STUDY OF REACTIVE POWER COMPENSATION AND REDUCTION OF VOLTAGE FLUCTUATIONS IN WIND MILL CONNECTED TO WEAK GRID SYSTEM USING UNIFIED POWER QUALITY CONDITIONER

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Abstract- In recent times, the grid integration of wind power generation to the standard grid has been increased significantly. The Wind Farm (WF) is to be connected to High Voltage (HV) power transmission grids through Medium Voltage (MV) distribution headlines. The poor voltage regulation at the Point of Common Coupling (PCC) is the main problem commonly found Wind Farm connected. Also, WF is affected by Tower Shadow Effect due disturbance in wind flow which causes voltage fluctuations in the system. Compensation techniques are used addresses the problem of poor voltage regulation at PCC and WF stability due system load changes.

In this Paper, a compensation strategy based on particular custom power device i.e. Unified Power Quality Conditioner (UPQC) has been proposed. Synchronous Reference Frame control scheme is used to mitigate voltage fluctuations and to regulate the WF terminal voltage at PCC caused by pulsating WF generated power and system load changes respectively. The effectiveness of the proposed compensation approach is demonstrated using a study case. Simulation results show that there is reduction in power fluctuations at grid and voltage fluctuations at PCC.

***Index Terms*— Wind Farm, Weak Grid, Unified Power Quality Conditioner, Voltage Fluctuations.**

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 centers. In case of facilities with medium power ratings, the WF is connected through Medium Voltage (MV) distribution headlines. Voltage Fluctuations will occur when Wind Farm is associated with Tower Shadow Effect while it is connected to the Grid [1]. 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 PCC, thus reducing the impact of Power Fluctuations and voltage regulation problems [2].

The other solution is using Active power compensators have fast response compared to the line frequency which allows great flexibility in enhancing the power quality in distribution systems by employing Custom Power Devices (CPD) devices [3]. In this paper, custom power device, the Unified Power Quality Conditioner (UPQC) used to mitigate the power quality problems caused by wind farm connected to weak grid. 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. 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 [4]. Wind Farm connected to Weak Grid, a study case power system is shown in the figure 1.

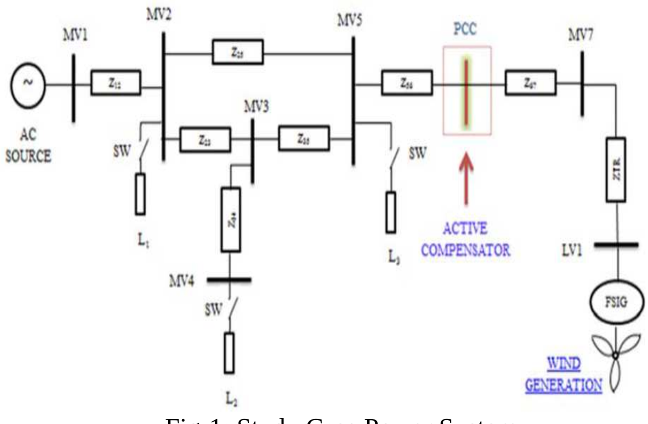

Fig-1: Study Case Power System

II. SYSTEM DESCRIPTION AND MODELLING

A. 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 (175kVAr), and is connected to the power grid via 630KVA 0.69/33kV transformer. This system is taken from [5], and represents a real case. The power that can be extracted from a wind turbine is determined by the following expression:

$$P = \frac{1}{2} . \rho . \pi . R^2 . \upsilon^3 . C_P \qquad (1)$$

Where ρ is air density, R the radius of the swept area, is 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 [6].

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:

$$P_T = \sum_{i-1,2,\ldots 36} P_i \qquad (2)$$

B. Weak Grid

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 (WF connected to Medium Voltage (MV) lines) is that the power generated is comparable to the transport capacity of the grid is known as WF to Weak Grid connection.

$$r = \frac{S_{SC}}{P_{WF}} \simeq 5.5 \qquad (3)$$

S_{sc} is Short Circuit Power =120 MVA P_{WF} is Wind Farm Power = 21.6 MW. r<20 is considered as a "Weak Grid" connection [7]. The Problem of weak grids connection with wind energy is voltage level fluctuations. To rectify this problem mainly two control strategies are preferred. One is Grid reinforcement, which increases the capability of the grid by increasing the cross section of the cables by erecting a new line parallel to the existing line for some part of the distance. Another control strategy is slightly more advanced, is to continuously control the power output of the wind turbine in such way that the voltage limit is not exceeded [8].

