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Voltage Sag/Swell Mitigation Using UPQC

S.Thirukkovai [1], J.Venkatesan [2], Dr.S.M.Girirajkumar [2]

Abstract— A new synchronous-reference-frame (SRF)-based control method is proposed in this project. It compensates power-quality (PQ) problems through a three-phase four-wire Unified Power Quality Conditioner (UPQC) under unbalanced and distorted load conditions. The proposed UPQC system can improve the power quality at the point of common coupling on power distribution systems under unbalanced and distorted load conditions. The main problem in the power distribution system is voltage sag, and voltage swell , to compensate these problems a power electronic device i.e., UPQC-(Unified power quality conditioner) is used in this proposed model . system. It is the combination of back to back connected series and shunt converters. The proliferation of power electronic based equipments has produced a significant impact on the quality of electrical power supply. The modern day equipments are highly sensitive to deviation from ideal sinusoidal voltages. Conventional power quality enhancement equipments are providing inadequate compensation. A very promising solution for supply voltage imperfection is UPQC (Unified Power Quality Conditioner). Unified power quality conditioners (UPQCs) allow the mitigation of voltage and current disturbances that could affect sensitive electrical loads while compensating the load reactive power. In this Paper, the simulation of UPQC connected system for voltage sag and swell mitigation is carried out using MATLAB 7.5 and the results are shown. The hardware implementation will be done using FPGA controller.

Index Terms— UPQC, Sag, Swell, SRF, Power Quality.

1 Introduction

Any problem related with voltage, current orfrequency deviation that results in failure of customerequipment is known as power quality problem.Low power quality affects electricity consumer inmany ways [1]. The extensive use of non -linear loads is further contributing to increased current and voltage harmonics issues. Apart from non-linear loads, some system events, both usual (capacitor switching, motor starting) and unusual (faults) could also inflict power quality problems. The consequence of power quality problems could range from a simple nuisance flicker in electric lamps to a loss of thousands of rupees due to power shutdown. A power quality problem is defined as any manifested problem in voltage or current of leading to frequency deviations that result in failure or miss operation of customer equipment. Power quality problems associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances. Short duration variations are mainly caused by either fault conditions or energisation distance related to impedance type of grounding and connection of transformer between the faulted location and node, there can be temporary load of voltage reduction (sag) or voltage rise (swell) at different nodes of the system.Voltage sag/sell is most important power quality problems challenging the utility industry can be compensated and power is injected into the distribution system.Voltage sag is defined as a sudden reduction in supply voltage to between 90% and 10% of the nominal value, followed by a recovery after a short interval. The standard duration of sag is between 10 milliseconds and 1 minute. Voltage sag can cause loss in production in automated processes since voltage sag can trip a motor or cause its controller to malfunction. Voltage swell is defined as sudden increase in supply between 110% and 180% of the nominal value of the duration of 10 milliseconds to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is a typical system event that causes swells. To compensate the sag/swell in a system, appropriate devices need to be installed in the system.The voltage sag/swell on the system is oneof the most important power quality problems. The voltage sag/swell can be effectively compensatedusing a dynamic voltage restorer, series active filter UPQC, etc. Among the available power quality enhancement devices, the UPQC has better sag/swell compensation capability [2].

- *S.Thirukkovai is currently working as assistant professor (EEE) in J.J. College of Engineering and technology,Trichy,India, E-mail: thirukkovairishi10@gmail.com*
- *J.venkatesan is currently pursuing master's degree program in power electronics and drives in J.J.College of Engineering and technology, Trichy, India. E-mail: venkat.hari.88e@gmail.com*

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2 Unified Power Quality Conditioner

UPQC is as one of the modern and very promising PQ improving device, and deals with both load current and supply voltage imperfections. UPQC is the integration of series and shunt active power filters, connected back-to-back on the dc side, sharing a common DC capacitor. It has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems.

