

THE COMPENSATION OF WIND POWER FLUCTUATIONS AT PCC ON A WEAK GRID SYSTEM USING DIFFERENT COMPATIBILITY MODEL

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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 are connected through medium voltage (MV) distribution Headlines. A situation commonly found in such scheme is that 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. In this thesis a proposed compensation strategy based on a particular custom power (CUPS) device technology will be used, 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 the 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. These approaches increase the compensation capability of the UPQC as well as enhancement of power quality and wind farm stability with respect to other custom strategies that use reactive power only.

Key Words: PCC, Simulation, Model Compatibility

I INTRODUCTION

Wind energy is said to be one of the most prominent sources of electrical energy in years to come. The increasing concerns to environmental issues demand the search for more sustainable electrical sources. Wind turbines along with solar energy and fuel cells are possible solutions for the environmental-friendly energy production. In this report, the focus is on the wind power as it is said to hit large integration in the near future. This technology has already reached a penetration level in some areas, which raises some technical problems concerning grid integration. Wind power has to overcome some technical as well as economic barriers if it

should produce a substantial part of the electricity. In this report, some of the technical aspects are treated, particularly those regarding the power system quality and stability. 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. 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. 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, it 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. 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. 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. These power disturbances 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 proposed. 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. 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. The use of these active compensators to improve integration of wind energy in weak grids is the approach adopted in this work. Connected to a weak distribution power grid, this system is taken from a real case. 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.

II METHOD AND METHODOLOGY

2.1 Model Description

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. In Fig.2.0 we see the basic outline of this compensator. The operation is based on the generation of three phase voltages using electronic converter

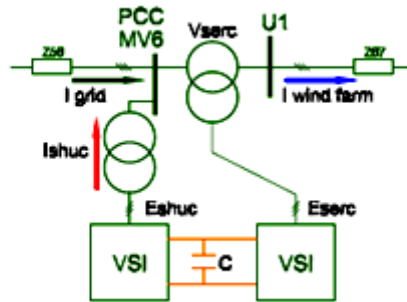


Fig.2.1 Block Diagram of UPQC

Either voltage source type (VSI–Voltage Source Inverter) or current source type (CSI– Current Source Inverter). VSI converter are 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. 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. 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, 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.

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 is radius of the swept area, v is wind speed, and C_p is power coefficient. For the considered turbines (600kW) the values are R = 31.2 m, $\rho=1.225$ kg/m³ 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:

$$P_T = \sum_{i=1,2,\dots,36} P_i \quad (4.3)$$

Moreover, wind speed v in equ. (3.1) 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 $3 \cdot N_{rotor}$. For the three-bladed wind turbine, while its amplitude depends on the geometry of the tower. In our case we have considered a mean wind speed of 12m/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.

Model of the power system in Matlab:

