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# Unified Power Quality Conditioner Using Injection Capacitors for Voltage Sag Compensation

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**ABSTRACT**

Power quality has become an important factor in power systems, for consumer and household appliances. The main causes of poor power quality are har ue of achieving active current distortion compensation, power factor monic currents, poor power factor, supply voltage variations etc. A techniq correction and also mitigating the supply voltage variations at load side is compensated by unique device UPQC presented in this thesis. This concept presents a multi loop based controller to compensate power quality problems through a three phase four wire Unified Power Quality Conditioner (UPQC) under unbalanced and distorted load conditions. Here the UPQC is constituted of two Voltage Source Converters (VSC) connected via power link. The series compensator is connected to the line in series and injects the voltage and thus compensates for voltage issues; whereas the shunt compensator injects current thus compensating for current issues, and is connected in shunt to the line. The voltage injection to the line uses an injecting transformer. The injection transformer is later replaced with injection capacitors, thus eliminating the drawback of conventional UPQC. In this way a good power quality is maintained.



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## 1. INTRODUCTION

A small distributed generation (DG) should be interconnected with the power system in order to maintain the frequency and voltage. Several studies proposed on the interconnection system for distributed generation with the power system [1] through the inverter because the inverter gives versatile functions in proving the ability of distributed generation. The attention to distributed generating sources is increasing day by day. The reason is their important roll they will likely play in the future of power systems. Recently, several studies are accomplished in the field of connecting DG to grid using power electronic converters.

One of the most effective solutions to power quality [2] issues in the distribution side is the installation of UPQC. UPQC is supported for alleviating all the voltage and current related problems (imbalances, Harmonics etc). Conventional UPQC constitutes of two VSC, an injection transformer and a common dc link. The presence of injection transformer can create problems like offset due to energization of transformers, increased losses in transformer windings and high cost of the system. Thus there is a need for a better injecting device. A DC isolation circuit was proposed in. This implementation increases the complexity of the system along with the increase in the cost of the system. In this paper, injection transformer as well as the DC isolation circuit is replaced with a series capacitor which acts as 'Voltage Injecting' source to the line. With the use of a series capacitor as injecting device, the cost and the complexity of the system is reduced and the system was found more efficient.

The conventional UPQC can eliminate three phase faults alone. The system remains idle for single phase faults. The cross phase connected UPQC enables to overcome the problems related to single line faults. The cross phase connection enables injection of voltage to a faulty phase from a healthy phase. Figure 1 shows the general structure of an UPQC with the combination of a series (DVR) and shunt (DSTATCOM) active filter.

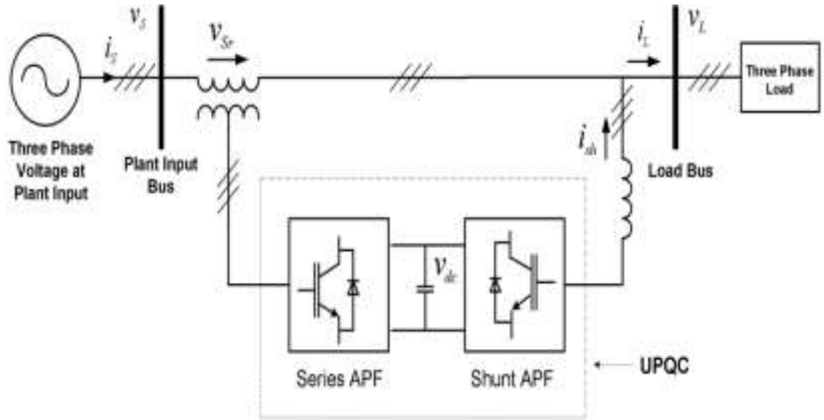


Figure 1. UPQC general structure

## 2. SYSTEM DESCRIPTION

### 2.1. Basic system with injection transformer

The circuit diagram of the UPQC system with injection transformer is shown in Figure 2. The series and shunt VSC are in full bridge configuration and are interconnected via a dc-link [3]. Dc-link is constituted of a single capacitor alone. The UPQC module is constituted of the VSCs in full bridge configuration and a dc-link. Out of the two bridged VSCs, one acts as the series VSC and other as shunt VSC. This conventional UPQC works when there is disturbance in the line. The control signals/gating signals are obtained from the control strategy used. This control signal activates the VSCs. The VSC acting as series VSC compensates for the voltage. Hence, when an over-voltage occurs, the system balances itself by injecting a voltage which in effect reduces the line voltage and maintains the desired voltage level. But whenever there is a voltage sag/swell, an additional voltage will be added to the line with the help of the injecting transformer. The shunt VSC compensates for the reactive component and thus conditions the current and reduces the harmonics. Thus the UPQC conditions power totally.

