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# Power Quality Improvement by Using UPQC in Wind Energy Conversion System

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**ABSTRACT:** Power quality has become a crucial factor today due to wide application of power electronics based equipment Day by day in industries and in distribution area power electronics based device are widely used and creates more power quality problems. The quality of the power is defective by certain reasons. This improvement of the quality of the power is seen e.g. as sag, swell, over voltages, under voltage, and harmonics Conventional equipment for enhancement of power quality is becoming inadequate. Unified power quality conditioner (UPQC) is one modern device which deals with voltage and current imperfections simultaneously. the unified power quality conditioner (UPQC), which consists of the parallel active power filter (PAPF) and the series active power filter (SAPF). The UPQC is a power conditioning device able to compensate all kinds of power quality faults. UPQC is also used to filter both current and voltage harmonics and to compensate the voltage sag. UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. This work deals with a way to improve the voltage compensation performance of the series APF. This improvement is achieved by improving the conventional hysteresis control system.

**KEYWORDS:** Power quality, UPQC,

### I. INTRODUCTION

Wide application of power electronic based equipment has resulted in a serious impact on the nature of electric power supply. Smooth uninterrupted sinusoidal voltage at desired magnitude and frequency should always be provided to the consumers. On the other hand consumers should draw sinusoidal current [1]. Efforts are being made by many researchers for the effective improvement of power quality. UPQC is considered as the most powerful solution to the problems arising due to power quality. It is adequate enough to take care of supply voltage disturbances like voltage sag/swells, voltage flickers, load reactive power as well as voltage and current harmonics. The UPQC can also be named as the universal active power line conditioner, universal power quality conditioning system and also universal active filter. It is a cascade connection of series and shunt active power filter (APF) connected through a common DC link capacitor [2]. Poor power quality affects electricity consumers in many ways. The poor power quality may result into loss of production, damage of equipment or appliances, increased power losses, interference with communication lines etc. The decline quality of electric power is mainly because of current and voltage harmonics due to wide range application of static power electronics converters, zero and negative sequence component originated by the use of single phase and unbalanced load, reactive power, voltage sag, voltage swell, flicker, voltage interruption etc. Therefore, it is very crucial to maintain a standard power quality. The series APF is coupled to the supply line through a series transformer. The series APF prevents the source side voltage disturbances from entering into the load side to make the load voltage at desired magnitude and frequency [2]. Whereas the shunt APF connected in parallel across the load confines the current related problems to the load side to make the current from the source purely sinusoidal [3].

### II. POWER QUALITY ISSUES AND ITS EFFECTS IN WIND ENERGY SYSTEM

The guidelines for measurement of power quality of wind turbine are developed by The International Electro-Technical Commission (IEC) in coordination with the Technical Committee-88. This commission explained the methodologies

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for measuring the power quality characteristics of a wind turbine [4]. For grid connection, the base for the analysis is provided by the data sheet with electrical characteristic of wind turbine. Perfect power quality means that the voltage is continuous and sinusoidal having a constant amplitude and frequency. Power quality can be expressed in terms of physical characteristics and properties of electricity. It is most often described in terms of voltage, frequency and interruptions. The quality of the voltage must fulfill requirements stipulated in national and international standards. In these standards, voltage disturbances are subdivided into voltage variations, flicker, transients and harmonic distortion [5]. Fig. 1 shows a classification of different power quality phenomena.

