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Research Article

MODELING AND SIMULATION OF UNIFIED POWER QUALITY CONDITIONER FOR POWER QUALITY IMPROVEMENT

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ABSTRACT
This paper gives an explanation about the Unified Power Quality Conditioner (UPQC) considering the power quality issue. The system considered consists of a shunt inverter, a series inverter, an induction generator connected to the DC link through a converter. The proposed scheme can compensate reactive power voltage sag, voltage interruption and also harmonics. Various power quality issues are discussed briefly and a unique system is proposed to overcome all those power quality problems. The investment cost of the proposed scheme is properly concerned so that in can be in an affordable range as compared to other systems. The performance of the proposed scheme is verified by the experimental results of the computer simulation.

Keywords: *FACTs; MATLAB/SIMULINK; UPQC; Wind Turbine; MPPT*

INTRODUCTION
The modern distributed power system is becoming highly sensitive to the different power quality problems. Broad use of non-linear loads is responsible for contributing increased voltage and current harmonics issues. In small or large-scale industries, installation of renewable energy systems based on wind energy, solar energy, fuel cell, etc., at distribution as well as transmission levels is increasing significantly which are very sensitive to power quality problems. Hence, it would be a challenge forever for maintaining the quality of power within the acceptable limits. The unfavourable effects of poor power quality are briefly discussed. Generally, poor power quality results into increased power losses, abnormal and undesirable behaviour of equipments and interference of communication lines.

This paper presents a configuration for mitigation of all power quality problems together named as Unified Power Quality Conditioner (UPQC). Khadikikar *et al.*, (2006) have presented a conceptual study of unified power quality conditioner (UPQC). One of the very attractive structures of energy conditioner is two back-to-back connected AC/DC fully controlled converters and is mostly popular as they can be functioned as active series and shunt filter to compensate load current harmonics as well as supply voltage functions simultaneously (Akagi and Fujita, 1998). In this case such equipment is called as UPQC. The function of unified power quality conditioner is to compensate supply voltage flicker that is voltage sag or swell, reactive power, negative sequence current and harmonics. An UPQC is a combination of shunt active power filter and series active power filter and is designed to overcome multiple power quality problems (Han *et al.*, 2006). There are two cascaded inverters joined back to back through a common DC link capacitor constituting the power circuit of a UPQC (Basu *et al.*, 2007). An active shunt filter is a preferable device for current-based compensation. Shunt active power filter (APF) includes current harmonics and reactive power compensation. The active series filter is generally used for voltage-based compensation (Vilathgamuwa *et al.*, 1998). In series APF, voltage harmonics, voltage sags and swells are compensated (Hosseinpour *et al.*, 2008). But, UPQC can control the power flow and voltage stability while, it cannot compensate the voltage interruption due to insufficient energy source in its DC link. The power quality performance evaluation of a photovoltaic generation system with UPQC (Cavalcanti *et al.*, 2005) has been reported satisfactory.

This paper presents a novel configuration of UPQC which has a wind energy generation system (WEGS) connected to the DC link through the converter. The UPQC can be able to compensate the voltage interruption in the source, while the wind energy generating system supplies power to the source and load or the load only. There are two modes of operation in the proposed system. The expressive advantage of this configuration, according to separate use of UPQC and wind energy generation system, is reduction in using of one inverter. Because, here shunt inverter of UPQC operates as a WEGS`s inverter. The present paper proposes a new configuration based on UPQC in which the voltage sag is compensated enhancing the capability of UPQC, as voltage sag is a source of major power quality problem (Lankannan and Ranjith, 2014). The proposed scheme has been evaluated and tested using matlab/simulink software. This work proposes the use of UPQC to improve the power quality and presents the simulink model of UPQC.

Power Quality Problems

Various types of power quality problems along with their causes and effects are discussed below.

(i) Voltage spikes and surges is a PQ problem because of lighting, heavy equipment effect, utility grid switching. Due to these factors, equipment failure, data corruption, system lock-up, data loss and such type of effects are occurred.

(ii) Harmonics is another PQ problem because of arc welding, fault clearing device, switch mode power supplies. Due to these factors, loss of command functions, improper wave shapes, data corruption and such type of effects are occurred.

(iii) Voltage fluctuation is a major PQ problem because of over burden distribution system, unstable generators, start-up of heavy equipment. Because of these factors, so many effects like system shut down, reduce performance, loss of system control, system lock-up and data loss are occurred.