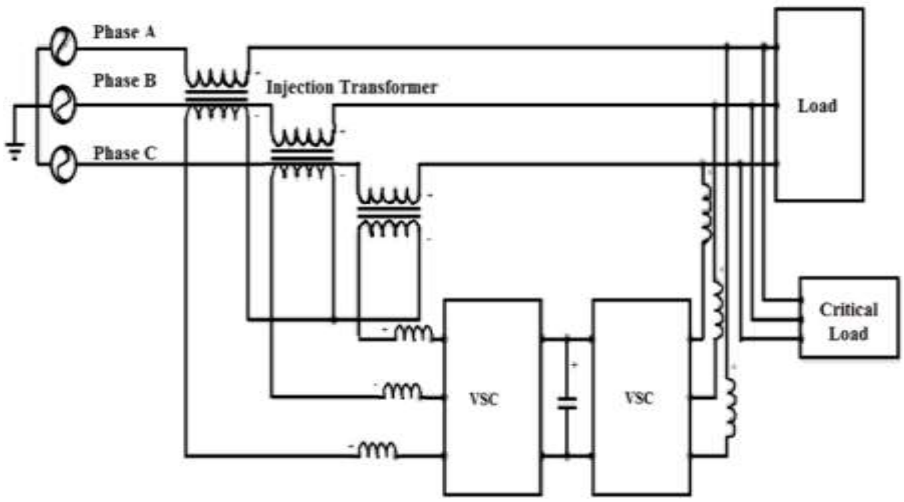


Figure 2. Circuit diagram of UPQC with injection transformer

### 2.1. Basic system with injection capacitor

The major difference between the conventional system and the proposed scheme are listed:

a. Replacement of the injection transformer with a capacitor. The voltage across the capacitor is adjusted so that voltage compensation is obtained in the system.
b. DC link between the VSCs is constituted of two capacitance- split capacitance.
c. The split capacitance provides one terminal for the injection capacitor.

The single line diagram of the device is shown in Figure 3. Both the VSCs are connected to the transmission line via a filter circuit. Here a filter inductance is used in both sides which are shown in the circuit diagrams for the both proposed system as shown in Figure 3 & conventional system as shown in Figure 2.