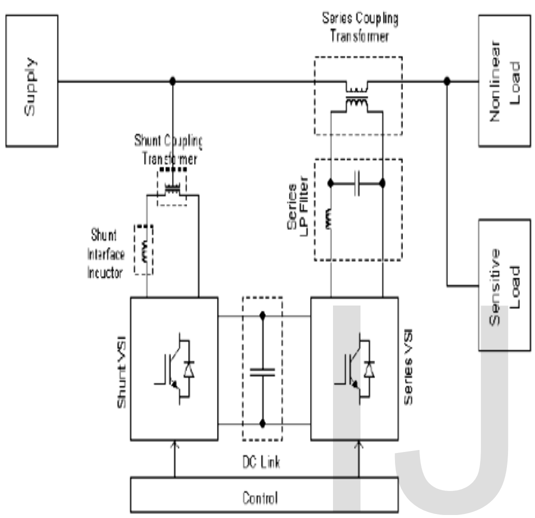

Figure 1 Block diagram of UPQC

3 Series Controller

A Series controller is a solid-state voltage source inverter, which generates a controllable AC voltage source, and connected in series to power transmission lines in a power system. The injected voltage (*Vinj*) is in quadrature with the line current *I*, and emulates an inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The compensation level can be controlled dynamically by changing the magnitude and polarity of *Vinj* and the device can be operated both in capacitive and inductive mode [13]. The main purpose of the series-active filter is harmonic isolation between a sub transmission system and a distribution system. In addition, the series-active filter has the capability of voltage. Flicker, imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). The series component of the UPQC inserts voltage so as to maintain the voltage at the Point of Common Coupling (PCC) balanced and free of distortion. The injected voltage is in quadrature with the line current I, and emulates an inductive or a capacitive mode. Reactance so as to influence the power flow in the transmission lines. The compensation level can be controlled dynamically by changing the magnitude and polarity of injected voltage and the device can be operated both in capacitive and inductive mode

- The voltage injected in series with the load by series APF is made to follow a control law such that the sum of this injected voltage and the input voltage is sinusoidal.

- Thus, if utility voltages are non-sinusoidal or unbalanced, due to the presence of other clients on the same grid, proper selection of magnitude and phase for the injected voltages will make the voltages at load end to be balanced and sinusoidal.

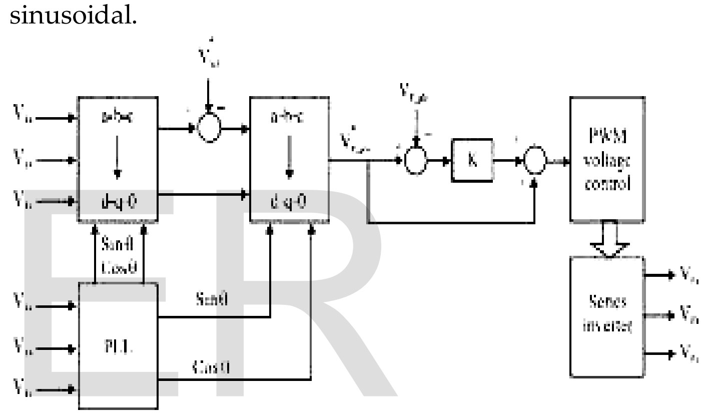

Figure 2 BLOCK DIAGRAM OF SERIES CONTROLLER

The series connected converter has the following control objectives,

1. To balance the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source.
2. To isolate the load bus from harmonics present in the source voltages, by injecting the harmonic voltages.
3. To regulate the magnitude of the load bus voltage by injecting the required active and reactive components (at fundamental frequency) depending on the power factor on the source side.
4. To control the power factor at the input port of the UPQC (where the source is connected). Note that the power factor at the output port of the UPQC (connected to the load) is controlled by the shunt converter.

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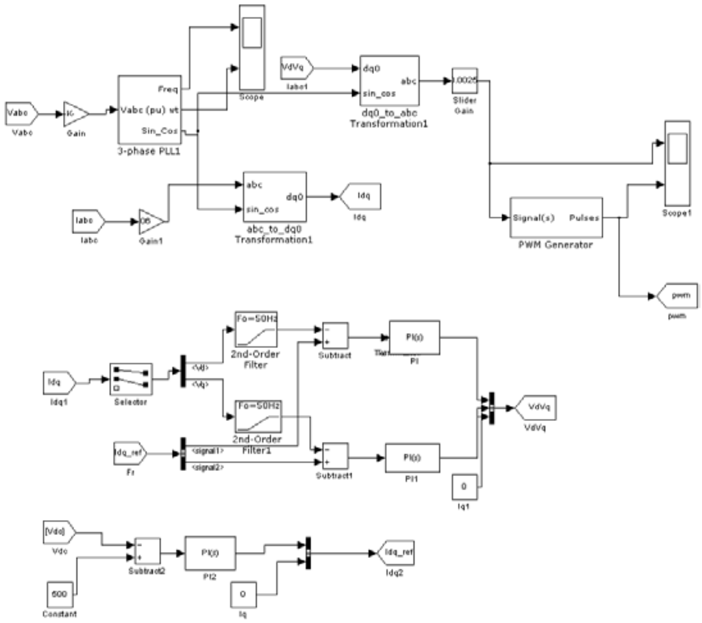

