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Design and Implementation of UPQC to Solve Power Quality Problems

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***Abstract*— this paper deals with conceptual study of Unified Power Quality Conditioner (UPQC) during voltage sag and swell on the power network. Power quality has become an important factor in power systems, for household appliances with production of various electric and electronic equipment and computer systems. The main reasons of a poor power quality are harmonic currents, reduced power factor, supply voltage variations etc. The Unified Power Quality Conditioner (UPQC) is a custom power device, which diminishes voltage and current related power quality issues. It also prevents load current harmonics from entering the utility and corrects the input power factor of the load. The system performance for current and voltage harmonics, voltage sags and voltage swell have been evaluated. The results obtained by means of the MATLAB / SIMULINK based simulations support the functionality of the UPQC.**

***Index Terms*— UPQC, UPQC Topologies, Voltage Sag, Voltage Swell, Etc.**

I. INTRODUCTION

In today's complex electronics environment, many problems can occur because of poor quality of power. Therefore, it has become necessary to provide a dynamic solution with greater degree of accuracy as well as with fast speed of response. With great advancement in all areas of engineering, mainly, digital processing, control systems, and power electronics, the load characteristics have changed totally. In addition to this, loads are becoming very sensitive to voltage supplied to them. The power electronics based devices have been used to overcome the major power quality problems [1].

There are sets of conventional solutions to the power quality problems, which have existed for a long time. However these predictable solutions use passive elements and do not always respond correctly as the nature of the power system conditions change. The power electronic based power conditioning devices can be effectively utilized to improve the quality of power supplied to customers. One modern solution that deals with both load current and supply voltage imperfections is the Unified Power Quality Conditioner (UPQC) [2], which was first presented in 1995 by Hirofumi Akagi.
UPQC is a combination of series and shunt active filters connected in cascade via a common dc link capacitor. The series active filter introduces a voltage, which is added at the Point of Common Coupling (PCC) such that the load-end voltage remains unaffected by any voltage disturbance. The main objectives of shunt active filter are: to compensate the load reactive power demand and unbalance, to eliminate harmonics from the supply current, and to control the common dc link voltage. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller bridge can control active and reactive power flows in a transmission line [3].

In case of the UPQC, the DC link voltage requirement for the shunt and series active filters is not the same; the shunt active filter requires higher DC link voltage when compared to the series active filter for proper compensation. The shunt active filter 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. With the high value of DC link capacitor, the Voltage Source Inverters (VSI) becomes bulky and the switches used in the VSI also need to be rated for higher value of voltage and current. This increases the entire cost and size of the VSI [20].

In literature, a hybrid filter has been discussed for motor drive applications. This filter is connected in parallel with diode rectifier and tuned at 5th harmonic frequency. In simpler words, Power quality is a set of electrical boundaries that allow a piece of equipment to function in its intended manner without significant loss of performance. Although a sophisticated work, the design is specific to the motor drive application and the reactive power compensation is not considered, which is an important aspect in shunt active filter applications [4].

The paper is organized as follows. The structure of the UPQC is presented in Section II. In Section III, the configuration of UPQC is described in detail. The all simulation results are presented in Section IV. Simulation results in this section demonstrate the efficacy and versatility of proposed design technique. Finally, Section V gives the conclusion.

II. STRUCTURE OF UPQC

A. *Need of UPQC*

The increased use of automatic equipment, like adjustable speed drives, programmable logic controllers, switching power supplies etc. are far more vulnerable to disturbances than were the previous generation equipment and less automated production and information systems. Even still the power generation in most advanced country is properly reliable, the distribution is not always so [17]. It is though not only reliability that the consumers want these days, superiority too is very important for them. With deregulation of the electric power energy marketplace, the awareness regarding the quality of power is increasing day by day among

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customers. Power quality is a problem that is becoming increasingly important to electricity consumers at all levels of usage. New generation loads that use microprocessor and microcontroller based controls and power electronic devices, are more sensitive to power quality deviations than that equipment used in the past [5].