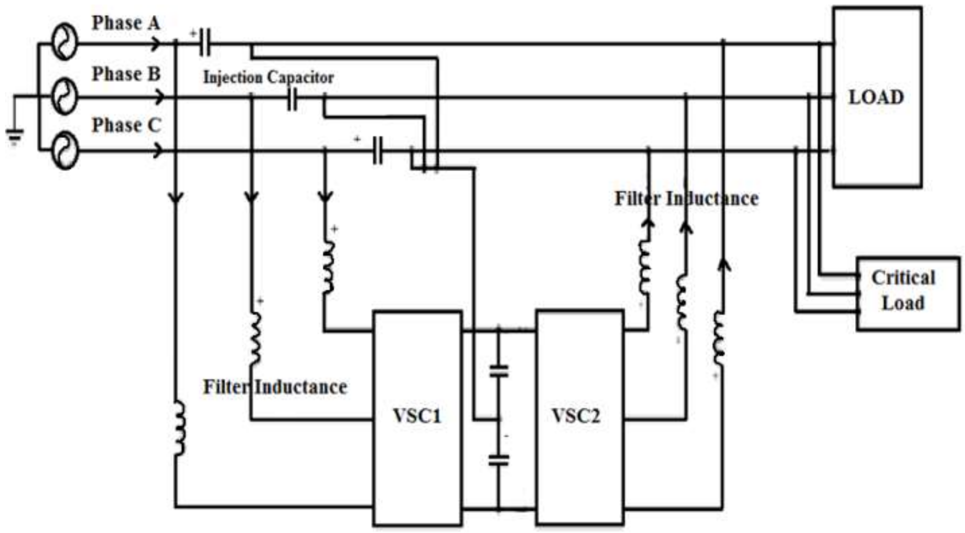


Figure 3. Circuit diagram of UPQC with injection capacitor

The circuit diagram of UPQC with the injection capacitor shows the filter inductances in both sides of the VSCs through which the VSCs are connected to the transmission line. The controller for series VSC produces a proportional signal according to the signal obtained from the comparison of the reference voltage with the actual voltage measured from the system. This error voltage is used for PWM signal generation. This PWM [4] signals generated is used for switching of the IGBT switches which constitutes the series VSC. The shunt VSC of the UPQC module is the responsible for the compensation of the current and elimination of the unwanted frequencies in the system. The PWM signal switches the VSC according to the changes in the system by producing a PWM signal accordingly so that the output of the VSC injected to the line conditions the power flow through the line. The switching frequency of the IGBT switches used for the comparative study is taken as 5 kHz.

## 3. CONTROL STRATEGY

The control strategy used here is a multi-loop based controller which is based on the feedbacks obtained from the systems. The control strategies for the series and shunt controllers are discussed below:

### 3.1. Control Strategy for the Series VSC

The flowchart for the series control strategy is shown in Figure 4. The control signals obtained from the PWM generator is used for switching the switches of the series VSC [5]. The feedbacks from the systems is taken and compared with various parameters.

The reference voltage generation is done by extracting the positive sequence component and its phase from the system voltage. The phase locked loops (PLL) [6] along with the positive extraction is used to generate the positive sequence component. Equation (1) represents the reference capacitor voltage.

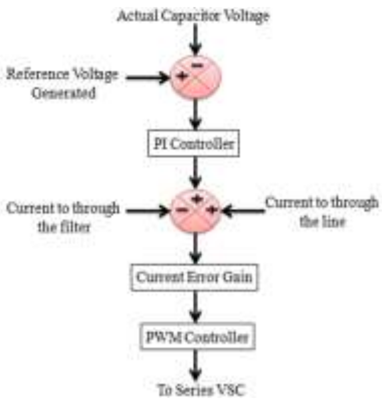


Figure 4. Flowchart for series VSC controller

$$\begin{bmatrix} V^{*}ca1 \\ V^{*}cb1 \\ V^{*}cc1 \end{bmatrix} = \begin{bmatrix} VI^{*}Cos(\omega t + \theta p) \\ VI^{*}Cos\left(\omega t - \frac{2\pi}{3} + \theta p\right) \\ VI^{*}Cos\left(\omega t + \frac{2\pi}{3} + \theta p\right) \end{bmatrix} - \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = V_{sp}^{*} \begin{bmatrix} Cos(\omega t + \theta p) \\ Cos\left(\omega t - \frac{2\pi}{3} + \theta p\right) \\ Cos\left(\omega t + \frac{2\pi}{3} + \theta p\right) \end{bmatrix} + V_{sn}^{*} \begin{bmatrix} Cos(\omega t + \theta n) \\ Cos\left(\omega t + \frac{2\pi}{3} + \theta n\right) \\ Cos\left(\omega t - \frac{2\pi}{3} + \theta n\right) \end{bmatrix} \tag{2}$$

$VI^{*}$ is the peak value of the line voltage. This is set by user. $\theta_p$ is the phase angle of the positive sequence component. Equation (2) shows the reference source voltage used to obtain the required capacitor reference voltage. The voltages $V_{sp}$ and $V_{sn}$ are the peak voltages of positive sequence component and negative sequence component respectively. $\theta_n$ is the phase angle of the negative sequence component of the line voltage. Thus the generated voltage is compared is with actual voltage and as per the algorithm gating signals are obtained the generated signal controls the switching of the switches of the series VSC [7].

### 3.2. Control strategy for the shunt VSC

The algorithm for the generation of control signals for the shunt VSC is shown in Figure 5. The feedbacks obtained from the system are compared and then used generate the PWM signals used for switching the switches of the shunt VSC.