Figure 3 SIMULINK MODEL OF SERIES CONTROLLER

3 SHUNT CONTROLLER

The main purpose of the shunt active filter is to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc-link voltage between both active filters. Shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link. The shunt APF is usually connected across the loads to compensate for all current-related problems such as the reactive power compensation, power factor improvement, current harmonic, compensation, and load unbalance compensation [10]. Two functions of the shunt inverter are to compensate the current harmonics and the reactive power, and to supply the active power to the load during voltage interruption. The configuration of shunt inverter control, which includes the current control for harmonic compensation, and the output voltage control in voltage interruption. In normal operation the shunt control calculates the reference value of the compensating current for the harmonic current and the reactive power, considering the power loss *p* due to the system and inverter operation. This loss should be compensated to maintain the dc link voltage during operation of the series inverter. The reference value of the compensating current is derived. The reference voltage is calculated by the PI controller.

□The shunt component of the UPQC injects currents into the AC system such that the currents drawn by the UPQC from supply are balanced, undistorted and in phase with the supply voltages.

□Also, the shunt device provides a path for real power flow to aid the operation of the series compensator and to maintain constant average voltage across the dc storage capacitor.

□The shunt APF acts as a current source and inject a compensating harmonic current in order to have sinusoidal, in phase input current. The shunt connected converter has the following control objectives,

□1. To balance the source currents by injecting negative and zero sequence components required by the load.

□2. The compensate for the harmonics in the load current by injecting the required harmonic compensation currents.

□3. To control the power factor by injecting the required reactive current (at fundamental frequency).

□4. To regulate the DC bus voltage.

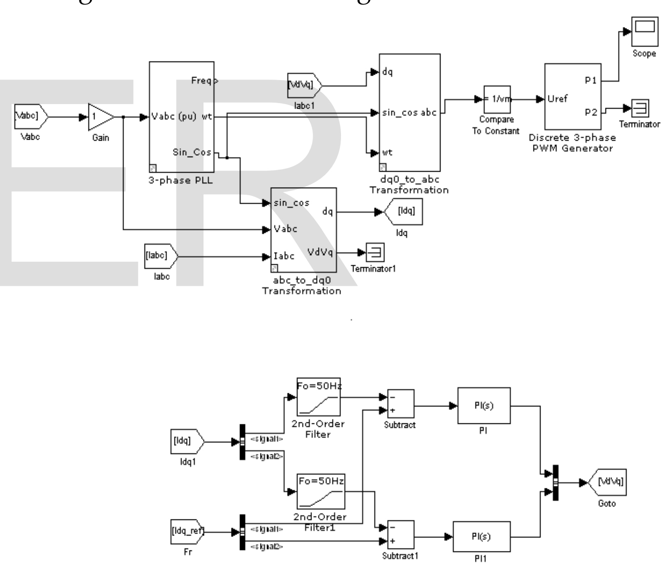

Figure 4 SIMULINK MODEL OF SHUNT CONTROLLER

5 DC LINK VOLTAGE CONTROL

The dc link voltage of the Unified Power Quality Conditioner (UPQC) can significantly deviate from its reference during a transient event, caused by load connection/disconnection or/and supply side voltage sag/swell, though in the steady state the average dc link voltage is maintained at a certain preset level. During such transients, due to considerable dc link voltage deviation, the magni-

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tude of the series injected voltage cannot be constant and this has an effect on the load voltage magnitude, which fluctuates. An improved sinusoidal pulse width modulation (PWM) voltage controller for the series compensator is proposed which adjusts continuously the amplitude modulation ratio in response to the dc link voltage deviations. Also, an adaptive dc link voltage controller is proposed which limits the dc link voltage deviation during transients and assures a negligible steady-state error.
There exist dc link voltage transients during which the average voltage across the dc link capacitor deviates from its reference value. Such transients can occur when a load is either connected or disconnected to/from the UPQC or a voltage sag/swell on the supply side takes place. The severity of the dc link voltage deviation depends on the depth of the source voltage sag/swell, the size of the load connected/disconnected to/from the UPQC, the dc link capacitor rating, and the performance of the dc link voltage controller [12].In the previous section it was concluded that the situations when Vdc< 0.7854 Vdcref should be avoided, otherwise, the magnitude of the fundamental component of the series inverter output voltage is lower than Vdc,ref/2. Thus, by some means, the dc link voltage drop has to be limited to 21.46% of Vdc,ref. Also, the dc link transient overvoltage has to be limited to some reasonable value.