C. Fixed Speed Induction Generator

The stator winding is connected directly to the grid and the rotor is driven by wind turbine and the power is transmitted to the grid by the stator winding. The pitch angle is controlled to limit the generator output power to its nominal value for high wind speeds. The reactive power that is absorbed by the induction generator is provided by grid.

D. Custom Power Devices (CPD)

Custom power is a strategy, which is intended principally to convene the requirement of industrial and commercial consumers. The concept of the custom power is tools of application of power electronics controller devices into power distribution system to supply a quality of power, demanded by the sensitive users. They have good performance at medium distribution levels and most are available as commercial products. For the generation of custom power devices VSI is generally used, due to self- supporting of dc bus voltage with a large dc capacitor.

III.UNIFIED POWER QUALITY CONDITIONER

The dynamic compensation of voltage variation is performed by injecting voltage and Active-Reactive Power at PCC (MV6) by UPQC [1]. The block diagram of UPQC is shown in figure 2.

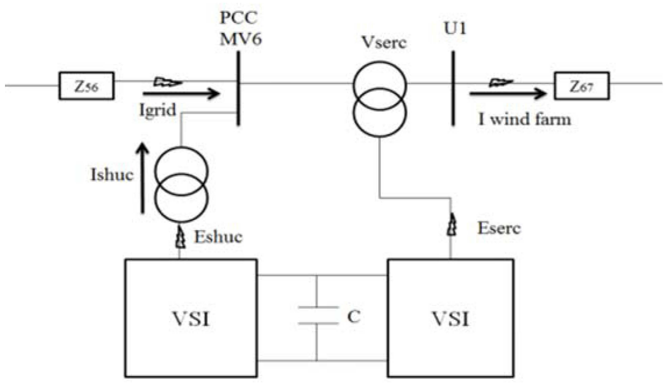

Fig.-2: Block Diagram of UPQC

The Shunt converter of UPQC is used to inject current at PCC. The Series converter generates Voltages between PCC and U1.Operation of both VSI converters sharing the same DC bus by exchanging the Active Power between them. A Unified

Power Quality Conditioner (UPQC) is a device that is similar in construction to a Unified Power Flow Conditioner (UPFC). The UPQC, just as in a UPFC, employs two Voltage Source Inverters (VSIs) that connected to a DC energy storage capacitor. One of these two VSIs is connected in series with AC line while the other is connected in shunt with the AC system. A UPQC combines the operations of a Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Regulator (DVR) together.

VI. UPQC CONTROL STRATEGY

The UPQC serial converter is controlled to maintain the WF terminal voltage at nominal value, 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. The injected voltage is obtained subtracting the PCC voltage from the reference voltage, and is phase–aligned with the PCC voltage. 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 currents injection in PCC. Also, the regulation of the DC bus voltage has been assigned to this converter.

A. Control Strategy of Series Converter

Figures 3 and 4 shows the control strategy of series converter. Control Strategy is based on extraction of unit vector templates and reference voltages from the three phases. Distorted wind farm terminal voltages are sensed at Point of Common Coupling (PCC). These unit vector templates are equal to pure sinusoidal voltages generated with proper phase delay. Distorted wind farm terminal voltages sensed at PCC contains both fundamental component and distorted component. To get unit input voltage vector U_{abc}, sensed voltage is multiplied by gain $k = 1/v_m$ where v_m equal to the peak amplitude fundamental input voltage.

$$U_a = \sin wt \qquad (4)$$
$$U_b = \sin(wt - 120) \qquad (5)$$
$$U_c = \sin(wt + 120) \qquad (6)$$

Multiplying the peak amplitude of fundamental input voltage with unit vector templates of above equations gives the reference voltage signals,

$$\mathbf{U_{abc,ref} = v_m U_{abc}} \qquad \mathbf{(7)}$$

Reference voltage signals are compared with the instantaneous voltage sensed at PCC. Error generated is then given to the PWM generator to generate the required gate signals for series converter; in such a way that it compensates the voltage variations at PCC to maintain the nominal value of wind farm terminal voltage by injecting voltage is in phase with the PCC voltage.