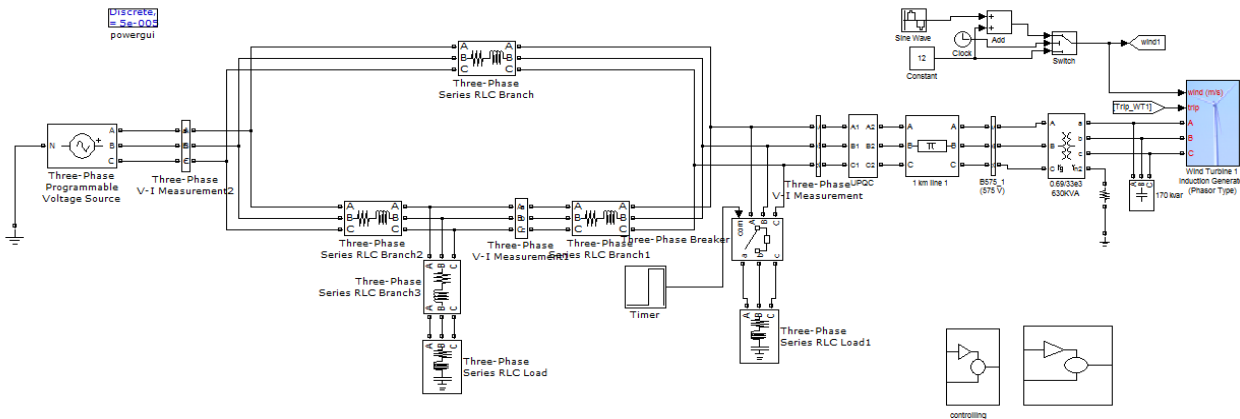


Fig 2.2: Model of the power system in Matlab

A-Subsystem Models:

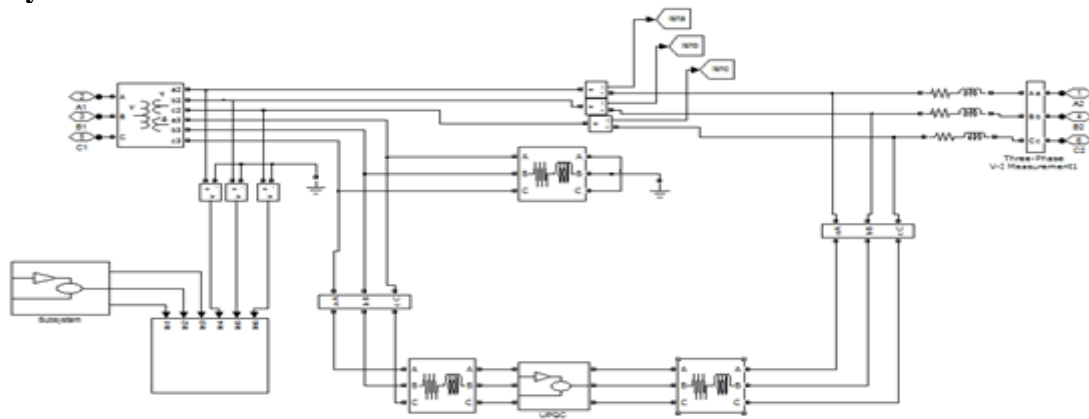


Figure.2.3.Subsystem Model of power system

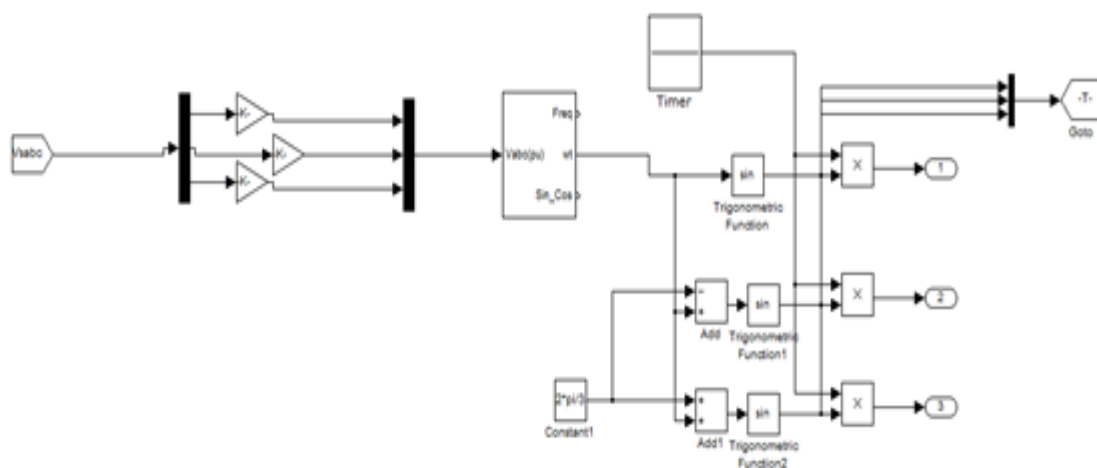


Figure.2.4.Subsystem for Generation of reference Voltage

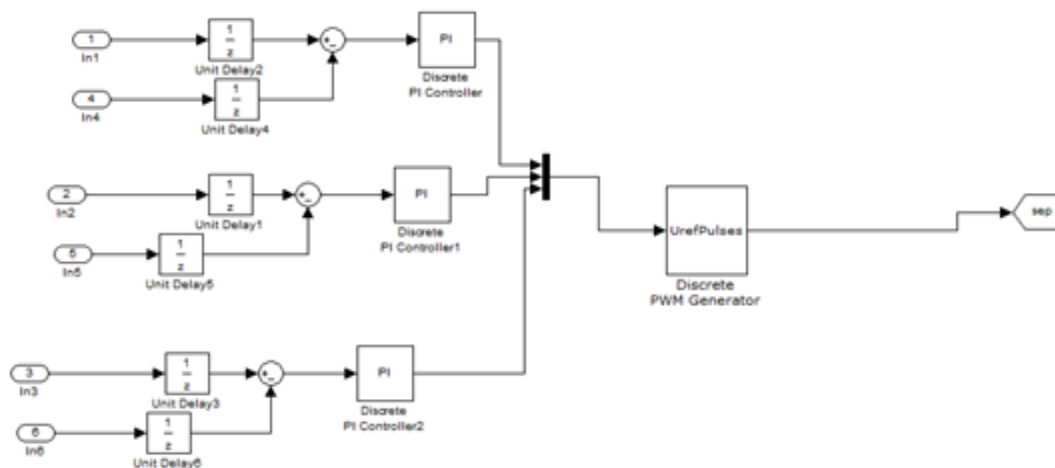


Figure2.5 Subsystem for Pulse Generation for series converter

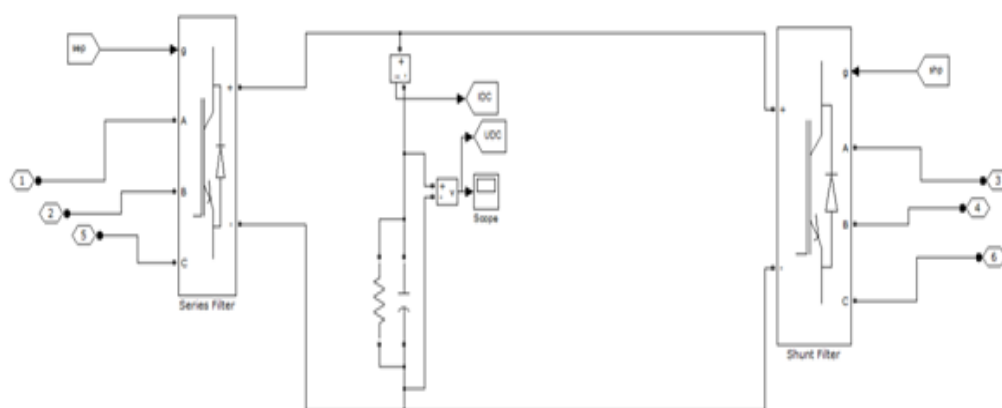


Figure 2.6.The model of UPQC

III RESULT SIMULATION AND DISCUSSION

Simulation results without UPQC

Simulation results for 0 sec < t < 6 sec are shown in Fig.5.7 and 5.8 when load is not connected to the system. And load is connected at 6 sec and disconnected at 10 sec.