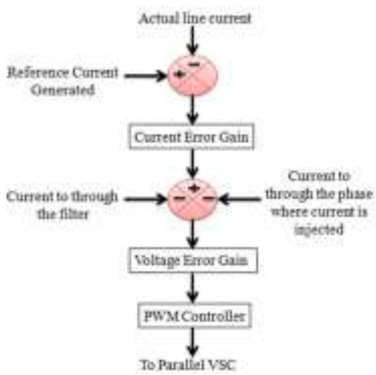


Figure 5. Flowchart for shunt VSC controller

The reference current generation for the shunt VSC controller is obtained using power balance theory [8]. The reference currents generated are in α-β reference frame [9]. This is transformed to abc reference frame and used as the reference current for the PWM generation. The generation of the reference current in abc frame is depicted in Figure 6. The $C_{PQ}^{-1}$ is a transformation matrix [9] and is given by the following equations,

Where, the voltages $V_\alpha$,$V_\beta$ are given as:

$$\begin{bmatrix} i^*\alpha f \\ i^*\beta f \end{bmatrix} = C_{PQ^{-1}} \begin{bmatrix} p_s \\ q_s \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & V_{-\alpha} \end{bmatrix}^{-1} \begin{bmatrix} p_s \\ q_s \end{bmatrix} \tag{3}$$

Where, the voltages $V_\alpha$,$V_\beta$ are given as below

$$\begin{aligned} V_\alpha &= V_{sd} * \cos((\omega t) + \theta_p) \\ V_\beta &= V_{sd} * \sin((\omega t) + \theta_p) \end{aligned} \tag{4}$$

$V_{sd}$ is the positive sequence component of supply. The reference current [10] generated in α-β reference frame is converted to abc reference frame. We obtain the reference frame currents $-I_{a^*}$, $I_{b^*}$& $I_{c^*}$.

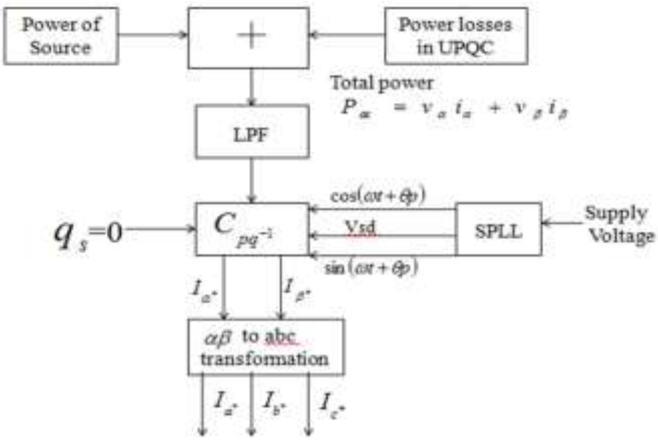


Figure 6. Reference current generation

## 4. SIMULATION RESULTS AND DISCUSSIONS

The scheme was verified using Matlab/SIMULINK version. A supply of 400V, 50 Hz and a non-linear load was applied to the system. A harmonics load with an RL load (50Ω, 60mH) is also switched to the system. The outputs were obtained for three phase faults.

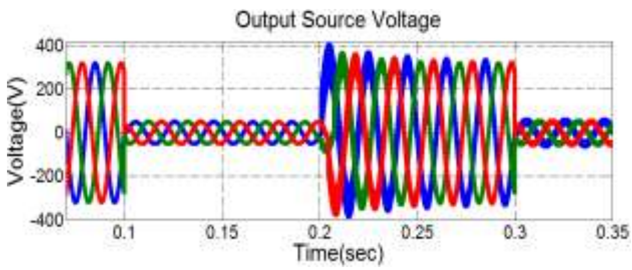


Figure 7. Simulation results for source voltage without UPQC

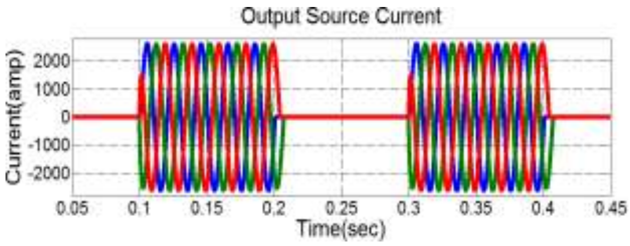


Figure 8. Simulation results for source current without UPQC

The system is applied with three phase symmetrical fault during 0.1s to 0.2s. At the time period from 0.3s to 0.4s, a harmonics load is switched to the system. The voltage and current waveforms are as shown in Figure 7 and Figure 8.