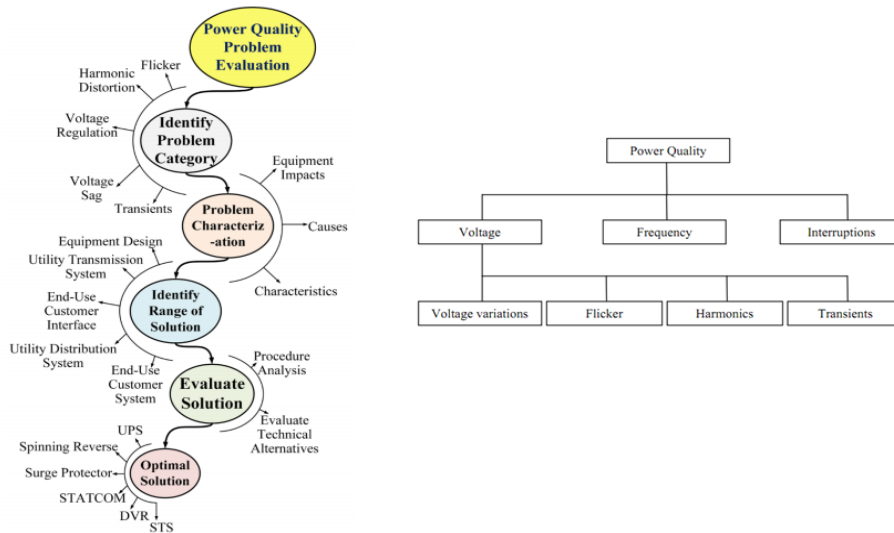


Fig. 1(a): Flow diagram for evaluation of power quality problems, solution of a problem comes through a process starting with identification of the problem category.

Fig. 1(b): Classification of different power quality phenomena

## 2.1. POWER QUALITY ISSUES

### A. VOLTAGE VARIATION

The voltage variation mainly results from the wind velocity and generator torque. The voltage variation is directly related to real and reactive power variations. The wind generating system equipped with an asynchronous generator consumes the reactive power and can cause additional negative problem for the grid. Switching the wind turbine generator ON and OFF also varies the voltages. The voltage variation is commonly classified as short duration and long duration voltage variation.

Various types of voltage variations are given as follows:

- Voltage sag.**                      **Voltage flicker.**
- Short interruptions**        **Voltage swells.**

### B. FLICKER

Voltage flicker describes dynamic variations in the network voltages caused by wind turbine or by varying loads. Thus the power fluctuation from wind turbine occurs during continuous operation. The amplitude of voltage fluctuation depends on grid strength, network impedance, phase-angle and power factor of the wind turbines. It is defined as a fluctuation of voltage in a frequency 10-35 Hz. The IEC 61400-4-15 specifies a flicker meter that can be used to measure flicker directly. The flicker coefficient gives a normalized dimensionless measure of flicker, independent of



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network situation and independent of short circuit apparent power of the grid. It gives ratio of short circuit power and generated rated apparent power, which is necessary to achieve a long term flicker level. (Plt), as the given equation.

$$C(\psi_k, V_a) = P_{lt} \frac{S_k}{S_n}$$

Where,  $C(\psi_k, V_a)$ -flicker coefficient depends on grid impedance angle  $\psi_k$  and the average wind velocity  $V_a$ .

$S_k$  - Short-circuit power of grid at point of common coupling. ,  $S_n$ - Apparent power of wind turbine at rated power.

$P_{lt}$ - Long term flicker emission.

The flicker standards are generally used to characterize the transient voltage variations. The short flicker is evaluated over a 10 min period and long term flicker is evaluated over 2 hours period.

**Causes**— Fluctuation of active and reactive power of wind turbine, i.e. yaw error, wind shear, wind turbulence or fluctuation in control system, switching operations in wind turbine. In fixed speed wind turbine each time a rotor blade passes through the tower, the power output of the turbine reduces. This effect cause's periodical power fluctuation with a frequency of about 1 Hz, where as in variable speed turbine power fluctuation are smoothed. Flickers are produced by arc furnace, arc lamps, capacitor switching.

**Consequences**—Degradation of power quality, damage to sensitive equipments.

## C. HARMONICS

It results from the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. The emission of harmonic current during the continuous operation of wind turbine with power converter has to be stated. The relative harmonic current limit is stated in the Table I.

Harmonic number	5	7	11	13
Admissible harmonic ( $I_h / I_1$ )	5-6	3-4	1.5-3	1-2.5

**TABLE I Relative Harmonic Current Limit**

Where  $I_h$  is the total harmonic current of  $h^{th}$  order caused by the consumer and  $I$  is the rms current corresponding to the consumer agreed power.

## D. WIND TURBINE LOCATION IN THE POWER SYSTEM

The way of connecting the wind generating system into the power system highly influences the power quality. As a rule, the impact on power quality at the consumer's terminal is located close to the load is higher, than connected far away from the load. When the wind generating system is connected to a medium voltage transmission line, the distance between the wind generating station and point of common coupling is small, such system are economical as compared to other location. Thus the operation and its influence on power system depends on the structure of the adjoining power network.