The main power quality problems are Voltage Sag, Voltage Swell, interruption and harmonic distortion. Voltage sag is a brief decrease in the rms line voltage of 10 to 90 percent of the nominal line-voltage. The duration of sag is 0.5 to 1 minute. Common sources that contribute to voltage sags are the starting of large induction motors and utility faults. A swell is a brief increase in the rms line-voltage of 10 to 80 percent of the nominal line-voltage for duration of 0.5 to 1 minute. The main sources of voltage swells are line faults and incorrect tap settings in tap changers in substations. An interruption is defined as a reduction in line-voltage or current to less than 10 percent of the nominal. Interruptions can occur due to power system faults, apparatus failures and control malfunctions [20]. When the supply voltage has been zero for a period of time in excess of 1 minute, the long-duration voltage variation is considered a sustained interruption. Voltage fluctuations are relatively small (less than 5 percent) variations in the rms line voltage. Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate, which is known as fundamental frequency (usually 50 Hz). The harmonic distortion originates in the nonlinear characteristics of devices and also on loads connected to the power system. Thus in this scenario in which customers increasingly demand power quality, term power quality attains increased significance [6].

B. *Basic Structure of UPQC*

The best protection for sensitive loads from sources with inadequate quality is shunt-series connection i.e. Unified Power Quality Conditioner (UPQC). Unified power quality conditioners are viable compensation devices that are used to ensure that delivered power meets all required standards and specifications at the point of installation. The UPQC is a custom power device that joins the series and shunt active filters, connected back-to-back on dc side and sharing a common DC capacitor, as shown in Fig 1. This dual functionality makes the UPQC as one of the most suitable devices that could solve the problems of both consumers as well as of utility. UPQC, thus can help to increase voltage profile and hence the overall health of power distribution system.

UPQC consists of two IGBT based Voltage Source Converters (VSC) that are connected to a common DC energy storage capacitor and an inductor and also consists of two filter banks. One of these two VSCs is connected in series with the feeder and the other is connected in parallel to the same feeder [18]. The series compensator is operated in PWM voltage controlled mode. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply. The series filter suppresses and isolates voltage based distortions, while the shunt filter cancels current-based distortions.

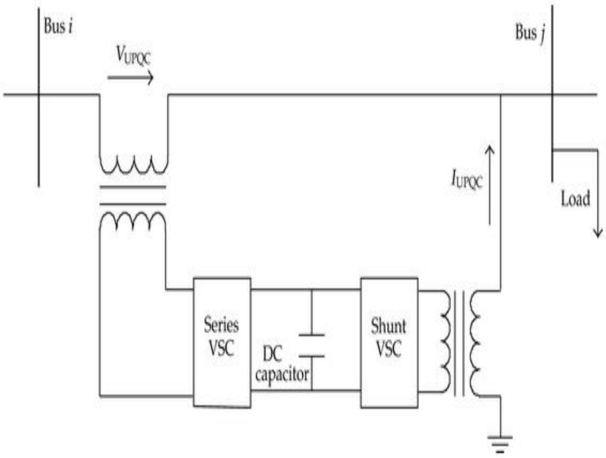


Fig. 1: General Structure of UPQC

The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance etc. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity sensitive loads to voltage flicker/imbalance. UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag. The voltage injected by UPQC to preserve the load end voltage at the desired value is taken from the same dc link, thus no additional link voltage support is required for the series compensator [7].

C. *Facilities Provided by UPQC*

- It eliminates the harmonics in the supply current, therefore improves utility current quality for nonlinear loads.
- UPQC provides the VAR requirement of load, so that the supply voltage and current are constantly 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/swell.
- The voltage inserted by UPQC to maintain the load end voltage at the desired value is taken from the dc link, thus no additional dc link voltage support is required for the series compensator [15].

III. CONFIGURATION OF UPQC

The Unified Power Quality Conditioner (UPQC) is a device that is employed in the distribution system to mitigate the disturbances that affect the performance of sensitive and/or critical load. It is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously. It is multi functioning device that compensate various voltage disturbances of the power supply, to accurate voltage fluctuations and to prevent harmonic load current from entering the power system [13].

UPQC consists of two IGBT based Voltage Source Converters (VSC), one in shunt and one in series. The shunt converter is connected in parallel to the load. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor [11].

It consists of a series voltage-source converter connected in series with the AC line and acts as a voltage source to diminish voltage distortions. It is used to remove supply voltage flickers or imbalance from the load terminal voltage and forces the shunt branch to absorb current harmonics generated by the nonlinear load. Control of series converter output voltage is usually performed by pulse-width modulation (PWM). The gate pulses required for converter are generated by fundamental input voltage reference signal [8].