The transient dc link voltage deviation can be reduced through proper choice of the dc link capacitor rating and design of the dc link voltage controller. Rather than increasing the dc link capacitor rating (which adds extra cost to the UPQC) a design-based solution has been derived which is presented in the following. Better performance of the dc link voltage controller is achieved by applying an adaptive control strategy.

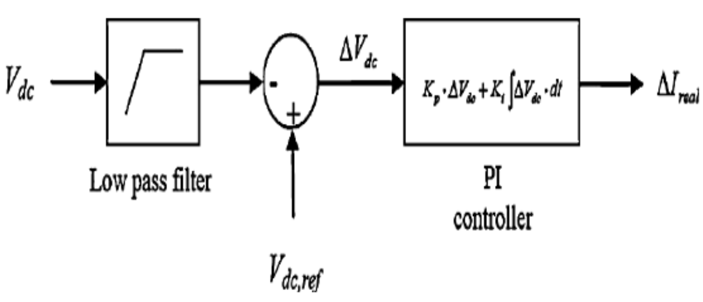


Figure 5 DC link Voltage Control

The dc link voltage control is achieved by adjusting the small amount of real power flowing through the shunt inverter into the dc link capacitor, thus compensating for the conduction and switching losses and keeping the dc link voltage constant. This small amount of real power is adjusted by changing the amplitude of the real fundamental component of the reference current.

6 SYNCHRONOUS REFERENCE FRAME

Among the several methods presented in the literature, the Synchronous Reference Frame method (SRF) is one of the most common and probably it is the best method. It is based on the fact that harmonics change their frequency in a rotating reference frame, and so they are better isolated with high pass filters. The compensator would produce desired results as long as its bandwidth is sufficient to follow the fluctuations in the load [3].
In the SRF, the load current signals are transformed into the conventional rotating frame d-q. If γ is the transformation angle, the transformation is defined SRF theory is based on the transformation of currents in synchronously rotating d–q frame. Sensed inputs are fed to the controller.Voltage signals have been processed by a phase-locked loop (PLL) to generate unit voltage templates (sine and cosine signals). Current signals have been transformed to d–q frame, where these signals are filtered and transformed back to a-b-c frame, which are fed to a hysteresis-based PWM signal generator to generate final switching signals fed to the UPQC Similar to the IRP theory, current components in α–β coordinates have been generated, and using θ as a transformation angle, these currents have been transformed from α–β to d–q frame defined as (Park's transformation)

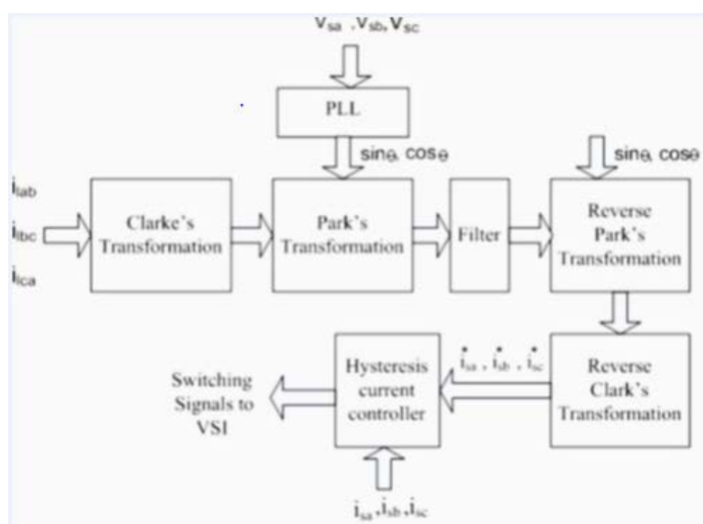


Fig 6.1 SRF CONTROL

However, where control is concerned, the integral component of the PI controller can lead to integrator windup resulting into instability of the controller and hence poor performance of the shunt active power filter. In order to improve performance, this project presents a method to effectively compensate the windup of the integral term of the PI controller. It is an integrator ant windup circuit.

In synchronous reference frame, the components of current corresponding to active and reactive power are controlled in an independent manner. This three-phase dq transformation and dq to three-phase transformation are discussed in detail in this chapter. The outer loop controls the dc bus voltage and the inner loop controls the line currents.