The Proposed UPQC System

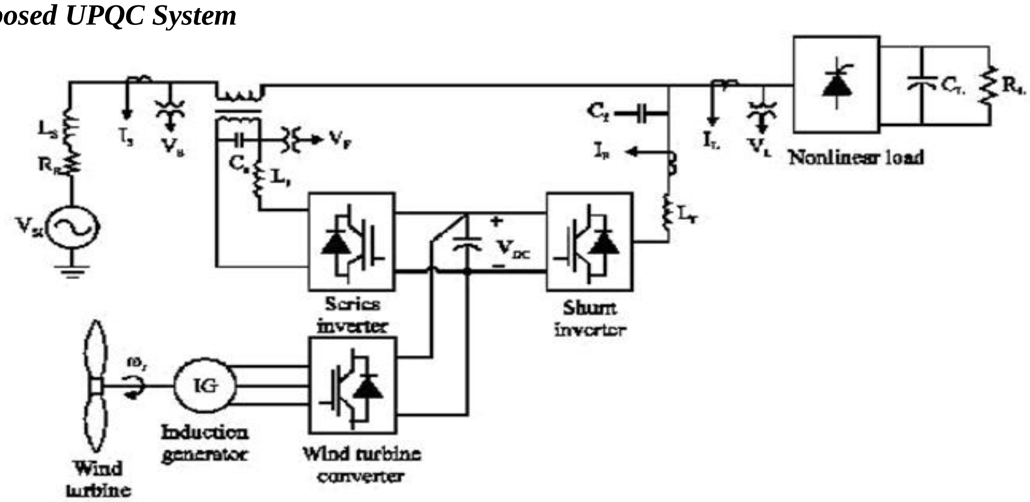

Figure 1: Proposed UPQC system

A novel configuration of UPQC used in this paper is shown in Figure 1 which has a wind generating system connected to the DC link capacitor through a converter. Mainly, there are six parts in the proposed system as shunt inverter, series inverter, induction generator, wind turbine, PWM rectifier and maximum power point tracking (MPPT) algorithm. There are two inverters; one connected across the load which acts as a shunt APF and another on is connected in series with the line act as a series APF. Shunt coupling inductor is used to interface the shunt inverter with the network. It also helps in improving the current wave form. Often an isolation transformer is used to electrically isolate the inverter from the network. A common dc link can be formed by using a capacitor or an inductor. The dc link is realized by using a capacitor that not only interconnects the two inverters, but also maintains a constant self-supporting dc bus voltage across it. An LC filter that acts as a passive low-pass filter (LPF) and helps to eliminate high-frequency switching ripples of the output voltage which is generated by the inverter. The function of series injection transformer is to connect the series inverter in the network. The shunt inverter has two major functions. One is to compensate reactive power and the current harmonics generated by the load and inject the active power of WEGS to the grid. Another function of shunt inverter is to supply the power to the load at the time of voltage interruption occurring in the source side. The main function of

series inverter is to compensate the voltage unbalance and the voltage harmonics in the source side which is due to the fault in the distribution line.
The VA rating of series and shunt inverters of UPQC determines the size of UPQC. The power loss depends upon the VA loading of UPQC.

Wind Turbine

The tip speed ratio of a wind turbine is expressed as:

$$\lambda = \frac{\omega_r R}{V_{Wind}} \quad (1)$$

The output power from a wind turbine is expressed as:

$$P_M = \frac{1}{2}\rho R^2 C_p V_{Wind}{}^3 \quad (2)$$

The output torque from a wind turbine is expressed as:

$$T_M = \frac{P_m}{\omega_r} = \frac{1}{2}\rho\pi R^5 C_p \frac{\omega_m{}^3}{\lambda^3} \quad (3)$$

Where,

λ is tip-speed ratio

V_{wind} is the wind speed

R is the blade radius

ω_r is the rotor speed rad/sec

ρ is the air density

C_p is the power coefficient

P_M is the mechanical output power

T_M is the output torque of wind turbine

The power coefficient C_p depends on the pitch angle β and the tip-speed ratio λ is expressed in Eq.4 as:

$$C_p = (0.44 - 0167\beta)\sin\frac{\pi(\lambda-2)}{13-0.3\beta} - 0.00184(\lambda-2)\beta \quad (4)$$

Pitch angle β is the angle at which the rotor blades can rotate along its long axis. For a fixed pitch type the value of pitch angle is kept at constant value.

Maximum Power Point Tracking

In this study, pitch angle should be kept at zero until the nominal power of the induction generator is obtained as shown in Figure 2. When the wind speed is high, the pitch angle is raised to limit the input power.

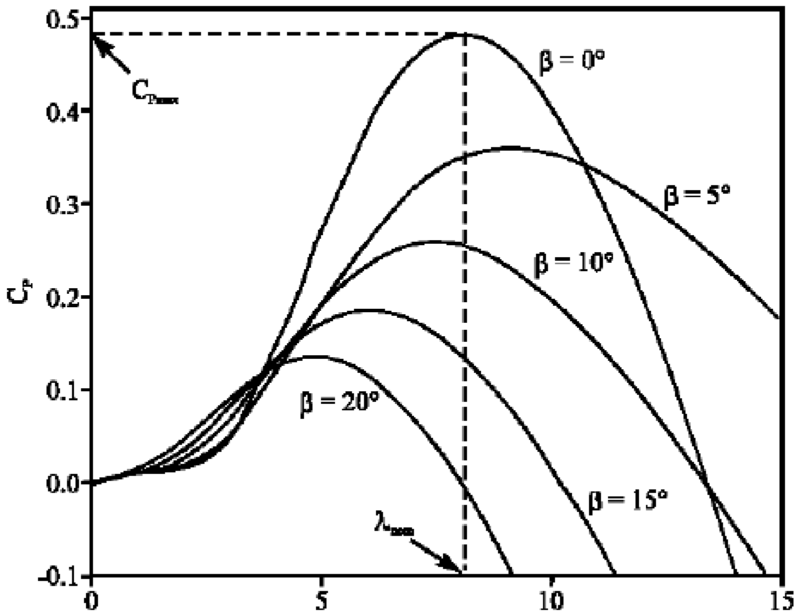

Figure 2: Power coefficient factor versus tip speed ratio for various pitch angle

Hence, the optimized rotational speed (ω_{opt}) at a given wind velocity when aerodynamic efficiency is maximum, is given by:

$$\omega_{opt} = \frac{\lambda_{opt} V_{wind}}{R} \quad (5)$$

Where,

λ_{opt} is the optimised tip-speed ratio when β is zero and C_p is maximum.