It consists of a voltage-source converter connected in shunt with the same AC line and acts as a current source to cancel current distortions, compensate reactive current of load, and improve the power factor. The gate pulses required for converter are generated by fundamental input current reference signal. It also consists of two transformers. These are implemented to insert the compensation voltages and currents, and for purpose of electrical isolation of UPQC bridge converters. The UPQC is capable of steady-state and dynamic series and/or shunt active and reactive power compensations at fundamental and harmonic frequencies [9].

The shunt active filter is responsible for power factor correction and compensation of load current harmonics and unbalances. Also, it maintains constant average voltage across the DC storage capacitor. The series active filter compensation goals are achieved by injecting voltages in series with the supply voltages such that the load voltages are balanced and undistorted, and their magnitudes are maintained at the desired level. This voltage injection is provided by dc storage capacitor and the series VSI. The control scheme of the shunt active power filter must calculate the current reference waveform for each phase of the inverter, maintain dc voltage constant, and generate inverter gating signals [10].

A. System Parameters

The parameters of the VSI need to be designed carefully for better tracking performance. The important parameters that need to be taken into consideration while designing conventional VSI are V, C_{sh}, L_{sh} , L_{se}, C_{se} and frequency (f) and are listed in Table 1.

Table-1: System Parameters

System Quantities	**Values**
Source	3-Phase, 25kV, 50Hz
Inverter Parameters	IGBT based, 3-arm, 6-Pulse
Input RC Load	Active Power= 5MW Capacitive Power= 2MW
Output RL Load	Active Power= 1GW Inductive Power= 1kW
Power Factor	0.9
Transformer 1	Y /Δ 25kV/600V
Transformer 2	Δ/ Y 600/600V
Shunt VSI Parameters	Voltage= 600V, L_{sh}= 1mH C_{sh}= 1mF
Series VSI Parameters	Voltage= 600V, L_{se}= 1mH C_{se}= 1mF

IV. SIMULATION RESULTS

In order to verify the effectiveness of control system with realistic parameters, a MATLAB / SIMULINK based digital simulation of a system has been carried out as shown in Fig.5. The performance of UPQC has been analyzed under different conditions such as voltage sag and swell.

A. Proposed Simulation Model of UPQC

The SIMULINK model of test system is shown in Fig 3. The system contains two controllers, one is connected in series and other is connected in parallel. It also contains transformers and filter banks for desirable output. The system is tested under different load conditions. A variable load is used to provide constant current output.

The series controller shown in Fig 2 is designed to inject a dynamically controlled voltage in magnitude and phase into the distribution line via a coupling transformer to correct load voltage. This is known as Dynamic Voltage Regulator (DVR) which is popularly used as a series connected custom power device [16].