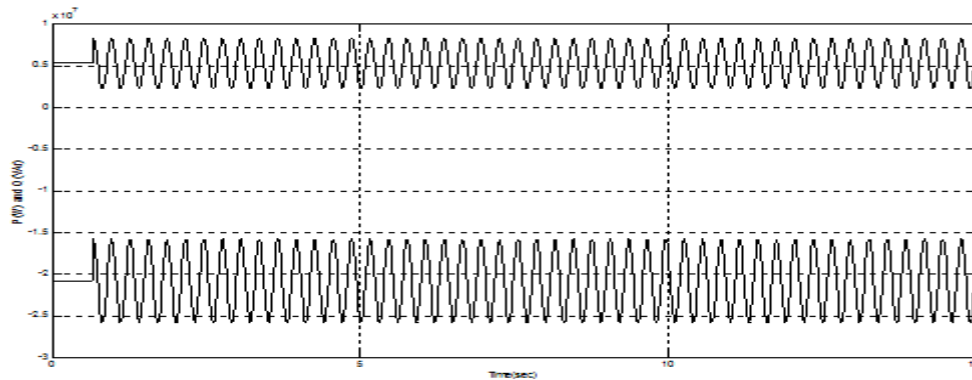


Figure.3.1 Active and Reactive power at the grid side

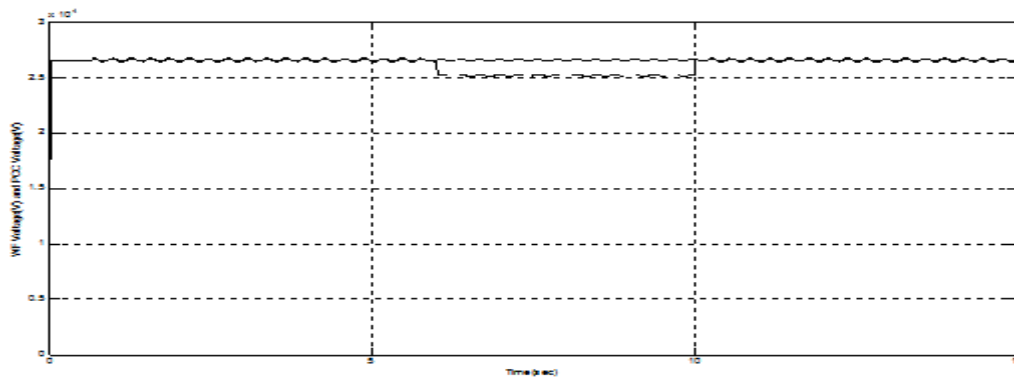


Figure3.2.Wind Farm terminal Voltage and PCC voltage

At t = 0.5 sec 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 $f = 3.4\text{Hz}$, 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.3.1 and Fig.3.2 for 0.5 sec < t < 3 sec. The fluctuation value is higher than the maximum allowed by the standards. This means that even in normal operation, the WF impacts negatively on the System Power Quality.

Clearly it is seen in the above fig.3.1 that fluctuating active power (P) and reactive power produced by the wind turbines ,which is injected in the grid produces flicker which further worsening the power quality of the grid. So it is important that power which is injected by the wind farm should be free from pulsation. Figure 3.2 shows the voltage fluctuation at point of common coupling due to wind pulsating power and the wind terminal voltage which has harmonics content due to the grid .So it is important that there should some compensation technique at the PCC which will improve the stability of the wind farm and minimize the voltage fluctuation at PCC.

Simulation results using UPQC proportional-integral (PI):