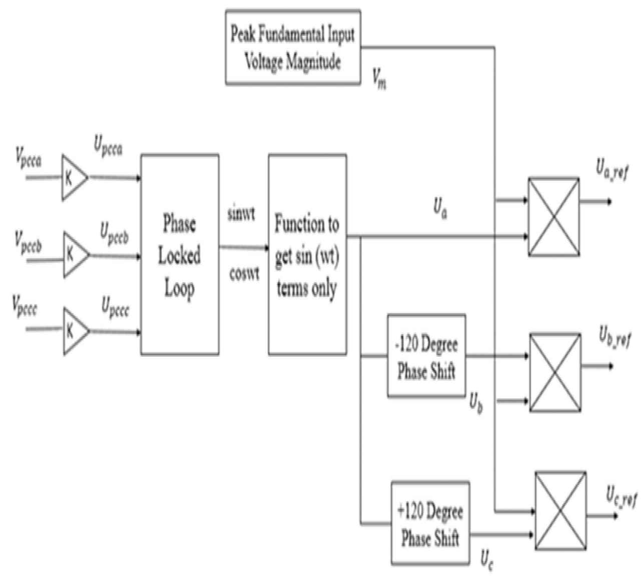

Fig.-3: Extractions of Unit Vector Templates

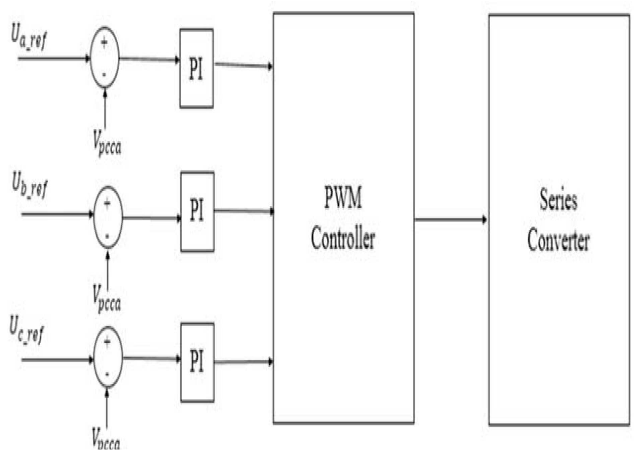

Fig.-4: Control Strategy of Series Converter

B. Control Strategy of Shunt Converter

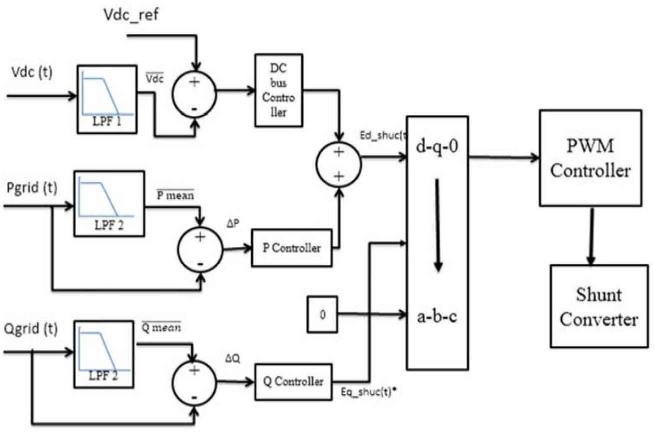

Fig.-5: Control Strategy of Shunt Converter

Control strategy of Shunt converter is based on "instantaneous power theory" as shown in figure 5. Mean values of active and reactive power are obtained by low-pass filtering, and the bandwidth of such filters is chosen so that the power fluctuation components selected for compensation. Shunt converter controller generates both voltage commands Ed_shuc(t)* and Eq_shuc(t)* based on power fluctuations ΔP and ΔQ, respectively. Such deviations are calculated subtracting the mean power from the instantaneous power measured in PCC. Ed_shuc(t)* also contains the control action for the DC–bus voltage loop. This control loop will not interact with the fluctuating power compensation.