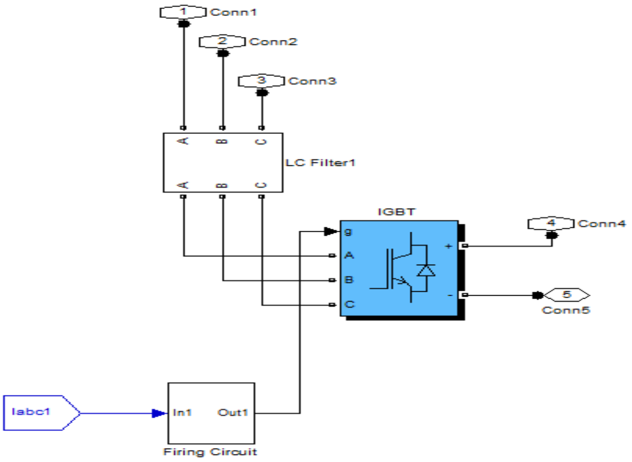


Fig. 2: Series Controller

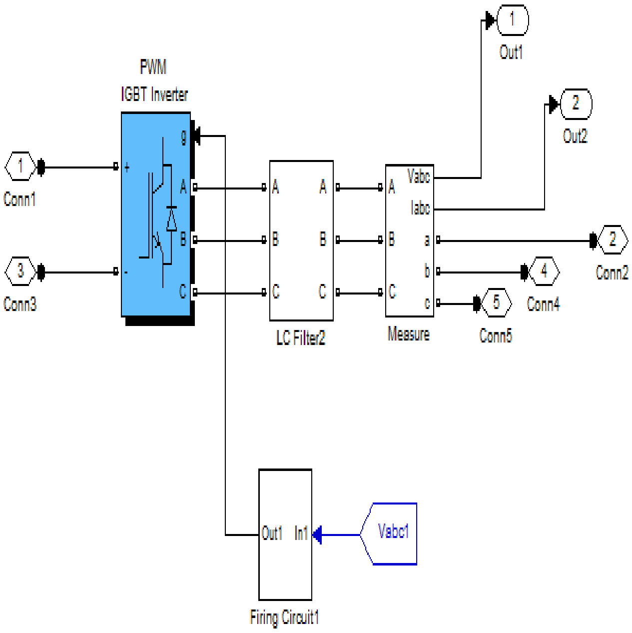


Fig. 3: Shunt Controller

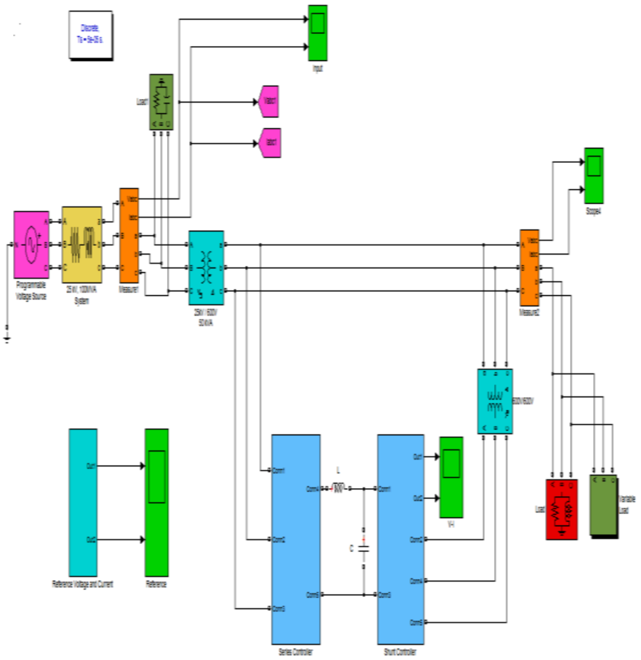


Fig. 4: Proposed Simulation Model of UPQC

The purpose of the Shunt Controller is to compensate current unbalance, current harmonics and load reactive power demand fed to the supply [19]. The coupling of shunt controller is three phase, in parallel to network and load as shown in Fig 4. It works as current sources, connected in parallel with the nonlinear load, generating harmonic currents the load requires. This is same as the popularly known shunt connected custom power device, D-STATCOM. UPQC is a combination of DVR and D-STATCOM.

B. Simulation Output of UPQC

In order to show the impact of sag and swell variation, a MATLAB/SIMULINK based simulation is carried out.

Fig. 5: Reference Voltage and Current

Fig. 5 shows the three phase reference voltage and current waveforms when UPQC is not connected in system. These are constant in phase as well as in amplitude. Fig 6 shows the control firing pulses for bridge converters. Each bridge contains six IGBTs and each IGBT requires a firing pulse at its gate terminal. These input pulses are required to ON the bridges.

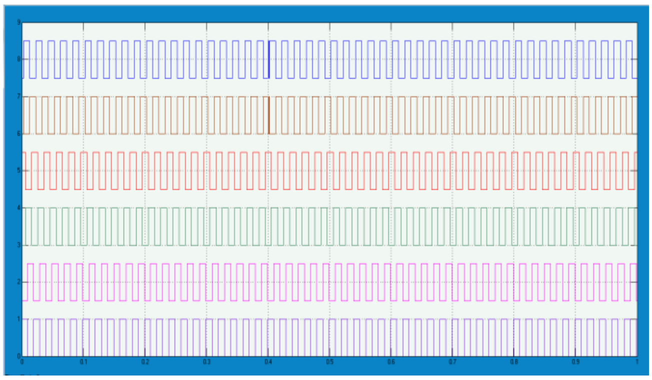


Fig. 6: Control Firing Pulses for UPQC Bridges

C. Effect of Voltage Swell

A voltage swell of 50% is now introduced in the system for a time span ranging from t=0.2 sec to t=0.4 sec, as shown in the Fig. 7. Under this condition the series filter injects an out of phase compensating voltage in the line through series transformers. The currents are unbalanced and distorted; the terminal voltages are also unbalanced and distorted.