7 Simulation Modal

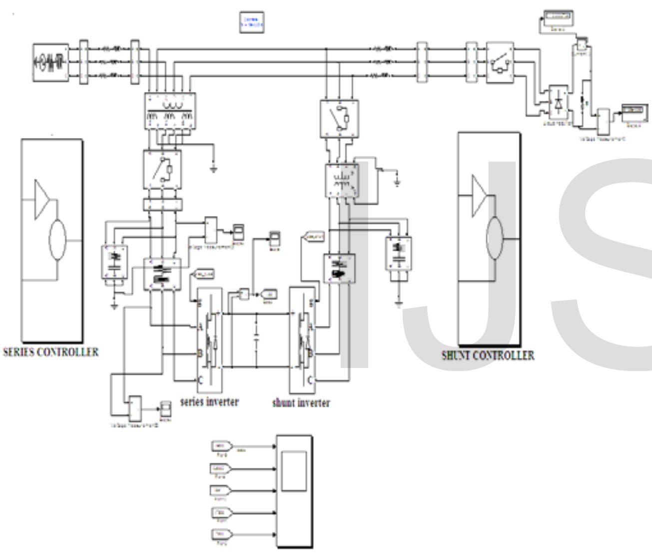
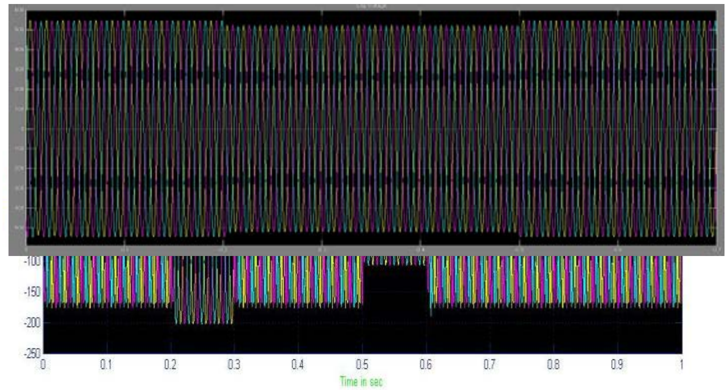


Fig 7.1SIMULINK MODEL OF UPQC

8 SIMULATION RESULTS

WITHOUT UPQC:



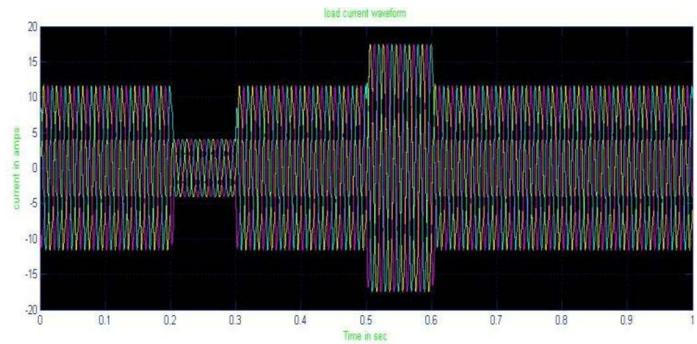
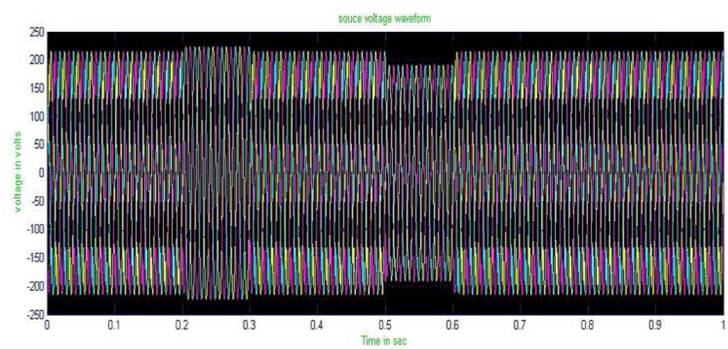


Fig 8.1 Load Voltage and Current
Voltage sag: 0.5 to 0.6 sec, Voltage swells: 0.2 to 0.3 sec