Compensation of voltage fluctuation

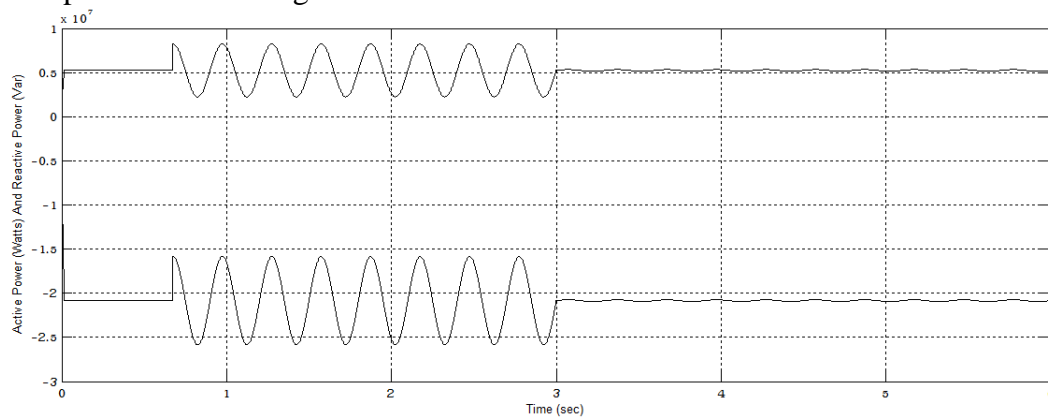


Figure 3.3.Active and Reactive power at the grid side

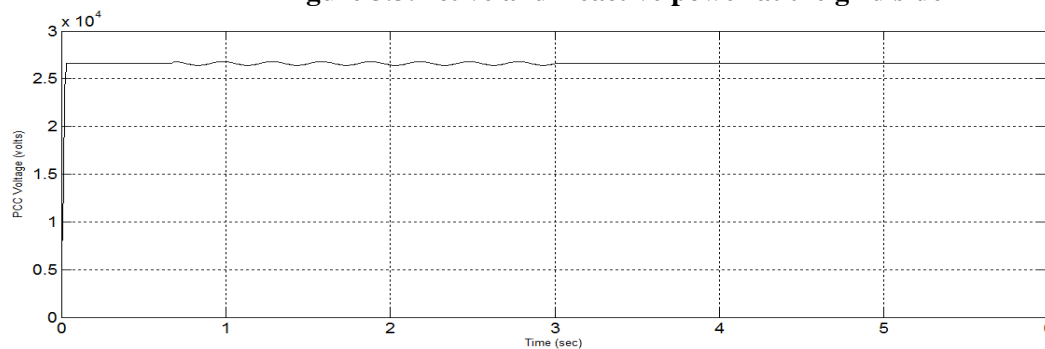


Figure 3.4 PCC voltage (Volts)

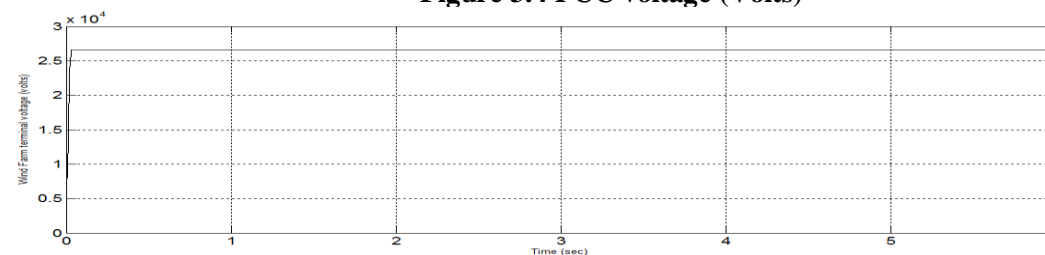


Figure.3.5 Wind Farm terminal Voltage (Volts)

Simulation results for 0 sec < t < 6 sec are shown in Fig.3.3, 3.4 and 3.5. 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:

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

This value agrees with standards, since is lower than the specified permissible maximum limit, 0.5% at 3.4Hz. In the curve of Fig.5.11, WF terminal voltage behaviour is shown; the series converter action maintains WF terminal voltage constant, regardless of the PCC voltage behaviour.The pulsation of active power and voltage at the UPQC DC-side, are shown in Fig.3.6 and 3.7. As can be observed in the upper curve, the series converter requires