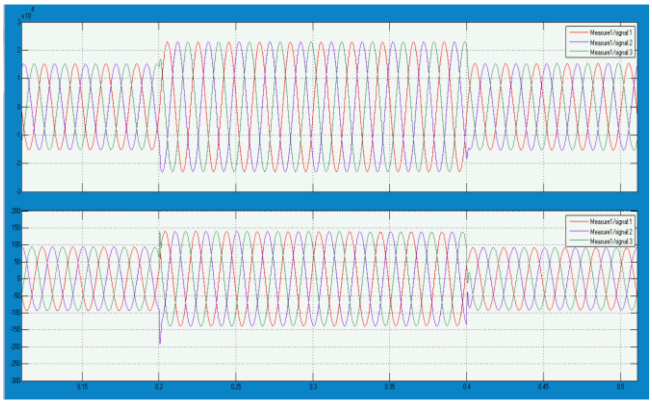


Fig. 7: Input Voltage and Current at Swell of 50%

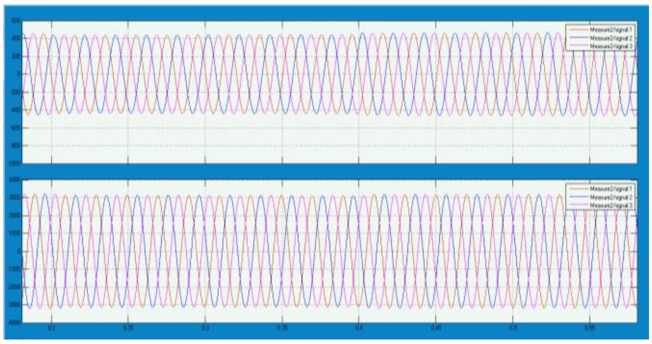


Fig. 8: Constant Output Voltage and Current with UPQC when Voltage Swell of 50% has occurred

The load output profile in Fig. 8 shows the UPQC is effectively maintaining the load bus voltage at desired constant level even during the swell on the system such that the loads are not affected by any voltage variation. In other words, the extra power due to the voltage swell condition is fed back to the source by taking reduced fundamental source current. The proposed UPQC maintained the load voltage free from swelling and at the desired level.

The above system model has been analyzed by varying the voltage swell from 10% to 80% for a time span of 0.2 seconds ranging from t=0.2 sec to t=0.4 sec. The input waveforms are highly unbalanced. The load output voltage and current shows that the UPQC effectively maintains the load bus output at desired constant level. It is seen that that voltage and current levels are maintained at desirable levels and the distortion is considerably reduced below 2%.

D. *Effect of Voltage Sag*

A voltage sag of 50% is now introduced on the same model of the system for a time span ranging from t=0.2 sec to t=0.4 sec as shown in Fig. 9. During this voltage sag condition, the series APF is providing required voltage by injecting in phase compensating voltage (50%). The load output waveforms shown in Fig. 10 shows that UPQC is maintaining it at desired constant voltage level at load even during the sag on the system such that the loads cannot see any voltage variation.