## E. SELF EXCITATION OF WIND TURBINE GENERATING SYSTEM

The self-excitation of wind turbine generating system (WTGS) with an asynchronous generator takes place after disconnection of WTGS with local load. The risk of self-excitation arises especially when WTGS is equipped with compensating capacitor. The capacitor connected to induction generator provides reactive power compensation. However, the voltage and frequency are determined by the balancing of the system. The disadvantages of self-excitation are the safety aspect and balance between real and reactive power.[6]-[8]

**Causes**—If the sensitive equipment is connected to the generator during the self-excitation, the equipment may be a subject to over load, under voltage and over frequency operation

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## III. UNIFIED POWER QUALITY CONDITIONER (UPQC)

The best protection for sensitive loads from sources with inadequate quality, is shunt-series connection i.e. unified power quality conditioner (UPQC). Recent research efforts have been made towards utilizing unified power quality conditioner (UPQC) to solve almost all power quality problems for example voltage sag, voltage swell, voltage outage and over correction of power factor and unacceptable levels of harmonics in the current and voltage. The basic configuration of UPQC is shown in Fig. 2. [9]

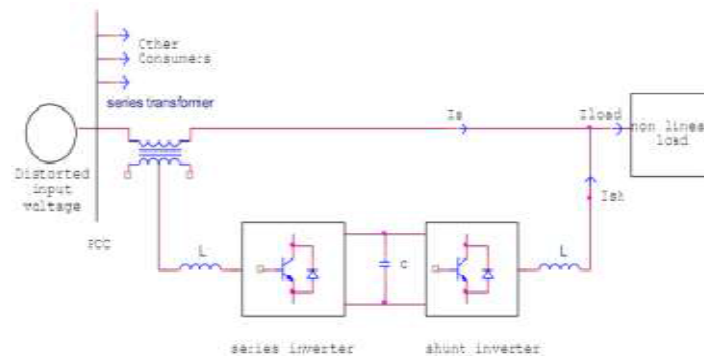


Fig.2 Basic configuration of UPQC

The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity sensitive loads to voltage flicker/imbalance. Unified Power Quality Conditioner (UPQC) for non-linear and a voltage sensitive load has following facilities:

- It eliminates the harmonics in the supply current, thus improves utility current quality for nonlinear loads.
- UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase, therefore, no additional power factor correction equipment is necessary.
- UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag. The voltage injected by UPQC to maintain the load end voltage at the desired value is taken from the same dc link, thus no additional dc link voltage support is required for the series compensator.
- The UPQC consists of two three phase inverters connected in cascade in such a manner that Inverter I is connected in series with the supply voltage through a transformer inverter II is connected in parallel with the load.
- The main purpose of the shunt compensator is to compensate for the reactive power demanded by the load, to eliminate the harmonics and to regulate the common dc link voltage.
- The series compensator is operated in PWM voltage controlled mode.
- It injects voltage in quadrature advance to the supply voltage (current) such that the load end voltage is always maintained at the desired value. The two inverters operate in a coordinated manner.

## IV. CONTROL ALGORITHM IN UPQC

Various control techniques have been used for the control of harmonics in voltage and current by using UPQC. Here mainly two methodology has been described i.e. the unit vector template generation technique and the Synchronous reference frame and PQ theory [10-11].-

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## 4.1 UNIT VECTOR TEMPLATE GENERATION

The control technique used here is Unit vector template generation technique. In this case, supply voltage is made distorted and Unit Vector Templates are extracted from it. The distorted input source voltage contains harmonic components in addition to the fundamental component. For extraction of these unit vectors, the supply voltage is first measured and the product of this and gain ( $1/V_m$ ) is done,  $V_m$  being the peak fundamental supply voltage. After this, unit vector templates are generated by using a phase-locked loop.