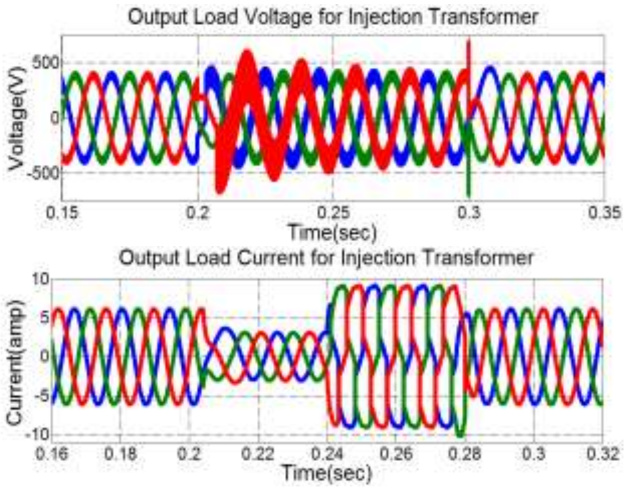


Figure 9. Simulation results for load voltage and load current

In Figure 9 the output results for the voltage and currents are shown when UPQC [11] is added with injection transformer. Here the faults are reduced but in-between 0.2s to 0.3s the voltage swell is visible which is due to the transformer effect, so some noise preserves.

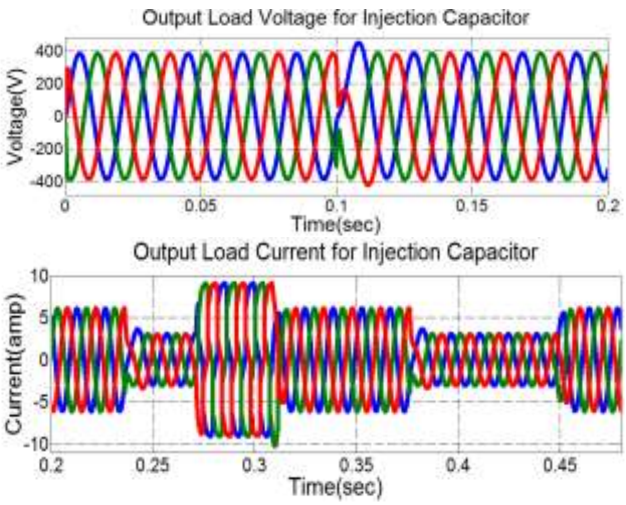


Figure 10. Simulation results for load voltage and load current

Figure 10 shows that by using ultra capacitors instead of transformers, the faults caused due to the transformers are eliminated and almost nearly accurate results are obtained. The voltage sag was found almost zero. Table 1 shows individual Total Harmonics Distortion (THD) for each phase with and without using UPQC [9]. It can be observed that THD of each phase without implementing UPQC are much higher whereas THD with using UPQC are within limit i.e. within the IEEE standard allowable limits.

Table 1. Comparison of Total Harmonics Distortion (THD)

| Phase | | THD Without UPQC (%) | THD With UPQC (%) |
|---|---|---|---|
| Voltage | For Phase A | 17.71 | 0.54 |
| | For Phase B | 17.05 | 0.89 |
| | For Phase C | 15.45 | 0.87 |
| Current | For Phase A | 20.38 | 3.12 |
| | For Phase B | 22.22 | 3.48 |
| | For Phase C | 22.35 | 2.33 |

## 5. CONCLUSION

The major power quality problems like harmonic currents, poor power factor [12], supply voltage variations etc. were minimized with the implementation of the UPQC in the system. The simulations using Matlab/SIMULINK were carried out to find the practicability of the configuration and effectiveness of the proposed control scheme. The use of continuous feedback from the capacitor voltage for the series VSC and the inductor & line currents for the parallel VSC enabled a better reference generation thus, a better output. The UPQC with two types of injecting devices were compared here to find out the efficiency and effectiveness of the UPQC with the change in the injecting devices.

Thus the proposed injecting device (injecting capacitor) was found effective for minimizing the power quality issues like voltage sag and current harmonics over the conventional injecting device (injecting transformer).