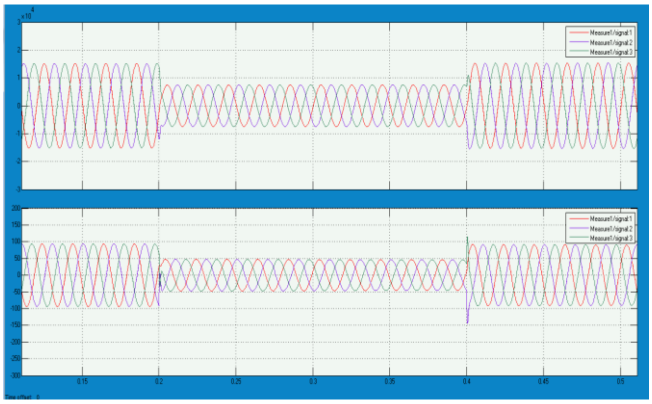


Fig. 9: Input Voltage and Current at Sag of 50%

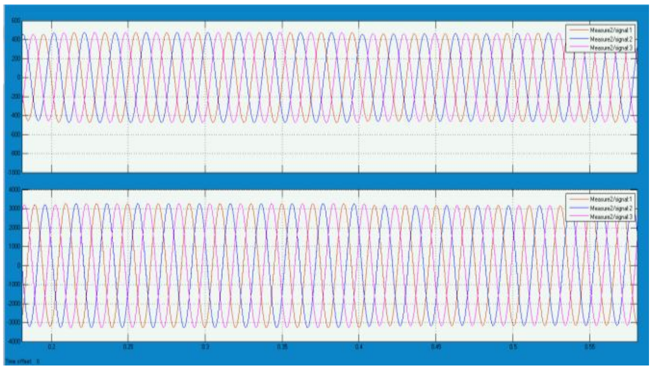


Fig. 10: Constant Output Voltage and Current with UPQC when Voltage Sag of 50% Occurred

This system is again analyzed by varying the voltage sag from 10% to 80% for a time span of 0.2 sec ranging from t=0.2 sec to t=0.4 sec. Before and after this time, the system is again at normal working condition. The load output profile in all these conditions show that it produces a constant output voltage and current when UPQC is connected to a system.

This system is again analyzed by varying the voltage sag from 10% to 80% for a time span of 0.2 sec ranging from t=0.2 sec to t=0.4 sec. Before and after this time, the system is again at normal working condition. The load output profile in all these conditions show that it produces a constant output voltage and current when UPQC is connected to a system.

E. *Effect of Voltage Sag and Swell on Voltage and Current with Increased Duration*

A voltage swell and sag of 50% is now introduced in the system for a time span ranging from t=0.5 sec to t=2 sec, as shown in the Fig. 11 and Fig. 12 respectively. Under this condition, the currents are unbalanced and distorted; the terminal voltages are also unbalanced and distorted. The load output waveforms shown in Fig. 13 shows that UPQC is maintaining it at desired constant voltage level at load even during the sag or swell for longer duration on the system.