Therefore, for full utilizing the wind energy, tip-speed ratio should be maintained at optimised value that is determined from blade design. Then, from Eq. 2:

$$P_{M\max} = \frac{1}{2} \rho \pi R^2 C_{p\max} V_{wind} \quad (6)$$

Where,

$P_{M\max}$ is maximum mechanical output power of wind turbine at a given wind speed. Once the wind velocity V_{WIND} is measured, the reference speed for extracting the maximum point is obtained from Eq.5.

Modeling and Simulation Results

Initially the modelling and simulation are carried out under Matlab/Simulink environment for various modes of operation of series as well as shunt inverters. The output voltage waveforms are also obtained and presented.

Modes of Operation of Series Inverter of UPQC

A bridge rectifier as shown in Figure 3 is used here to convert input AC voltage into DC voltage. The circuit diagram and mode of operation of a full wave rectifier is done in the MATLAB and described as below. The circuit diagram and its corresponding voltage waveform of full wave rectifier are shown in Figure 1.

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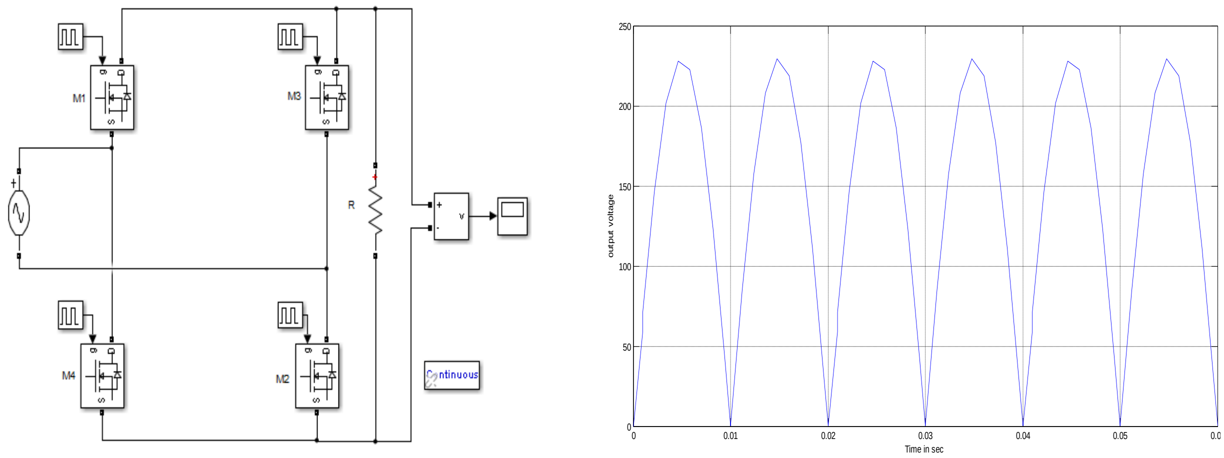

Figure 3: Circuit diagram and output voltage waveform of full wave rectifier

There are two modes of operation involved in this circuit. Accordingly, both the modes are modelled and the output waveforms are studied.

Mode 1: $(0^0$ *to* $180^0)$

During this mode, that is, during the positive half cycle of the input AC voltage, the switches M1 and M2 are forward biased AND M3 and M4 are reverse biased.

Hence, the current flows through source-M1-M2. The circuit diagram and waveform of output voltage are shown in Figure 4.