$$V_a = \sin \omega t$$

$$V_b = \sin (\omega t - 120^\circ)$$

$$V_c = \sin (\omega t + 120^\circ)$$

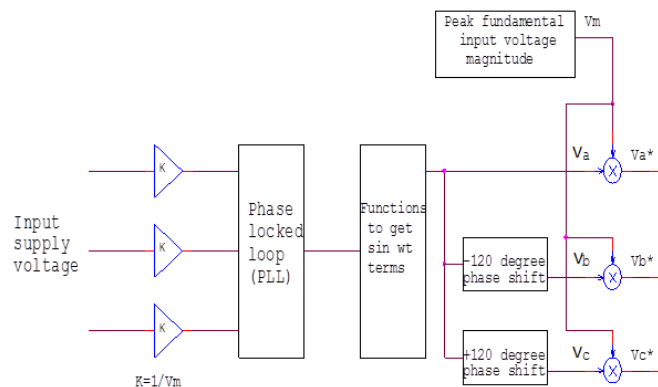


Figure 3 Generation of Unit Vector Templates and reference Load Voltages

Supply voltage is then multiplied with the unit vector templates and reference load voltage is generated. The reference load voltage generated is given by  $V^*_{abc}$ .

$$V^*_{abc} = V_m \cdot U_{abc}$$

Then the comparison of actual load voltage and reference load voltage is done. Error is calculated and sent into a hysteresis band for generating the gate pulse for the series inverter. Shunt Active Power Filter is used for current harmonics compensation. Generation of pulses for the shunt inverter DC link voltage is then measured and its comparison is done with the reference DC link voltage. After that error is processed by utilizing a PI controller, and to produce the reference current these results are multiplied by unit vector templates. Comparison of reference and actual source current is done and a hysteresis band controller is used for processing the error and production of gate pulses for parallel inverter circuit is completed. [10-11]

## 4.2 SYNCHRONOUS REFERENCE FRAME AND P-Q CONTROL OF UPQC-

### 4.2.1-Control Method for Series Active Filter

For controlling the source side voltage aggravation SAF is utilized. In this method, the reference voltage that needs to be infused by the series transformers is ascertained by comparison of the positive – sequence component of the source voltage with that of the source voltage. The reference generation calculation for SAF is demonstrated as follows-

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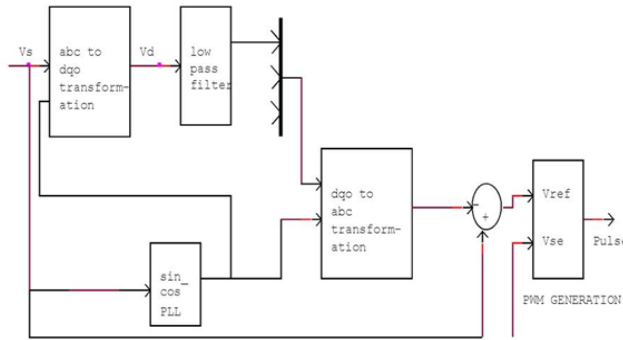


Figure 4 Control algorithm of SAF

Equation depicting transformation of supply voltage and load current into d-q-o coordinate are given below

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad \dots (1)$$

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} \quad \dots (2)$$

Along with the fundamental component harmonics are also present in the d-axes voltage. A second order LPF is used for filtering out the harmonic components. Then the reference voltage Vref is then estimated by utilizing d-q-o to a-b-c transformation. Then the output of series active filter and the reference voltage generated is fed to a hysteresis band controller to generate the gate pulses

#### 4.2.2-Control Method Employed for Shunt Active Filter-

For calculating the reference current in this method P-Q methodology has been utilized. Clarke's transformation given in equation (1),(2),(3) and (4) are used for transformation of reference voltages generated at SAF and load current in to  $\alpha$ - $\beta$ -0 coordinates

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad \dots (3)$$

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad \dots (4)$$

Equation (5) is used for the calculation of real power and imaginary power in the Source side. These are instantaneous power-

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad \dots (5)$$

For compensating reactive power and the harmonic component, real power is taken as the reference and the source current reference can be calculated by Eq.(6).

$$\begin{bmatrix} I\alpha^* \\ I\beta^* \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} P + \Delta P \\ 0 \end{bmatrix} \quad \dots (6)$$