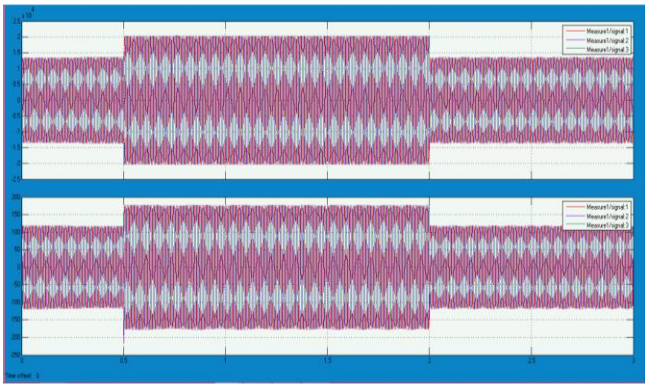


Fig. 11: Input Voltage and Current at Swell of 50%

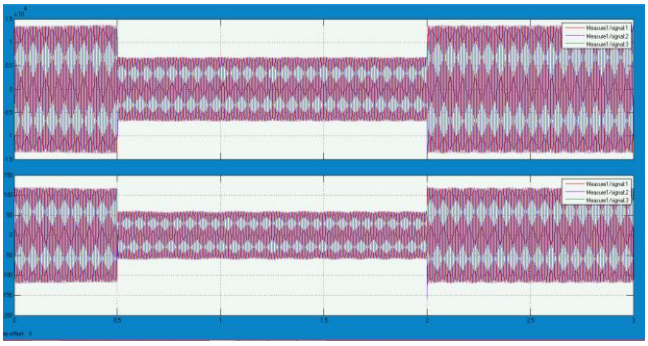


Fig. 12: Input Voltage and Current at Sag of 50%

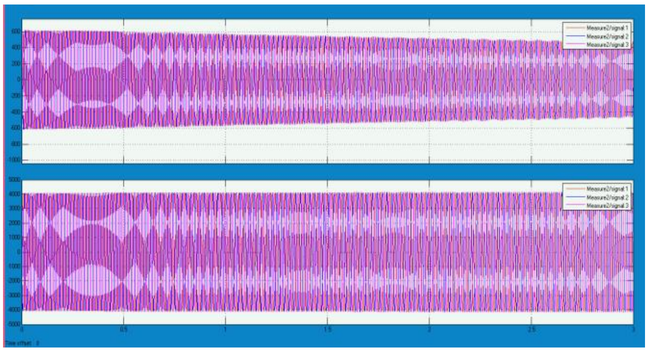


Fig. 13: Constant Output Voltage and Current with UPQC when Voltage Sag or Swell of 50% Occurred

F. *Effect of Harmonics*

The harmonics have the property that they are all periodic at the fundamental frequency; therefore the sum of harmonics is also periodic at that frequency. Harmonic frequencies are correspondingly spaced by the width of the fundamental frequency and can be found by repeatedly adding that frequency. Harmonics are the multiple of the fundamental frequency. They occur frequently when there are large numbers of personal computers (single phase loads), uninterruptible power supplies (UPSs), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC. Non-linear loads generate harmonics by drawing current in abrupt short pulses as shown in fig 14 and its output is shown in fig 15.

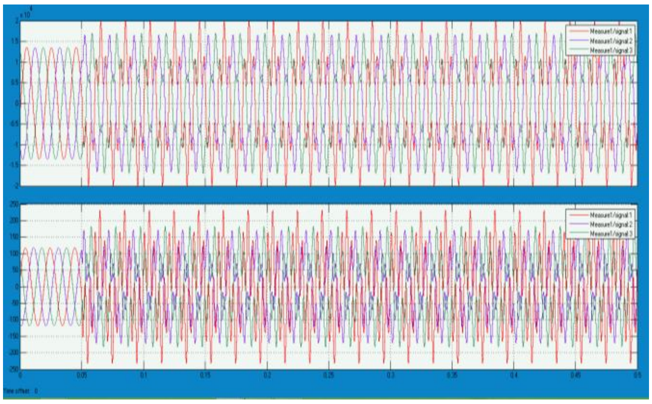


Fig. 14: Input Voltage and Current with 5th order harmonics

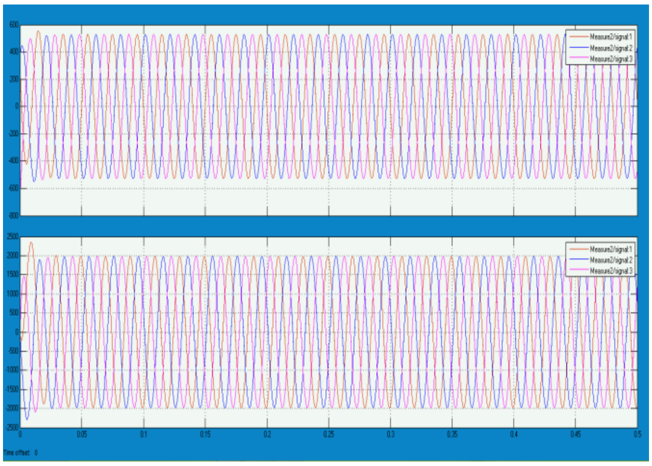


Fig. 15: Constant Output Voltage and Current with 5th Order Harmonics Input

G. *Effect of Interruption*

A voltage interruption is a large decrease in RMS voltage to less than a small percentile of the nominal voltage, or a complete loss of voltage. Voltage disruptions may come from accidents like faults and component malfunctions, or from planned downtime. Short voltage interruptions are typically the result of a malfunction of a switching device or a deliberate or inadvertent operation of a fuse, circuit breaker, or reclose in response to faults and disturbances. Long interruptions are usually resulting of scheduled downtime, where part of electrical power system is disconnected in order to perform maintenance or repairs. When a three phase fault is introduced in the system having duration 0.16 to 0.84 sec, it generates an interruption in the input signal as shown in fig 16. When UPQC is connected within the system, it resolves this power quality problem and provide us constant output signal as shown in fig 17. The analysis of input and output signals can be done by FFT Analysis tool provided in Simulink block. The analysis of input waveform having harmonics is given by fig 18. The upper part shows the input voltage signal having 5th order harmonics and lower part shows its fundamental frequency components present in the signal and also provides total harmonic distortion (THD). Similarly, the fig 19 shows the output waveforms of input harmonic signal and their FFT analysis. The THD in fig 20 shows that this output signal is distortion free.