Control voltage commands transform to phase voltages by using Inverse Park's transformation is then given to the PWM generator to generate the required gate signals for shunt converter. Powers PshuC and QshuC are calculated in the rotating reference frame, as follows:

$$PshuC(t) = \frac{3}{2}.V_d^{PCC}(t).I_d^{shuC}(t) \quad (8)$$

$$QshuC(t) = \frac{3}{2}.V_d^{PCC}(t).I_d^{shuC}(t) \quad (9)$$

Ignoring PCC voltage variation, these equations can be written as follows.

$$PshuC(t) = k'_p.\ I_{d\_}\ shuC(t) \quad (10)$$

$$QshuC(t) = k'_q.I_{q\_}\ shuC(t) \quad (11)$$

VSI model proposed leading to linear relationship between the generated power and the controller voltages. Resultant equations are,

$$PshuC(t) = k''_p.\ E_d\_shuC*(t) \quad (12)$$

$$QshuC(t) = k''_q.E_q\_shuC*(t) \quad (13)$$

VII. SIMULATION RESULTS AND DISCUSSIONS

The simulation in this project is carried by connecting UPQC Custom power device at the point of common coupling where the wind farm to weak grid connection occurs. The model of the power system scheme in fig.-6 includes controllers with control strategy and it was implemented by using MATLAB/SIMULINKR SOFTWARE.