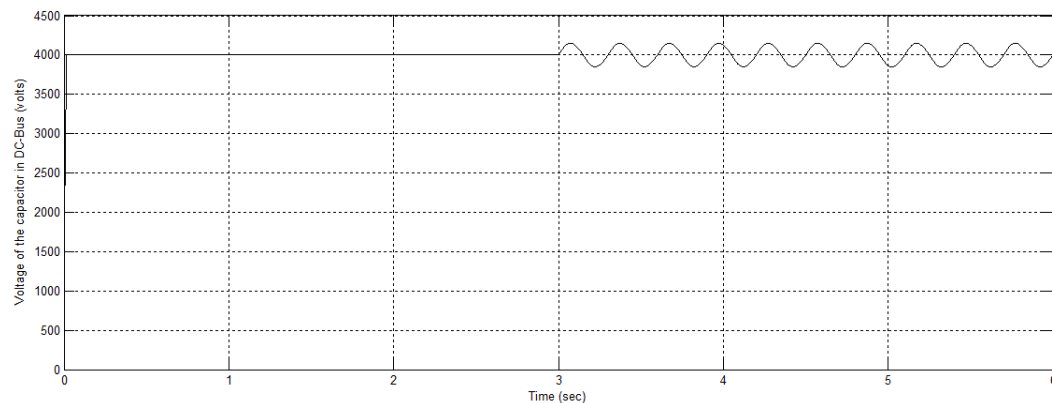


Fig.3.6. Voltage of the capacitor in the DC-Bus (V)

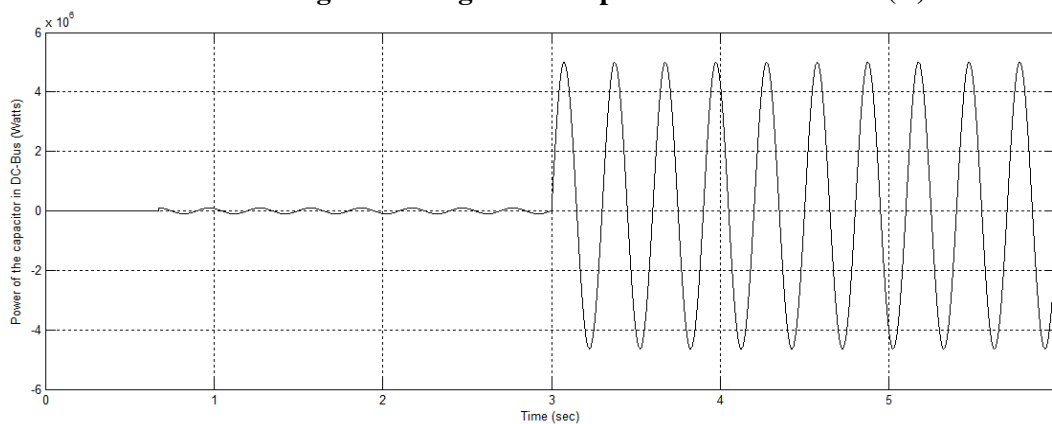


Fig.3.7. Power of the capacitor in the DC-Bus (watts)

Negligible power to operate, while the shunt converter demands a high instantaneous power level from the capacitor when compensating active power fluctuation, Compensation of reactive powers has no influence on the DC side power. The DC-bus has voltage level limitations in accordance with the VSI's operational characteristics. As the fluctuating active power is handled by the capacitor, its value needs to be selected so that the ripple in the DC voltage is kept within a narrow range. In our case, we have considered a capacitor size $C = 0.42$ F. This high value can be easily obtained by using emerging technologies based capacitors, such as double-layer capacitors, also known as ultra-capacitors.

IV CONCLUSION

The model of the power system scheme illustrated in Fig 2.2, including the controllers with the control strategy detailed in chapter 4, was implemented using Matlab/Simulink software. 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 $t = 0.0$ sec the simulation starts with the series converter and the DC-bus voltage controllers in operation.
- At $t = 0.5$ sec the tower shadow effect starts.
- At $t = 3.0$ sec Q and P control loops are enabled.
- At $t = 6.0$ sec L3 load is connected.

At $t = 10.0$ sec L3 load is disconnected

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