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**APPENDIX**

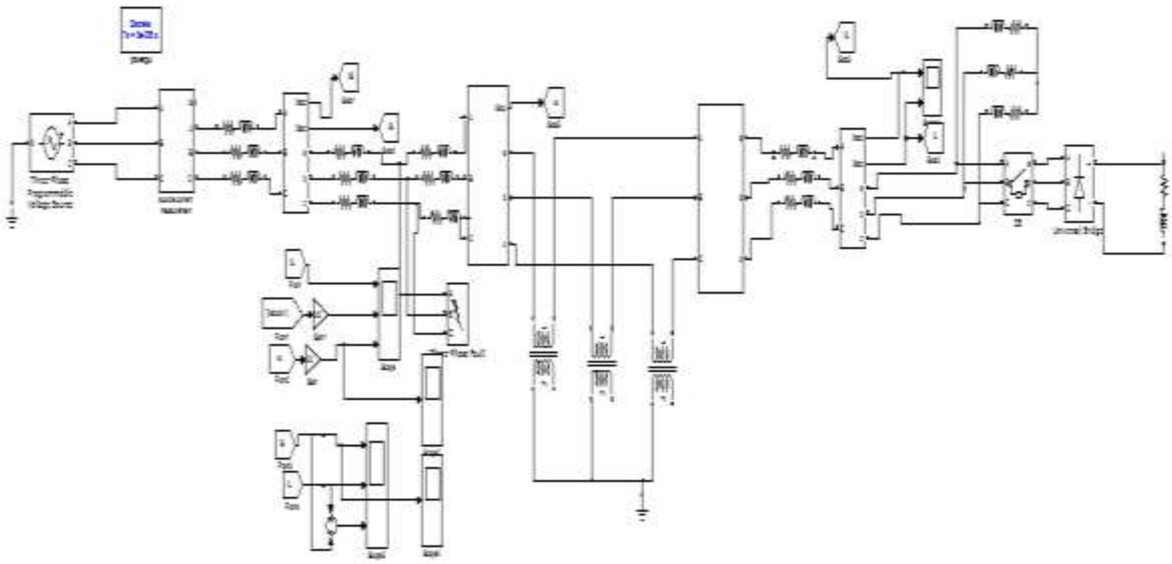

Figure 11. Simulink circuit without using UPQC

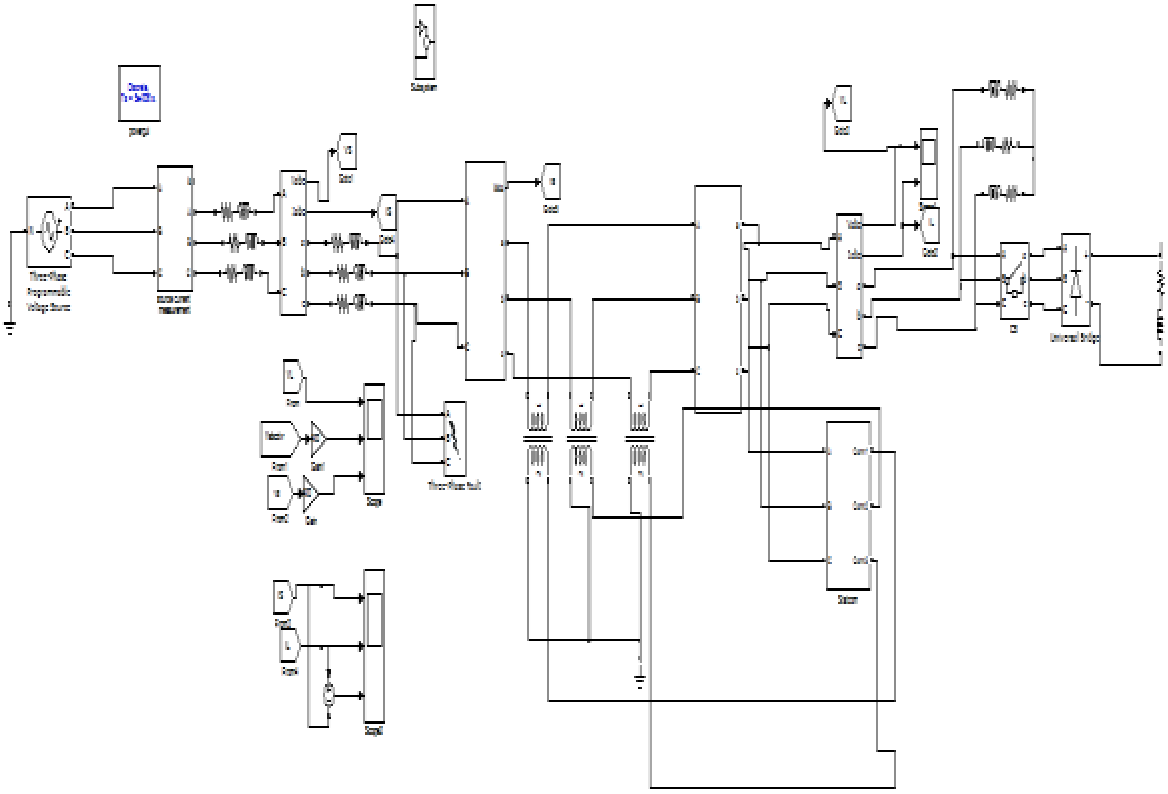