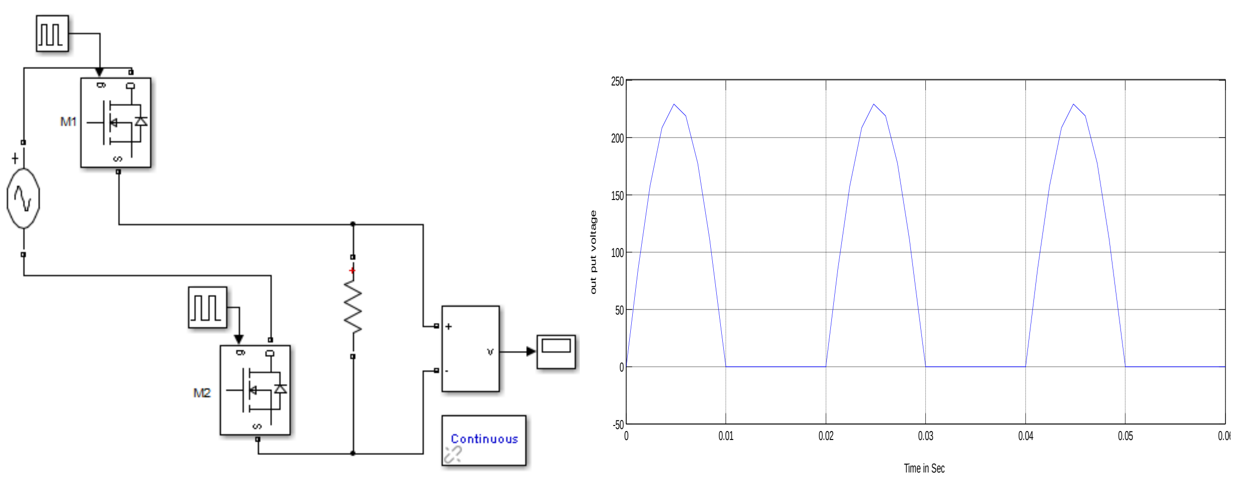

Figure 4: Mode 1 operation of full wave rectifier and its output

Mode 2: $(180^0$ *to* $360^0)$

During this mode, that is, during the negative half cycle of the input AC voltage, the switches M3 and M4 are forward biased AND M1 and M2 are reverse biased.

Hence, the current flows through source-M3-M4. The circuit diagram and waveform of output voltage are shown in Figure 5.

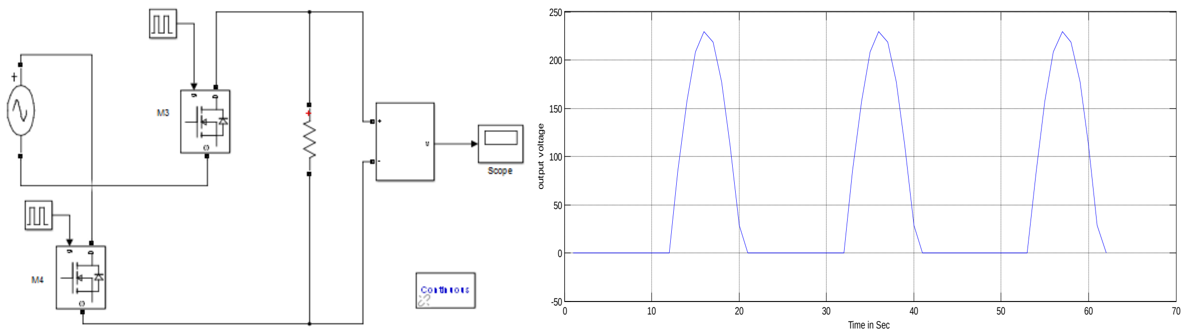

Figure 5: Mode 2 operation of full wave rectifier and its output

Modes of Operation of Shunt Inverter of UPQC

The circuit diagram and output voltage wave forms of shunt inverter are shown in Figure 6. Here, also two modes of operation are there which are studied briefly below:

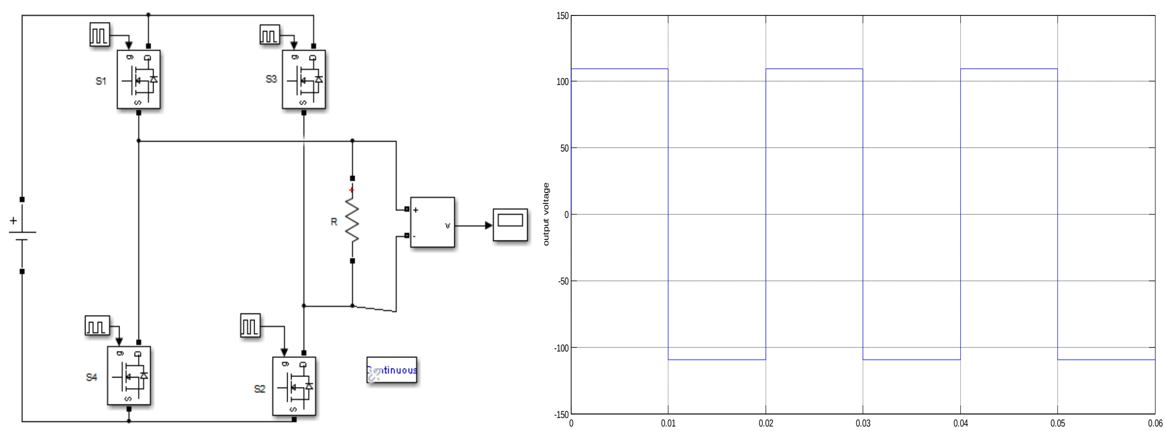

Figure 6: Circuit diagram and output voltage waveform of shunt inverter

Mode 1: (0^0 *to* 180^0)

During this mode, that is, during the positive half cycle of the input AC voltage, the switches S1 and S2 are forward biased and S3 and S4 are reverse biased. Hence, the current flows through source-S1-S2. The circuit diagram and waveform of output voltage are shown in Figure 7.