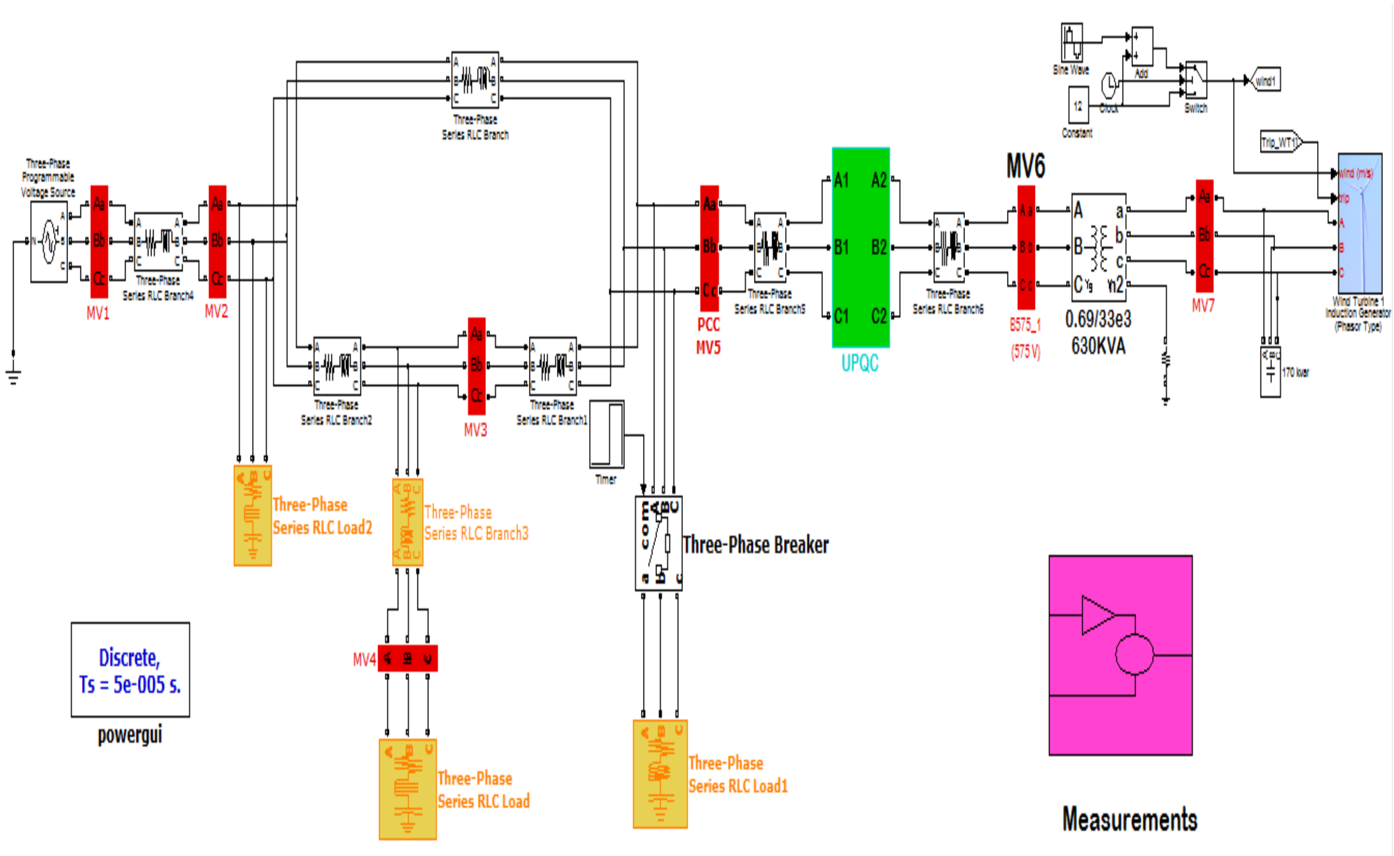

Fig.-6: Simulation model of Grid connected Wind form with UPQC

Upper curve represents active power P (w) at grid side. At t=0.5 it begins the cyclical power pulsation produced due to tower shadow effect. Lower curve represents reactive power Q (var) at grid side. At t=0.5 it begins the cyclical power pulsation produced due to tower shadow effect. Tower shadow effect occurs due to the variation in torque.

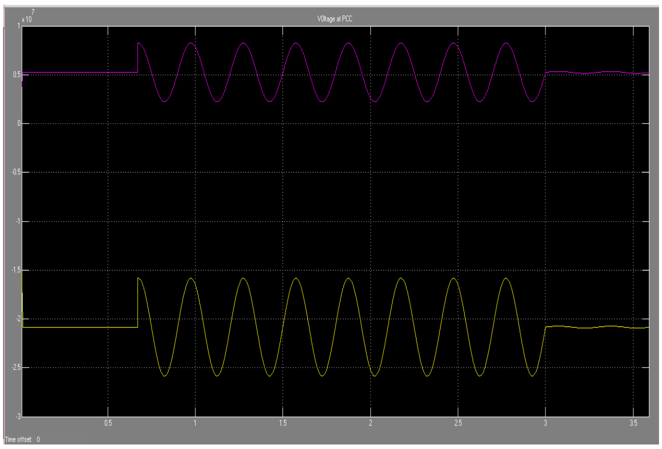

Fig.-7: Active P(w) and Reactive power Q(w) at grid side. (Power v/s Time)

The voltage fluctuations is seen in above figure at the point of common coupling for the time period 0.5 < t < 3. Due to these power quality problems occurred in wind farms. After t=3, constant voltage is maintained due to the attenuation because of P and Q controllers came in to action at t=3.So the active and reactive power is also constant after t=3 shown in fig.-8.

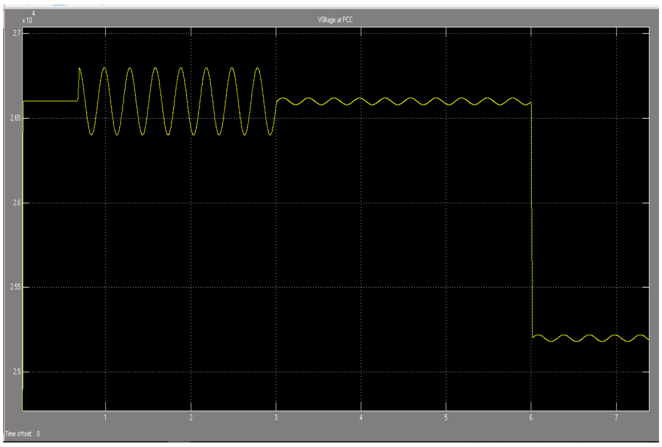

Fig.-8: voltage at PCC. [Vpcc (v)]. (Voltage v/s Time)

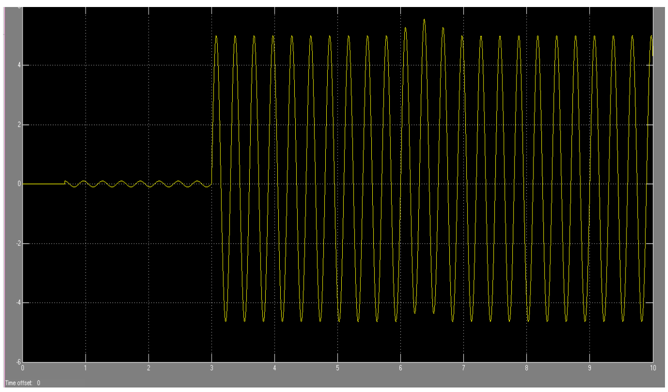

Fig.-9: Active power of UPQC dc side. (Power v/s Time)