Fig8.2 Source Voltage



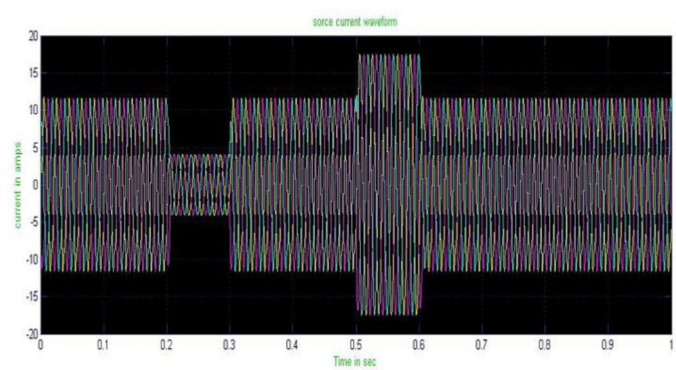


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Fig 8.3 Distortions in Voltage and Current

RESULTS WITH UPQC

Fig 8.4: Supply voltage

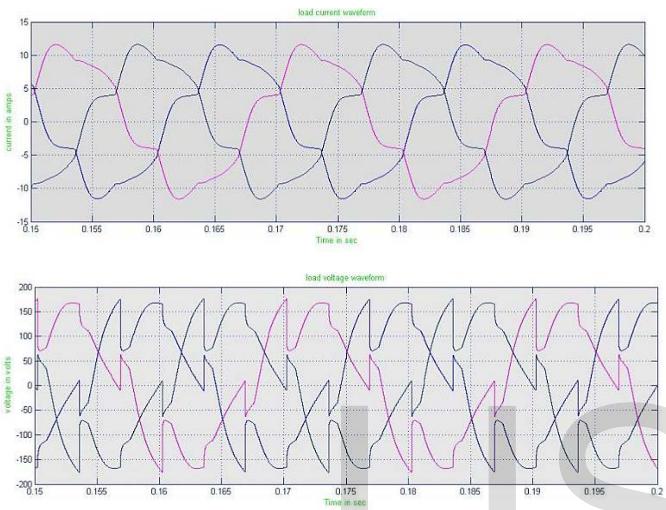

Fig 8.5 Sag voltage

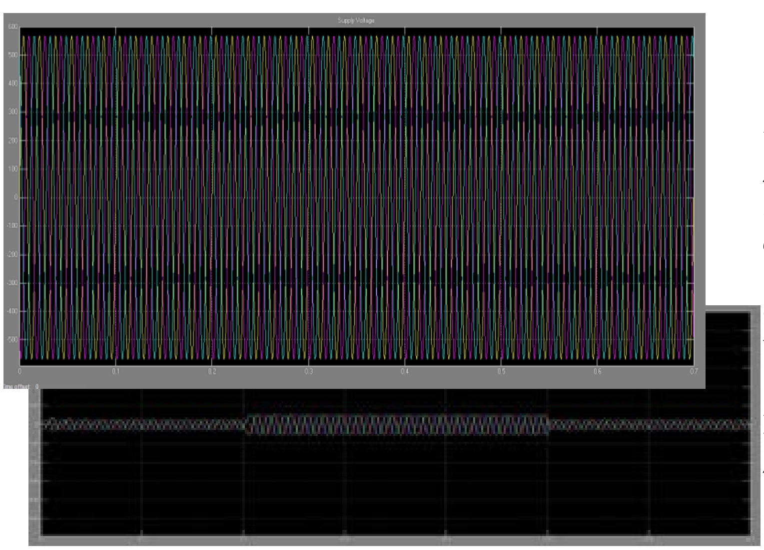

Fig 8.6 Injected voltage

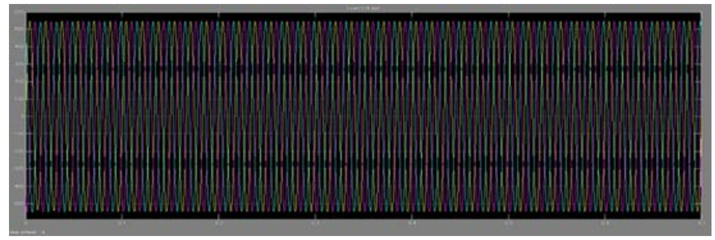

Fig 8.8: Compensated Load voltage

9 Conclusion

The main objective of this paper was to develop the UPQC scheme and its two controllers for the improvement of power quality in power distribution system, by eliminating the Voltage Sag and swell. The simulation has been implemented using the SRF control strategy which gives the reference signals for series and shunt controllers. The objectives laid down for this paper have been successfully realized through analytical and simulation investigations. As part of this research activity also, a UPQC simulation model has been built in Simulink, developing new control solutions. The effectiveness of the UPQC has been proved through simulation results. The Hardware is to be implemented by using FPGA.

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