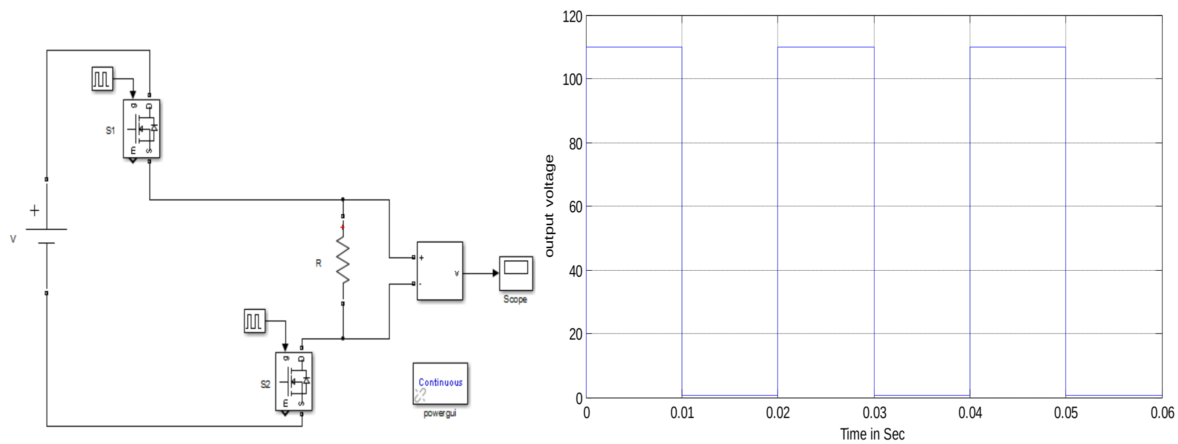

Figure 7: Mode 1 operation of shunt inverter and its output

Mode 2: (180^0 *to* 360^0)

During this mode, that is, during the negative half cycle of the input AC voltage, the switches S3 and S4 are forward biased and S1 and S2 are reverse biased. Hence, the current flows through source-S3-S4. The circuit diagram and waveform of output voltage are shown in Figure 8.

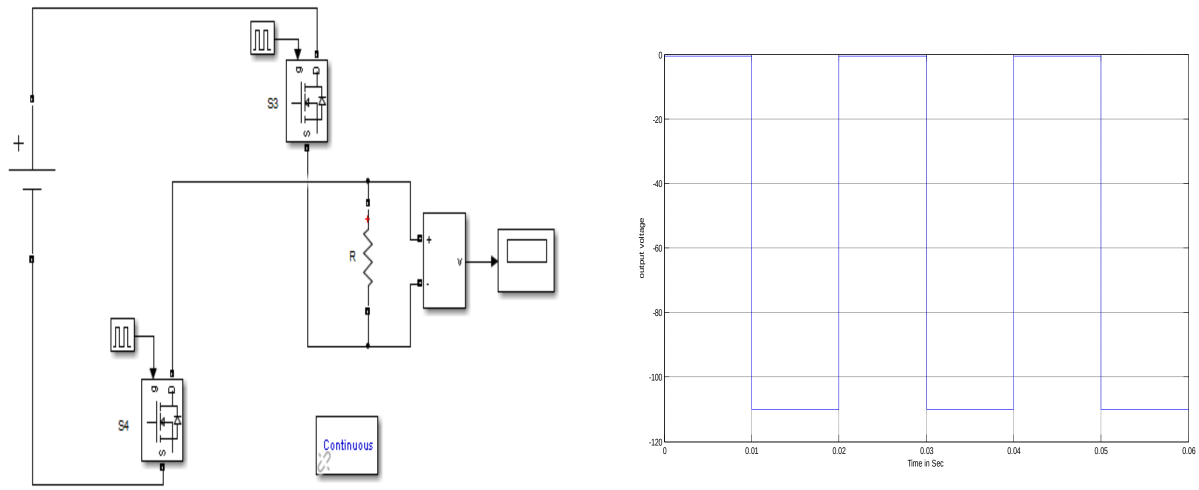

Figure 8: Mode 2 operation of shunt inverter and its output

Modelling and Simulation of a Line without UPQC

A line model is constructed without compensation circuit i.e., without UPQC as shown in Figure 9. After simulation it is observed that, voltage sag occurs at time 0.2 sec and after connecting the second load the output voltage remains at 0.8V. At the time instant of 0.2 second, the second load is connected by the breaker. The real power, reactive power, voltage across load 1 and voltage across load 2 are shown in Figure 10 (a), (b), (c) and (d), respectively. It is observed that the obtained real and reactive powers are as follows.