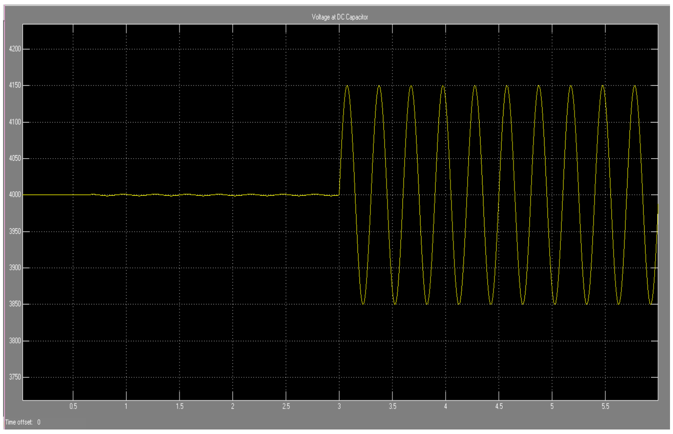

Fig.-10: voltage at UPQC dc side. [V_{dc}(v)] (Voltage v/s Time)

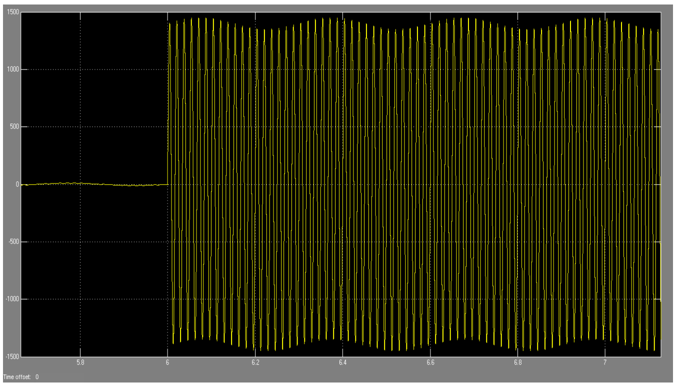

Fig.-11: Series injected voltage. [Vser(v)] (Voltage v/s Time)

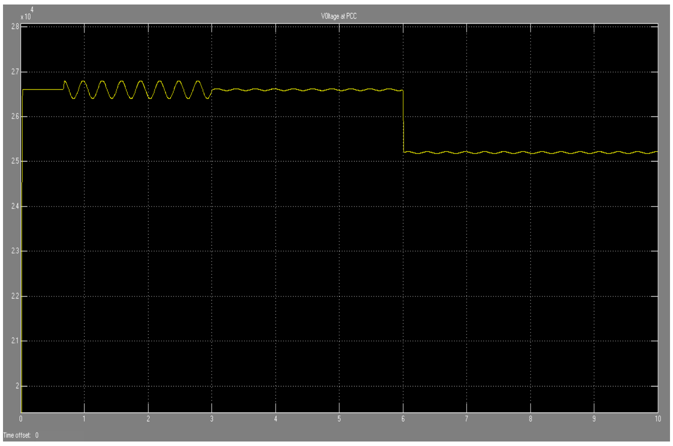

Fig.-12: Voltage at PCC due to series injected voltage. (Voltage v/s Time)

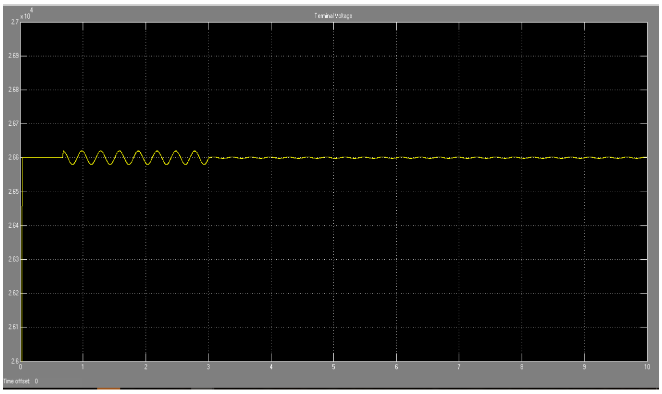

Fig.-13: Terminal voltage at wind farm. (Voltage v/s Time)