Where  $\Delta P = P_o + P_{loss}$



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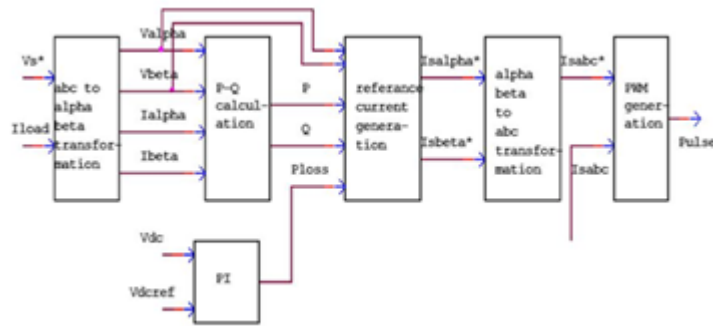


Figure 5 Control algorithm of PAF

Due to the absence of unbalance the power  $P_o$  is zero. Comparison of measured and reference DC-link voltage is done and a Proportional integral controller is used for processing the error produced. The main reason behind using this controller is that it helps in reducing the steady state error to a zero value. PI controller's yield is termed as  $P_{loss}$ . Then the reference source current is converted to a-b-c frame of reference using the Eq.(7)-

$$\begin{bmatrix} I_{sa}^* \\ I_{sb}^* \\ I_{sc}^* \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{\alpha}^* \\ I_{\beta}^* \end{bmatrix} \dots (7)$$

Finally the comparison of these current and actual source current is done by the help of a hysteresis band controller and gate pulses for the shunt Active power filter are generated [12]

## V. SIMULATION RESULTS

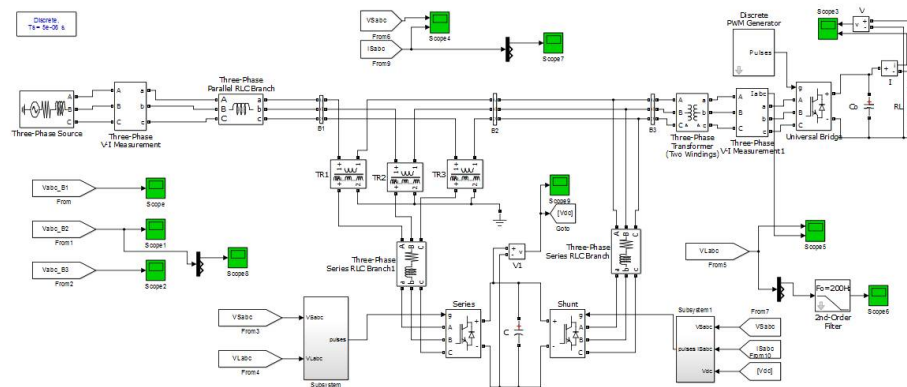


Figure 6 Simulink Model

In this work present proposed control technique based on d-q-0 algorithm for UPQC. A matlab/simulink based model has been simulated to verify the effectiveness of proposed technique [13]. The simulation result show that voltage sag and voltage swell can be compensated very effectively proposed control technique [14]. The UPQC analyzed based on d-q proposed control techniques which are given below.

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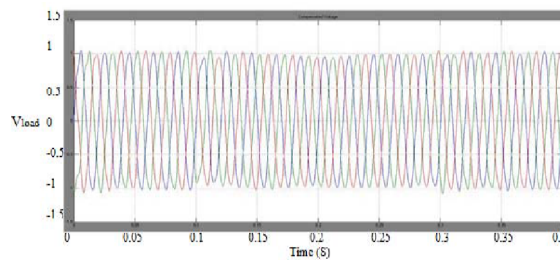
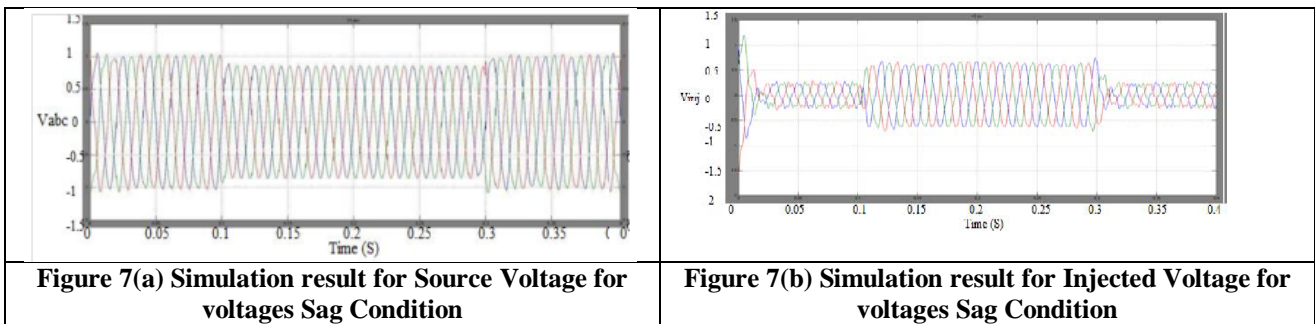
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A. 20% sag compensation:- The UPQC model 20% voltage sag created in 0.1s to 0.3s in three phase voltage as shown in fig(7)(a). When the three phase supply voltage sag is produce at 0.1s to 0.3s the series APF are activated and inject the lost sag voltage fig (7)(b). The load voltage side to maintain the magnitude constant during voltage sag condition as shown in fig (7)(c). The series injection voltage is during only sag condition than clear the supply voltage sag and the three phase voltage is balance [15]

