPQC loop enables and comes into operation.

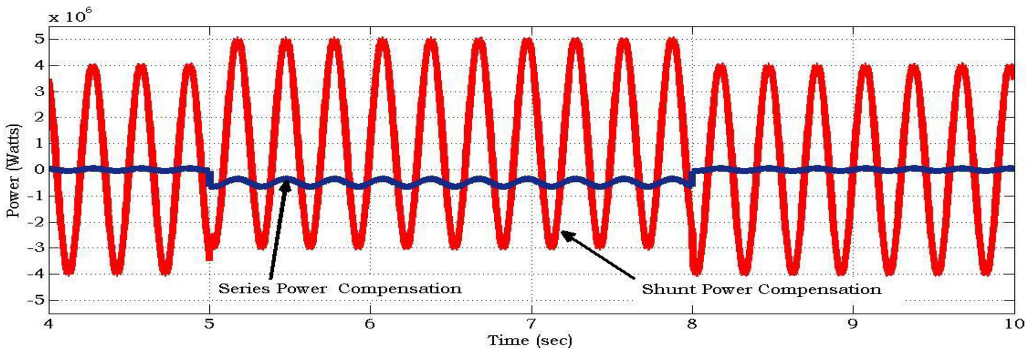

Figure 16: Response of series and shunt converters real power during load addition/rejection cases.

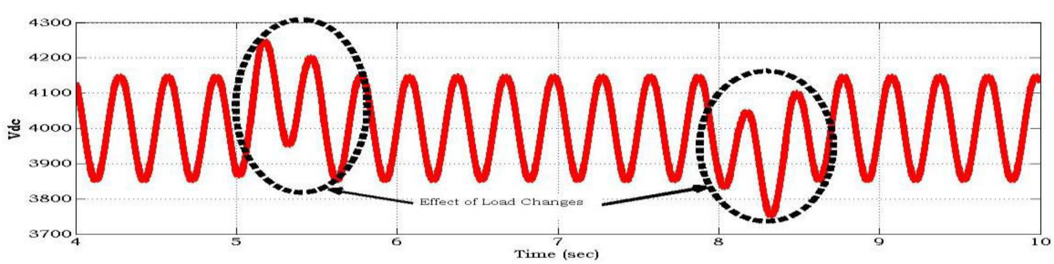

Figure 17: Response of DC Bus link Voltage variations during load addition/rejection cases.

At instant T = 5, suddenly load is increased in large amount, in general, any power system/grid is going voltage instability because longtimevoltage fluctuations are caused and it leads to poor voltage regulation. If any system faces the poor voltage regulation and voltage variations along with reactive power unbalance for a long time the system going shut down. In figure 14 two different responses are present i) voltage at PCC, ii) Voltage response of Wind Farm. With the help of UPQC, the wind farm maintains the good voltage level even under load varying conditions. But at the point of common coupling voltage drop is clearly observed when the load is suddenly added.

When load changes occur the UPQC is acting accordingly and it can be observed in figure 15 and 16. At T= 5 sec a large amount of load is added to the system then in UPQC shunt converter boost up the active power instantaneously and series converter response goes down when the excess amount of load the is relieved. Same as in figure 16 the DC bus voltage response shows the voltage level variations when sudden load is added/relived, in both cases the variations we can observe and the load it comes to a normal position at T = 8.

IV. CONCLUSION

This paper discusses power quality issues which are mainly related to both conventional and grid-integratednon-conventional energy sources and which industries are more affected by power quality problems. This paper describes the different cases like tower shadow effect, atmospheric variations for wind farms, load variations. All these cases are studied and simulated with and without UPQC. By providing the UPQC the sag, swells of voltage problems are overcome and the DC link provides the constant DC supply to rectifier and inverter. With the help of UPQC, all these problems are minimized with a very fast response. It is not possible with any other custom power devices because any device can be acted as a series converter or shunt converter only but only by the internal structure of UPQC it is possible, UPQC is a combination of series and shunt converter. The proposed system is more useful for all types of general faults then it improves the power quality as well as the reliability of the power supply.

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