Real power, P= 0.9268 MW

Reactive power, Q= 0.1214 MVAR

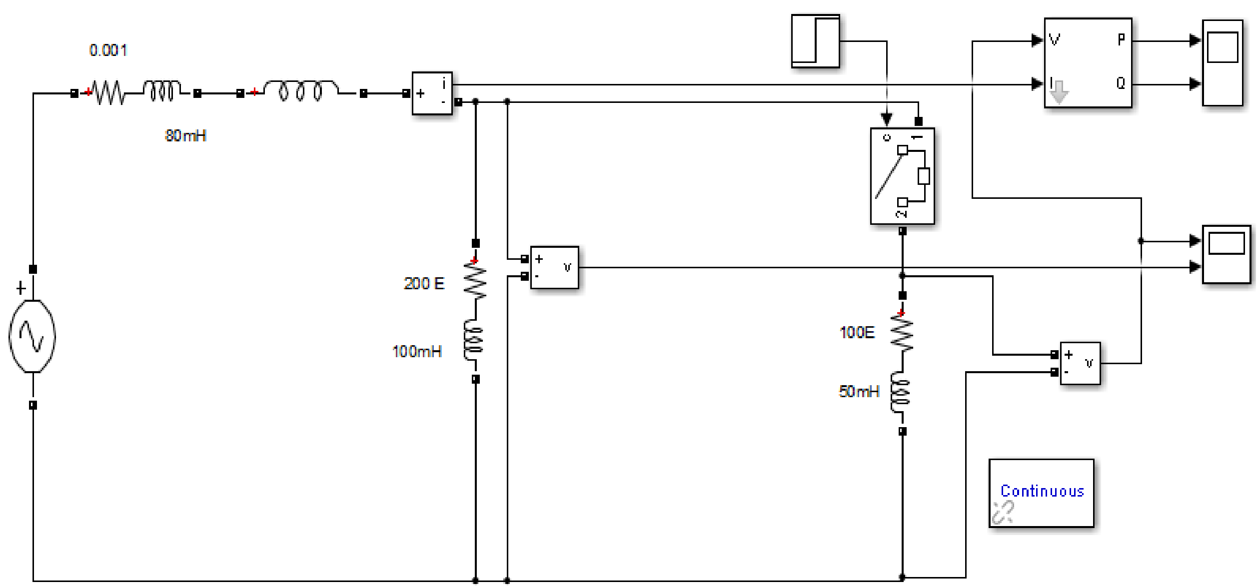

Figure 9 Line Model without Compensation Circuit

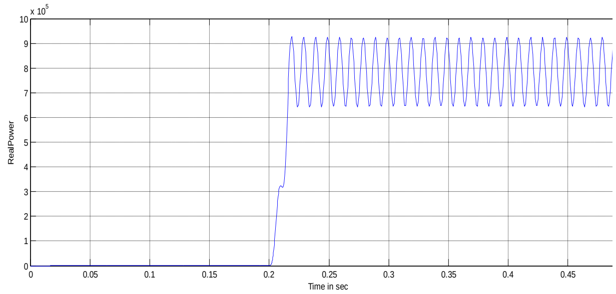

Figure 10(a): Real Power

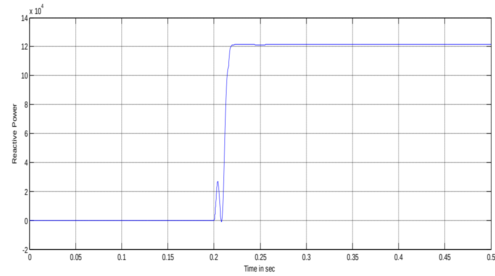

Figure 10(b): Reactive Power

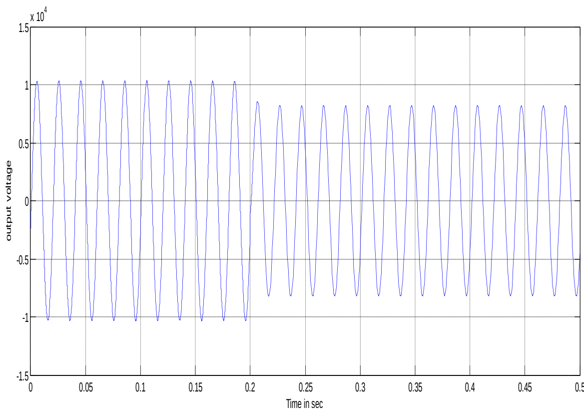

Figure 10(c): Voltage across load-1

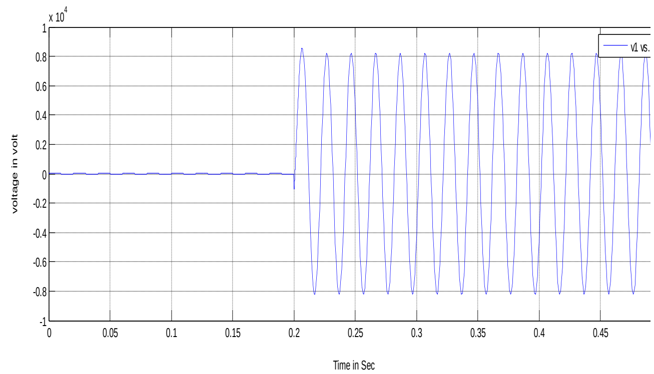

Figure 10(d): Voltage across load-2

Modelling and Simulation of a Line with UPQC

Now, we simulate the line model with the compensation circuit UPQC as shown in Figure 11 and the outputs are observed. The voltages across load 1 and load 2 at $\alpha = 0^0$ are shown in Figures 12(a) and (b), respectively. Similarly, the voltages across load 1 and load 2 at $\alpha = 30^0$ and 60^0 are shown in Figures12(c) and (d), respectively. The real power and reactive power at $\alpha = 0^0, 30^0$ and 60^0 are shown in Figures 13(a), (b), (c), (d), (e) and (f), respectively.