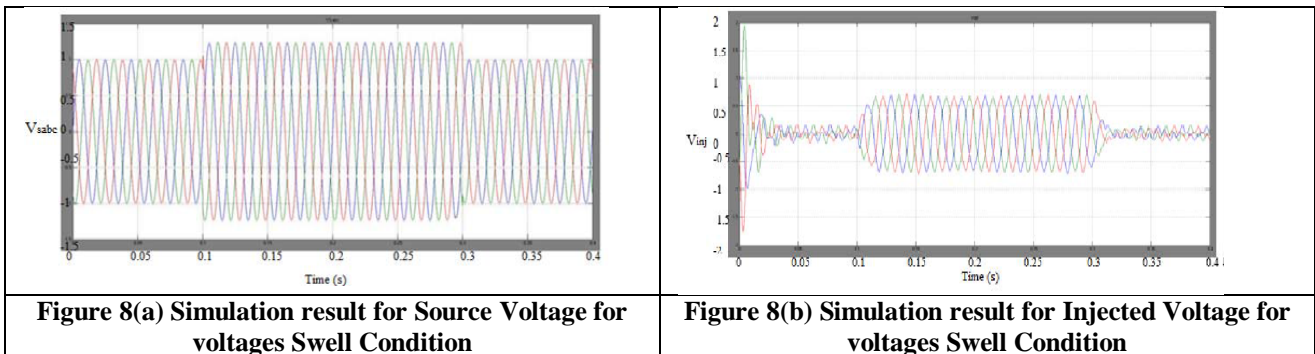
B.



**Figure 7(c) Simulation result for Load Voltage for voltages Sag Condition**

**B. 20% swell compensation:-**

In this simulation 20% voltage swell are created in three phase at 0.1s to 0.3s as shown in fig (8) (a). When voltage swell are produced in 0.1s to 0.3s the series APF is activated and inject the missing voltage as shown in fig (8)(b)[10]. The series APF operation and injection voltage is out of phase with supply voltage swell condition. After the swell will be cleared the load voltage waveform will be balanced fig (8)(c)





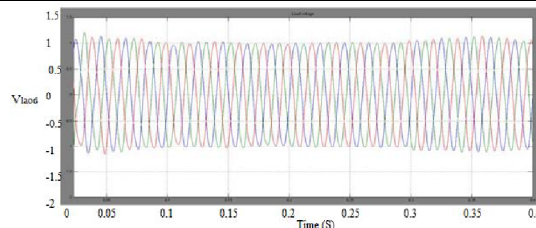


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**Figure 8(c) Simulation result for Load Voltage for voltages Swell Condition**

## VI. CONCLUSION

This paper describes a new control strategy used in the UPQC system, the proposed control strategy use only loads and mains voltage measurements for series APF based on the synchronous reference frame theory. The instantaneous reactive power theory is used for shunt APF control algorithm by measuring mains voltage and currents. The conventional methods require measurements of the load, source and filter voltages and currents. The simulation results show that the voltage sag, voltage swell, can be compensated very effectively using proposed control technique.

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