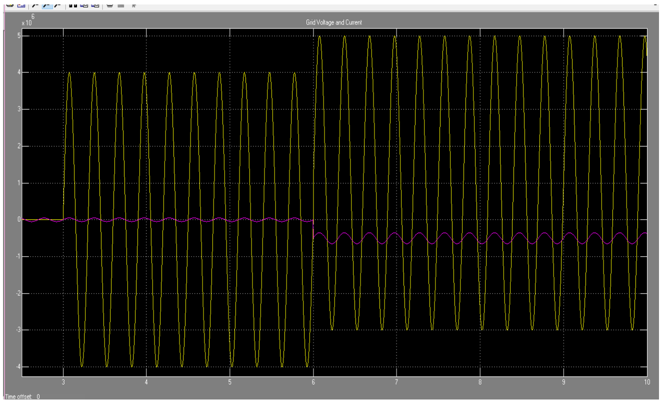

Fig.-14: Shunt & Series converters active power & DC bus voltage.

At t=6, load is connected by injecting series voltage shown in fig.-15. So the voltage at PCC changes suddenly shown in fig 13 and WF terminal voltage is remains constant shown in fig 14. At t=10 ,load is disconnected The mean power injected by series convertor is absorbed by shunt converter due to voltage regulation loop action vice versa. So the step shows that the active power in series converter is same but opposite to that of shunt converter power.

DISCUSSIONS

Simulations are carried to determine and compensate voltage fluctuations due to wind power variations and sudden load change. The simulation was performed based on the following chronology:

Case 1: At t = 0

Simulation will be started by series converter and dc bus voltage controllers.

Case 2: At 0.5 < t < 3 (without compensator)

In this case wind farm will be affected by tower shadow effect and it produces variation in torque. So the active and reactive power will be fluctuated .For normal wind speed the frequency of power fluctuations is f=3.4Hz and hence the amplitude is 1.5%.

The voltage fluctuations are occurred which are shown in above simulation results and it will cause disturbances in load and hence worsens of power quality and WF stability.

Case 3: At, t = 3 (with compensator)

In this case P and Q controllers are come in to action and attenuates the power pulsations. The amplitude of the PCC voltage fluctuation is decreased compared with above case i.e., 0.18%.

The series converter injects voltage to maintain constant terminal voltage of wind form. Series convertors require negligible power to operate where as shunt converters requires a high instantaneous power to operate this can be done by using capacitors for compensating active power fluctuation. Reactive power compensation has no influence on dc□side power In DC□bus Voltage source invertors (VSI's) have voltage level limitations based on their characteristics. Power fluctuations depend on the capacitor size so the capacitor has to be selected so that ripples in the dc voltage are kept in the narrow level. Generally ultra capacitors are used which is having size of C = 0.42 F.

Case 4: At, t = 6 (switching ON the load by closing L3) and at t=10 (switching OFF the load by opening L3)

UPQC is also operated to maintain voltage variations at the time of sudden ON and OFF of loads. In this case load is connected at t =6 and disconnected at t=10 and that is seen in above simulation figures that there is a sudden change in PCC voltage. Due to series converter action WF terminal voltage is almost constant.

VIII. CONCLUSION

In this paper UPQC custom power device is placed at the point of common coupling to compare the transport capacity of grid with power generated by the wind farm (WF). UPQC employs Shunt and series connected voltage source inverters (VSI's). Shunt converter is for injecting current at PCC and series converter is for injecting voltage between PCC for maintaining constant terminal voltage rejecting voltage variations at PCC. The important property of UPQC is the operation of both VSI converters sharing the same DC bus which enables the active power exchange between them. Hence, the voltage fluctuations at grid side are reduced. MATLAB simulink model is designed by connecting UPQC at the point of common coupling. It shows a good performance compared with DVR and D□STATCOM by rejecting power fluctuation due to tower shadow effect and the regulation of voltage due to sudden change in load.

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