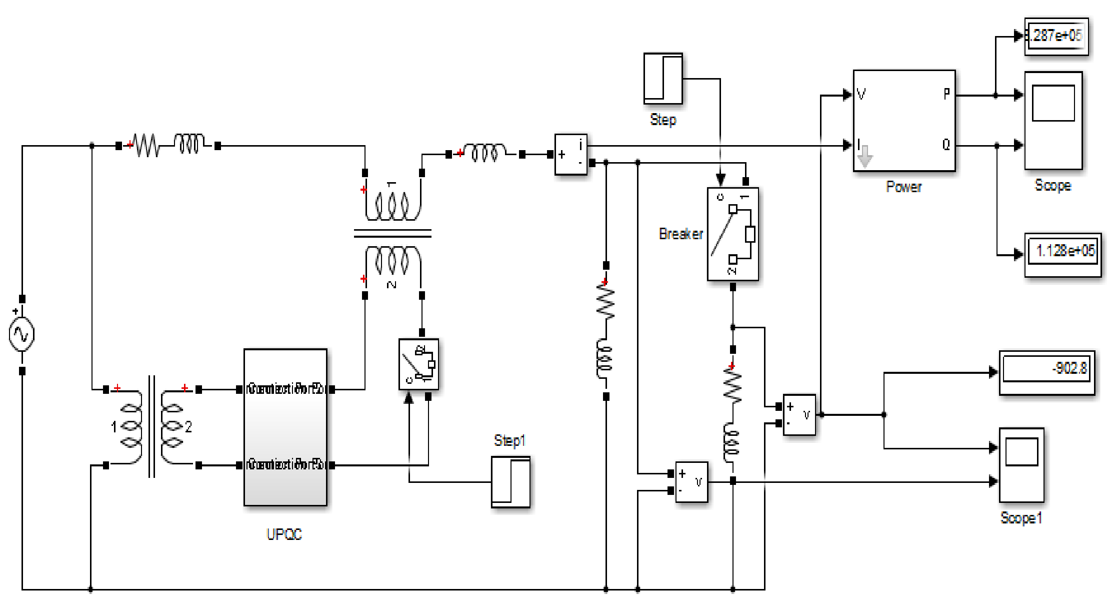

Figure 11: Line Compensation Circuit with additional UPQC

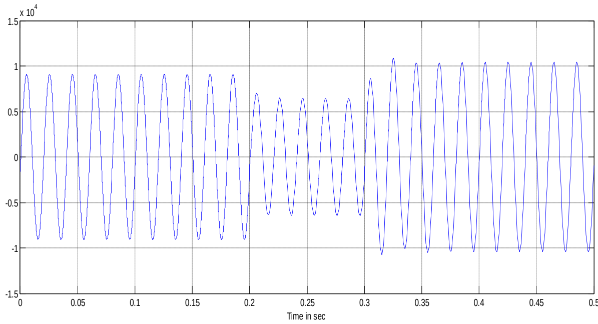

Figure 12(a): Voltage across load 1 at $\alpha = 0^0$

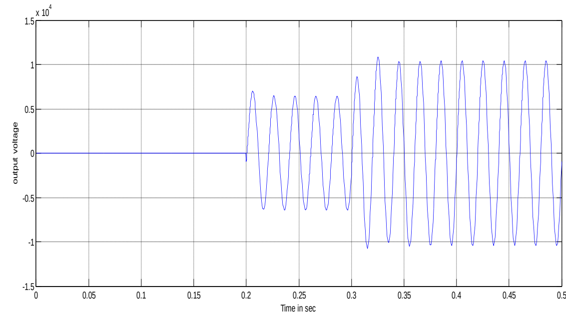

Figure 12(b): Voltage across load 2 at $\alpha = 0^0$

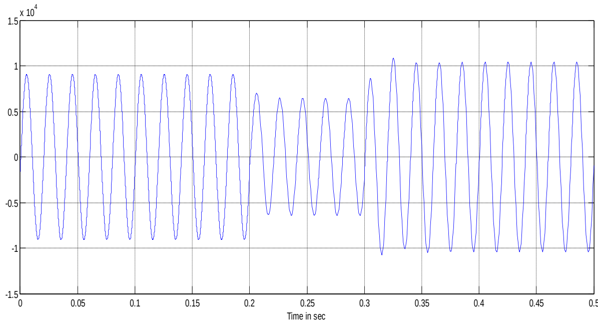

Figure 12(c): Voltage across load 1 at $\alpha = 30^0$, 60^0

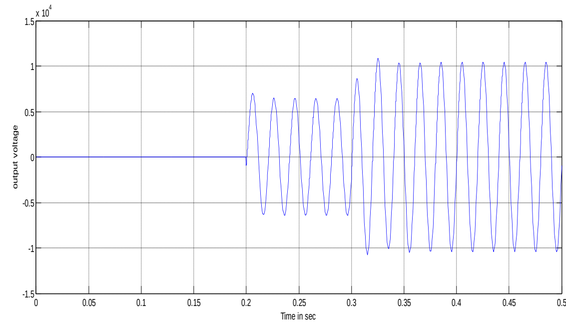

Figure 12(d): Voltage across load 2 at $\alpha = 30^0$, 60^0

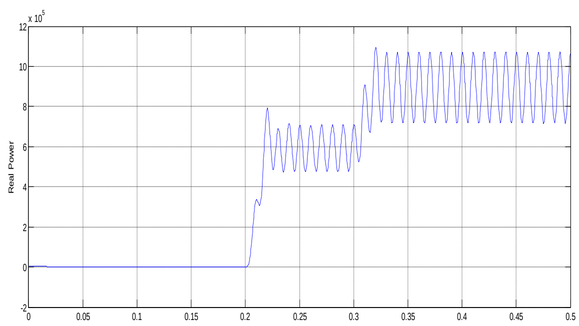

Figure 13(a): Real Power at $\alpha = 0^0$

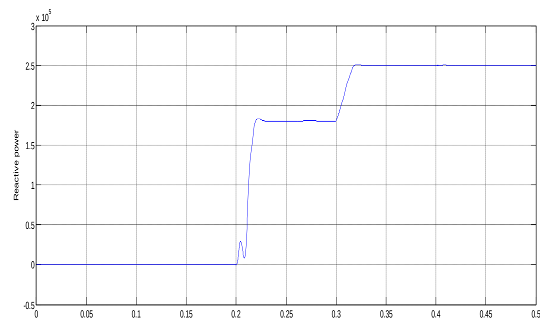

Figure 13(b): Reactive Power at $\alpha = 0^0$

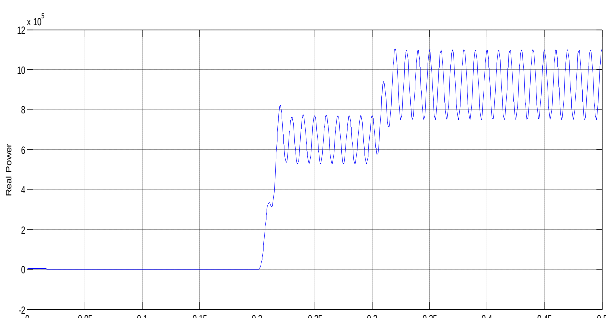

Figure 13(c): Real Power at $\alpha = 30^0$

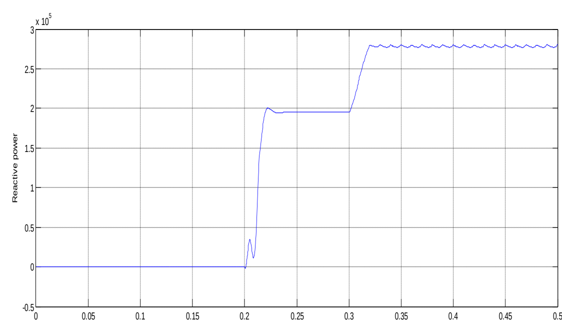

Figure 13(d): Reactive Power at $\alpha = 30^0$

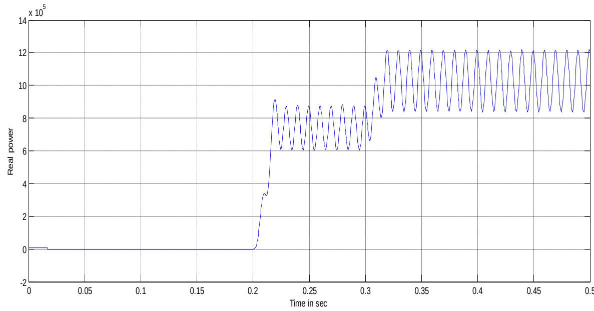

Figure 13(e): Real Power at $\alpha = 60^0$

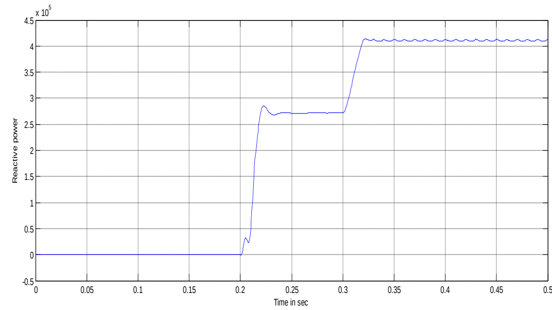

Figure 13(f): Reactive Power at $\alpha = 60^0$

Table 1: Effect of change in firing angle on real and reactive power

Firing angle (Degree)	Real Power (MW)	Reactive Power (MVAR)
0	1.0936	0.25063
30	1.1047	0.28047
60	1.2181	0.4137

The real and reactive powers obtained at different firing angles are tabulated in Table 1. The simulation results at different firing angles are analyzed and it is observed that the voltage across load 1 and load 2 are not affected by changing the firing angle. However, the real power and reactive power are improved by increasing the firing angle. The voltage sag that occurs without compensating device at 0.2 sec is now compensated with addition of UPQC circuit.

Conclusion

This paper presents a combined operation of the unified power quality conditioner with wind power generating system. The proposed system can compensate voltage sag, voltage swell, voltage interruption, reactive power and also harmonics. In this paper we mainly focused on voltage sag, as it is a major power quality problem that often occurs. The VA rating of series and shunt inverters of UPQC is estimated for proposed system. The circuit of series and shunt inverter are simulated. All simulation are done in MATLAB and found to be promising. The proposed UPQC finds applications in power system grid when generations with non-conventional energy sources like wind, photovoltaic, fuel cell are integrated.

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