Figure 12. Simulink circuit using UPQC with injecting transformer

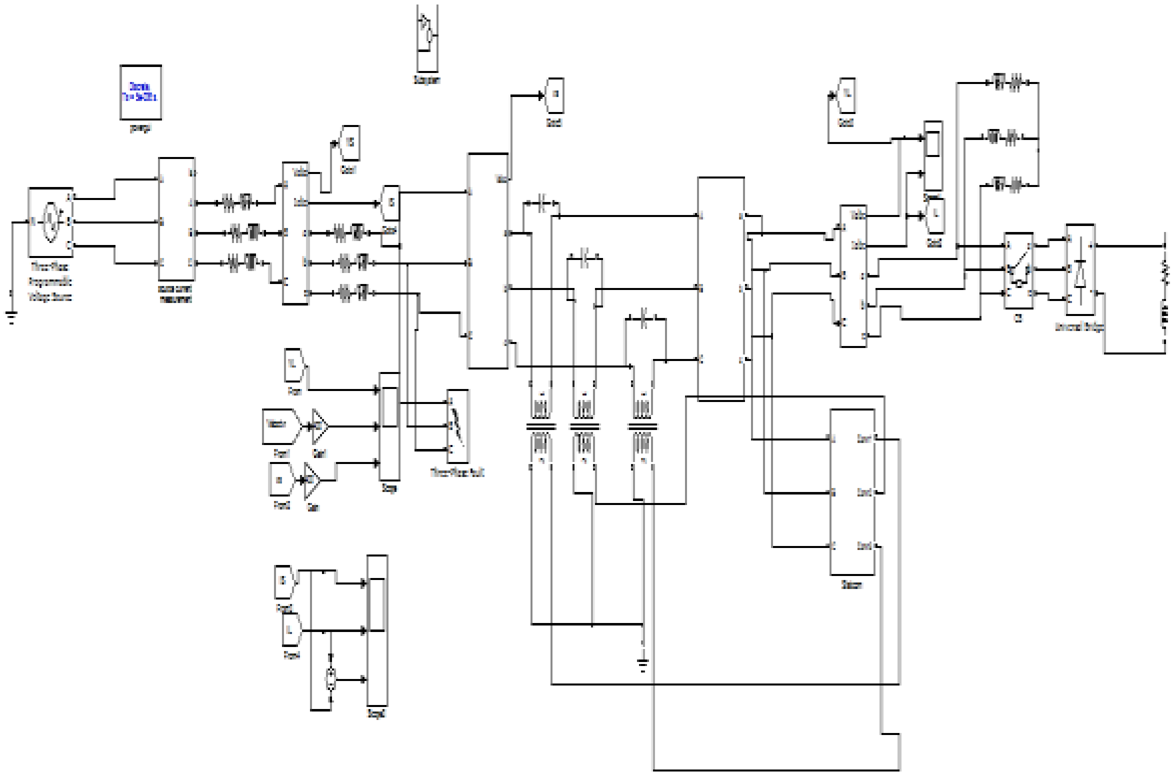

Figure 13. Simulink circuit with UPQC having ultra capacitance

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