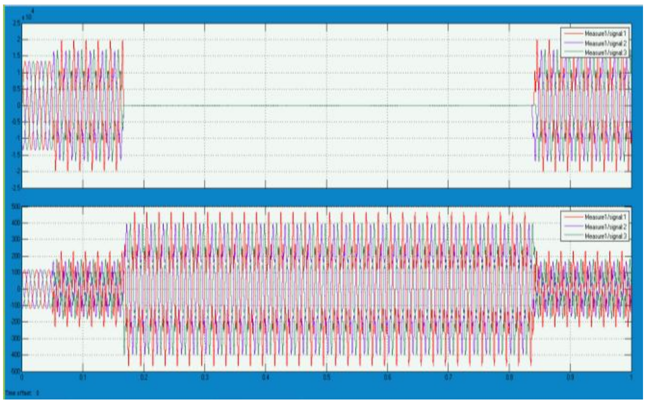


Fig. 16: Input Voltage and Current Waveforms having Harmonics and Interruption

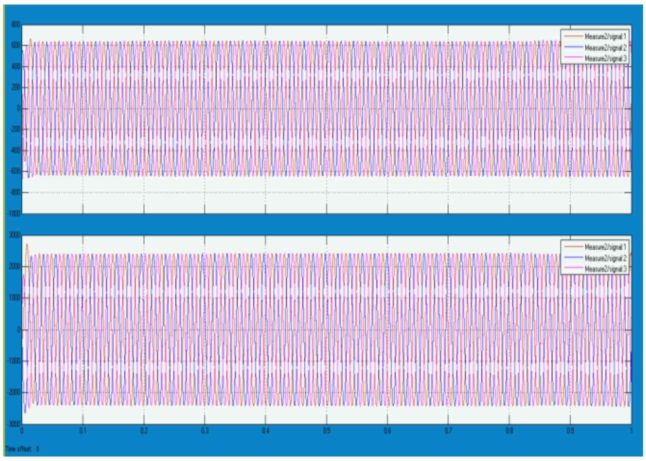
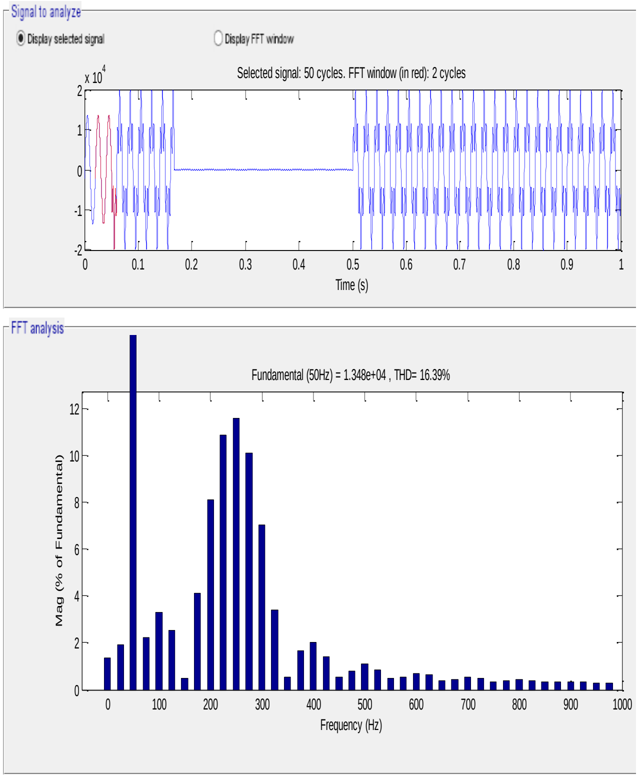


Fig. 17: Output Voltage and Current Waveforms with UPQC having No Harmonics and Interruption



Selected signal: 50 cycles. FFT window (in red): 2 cycles

Fundamental (50Hz) = 1.348e+04 , THD= 16.39%

Fig. 18: Input THD having Harmonics and Interruption

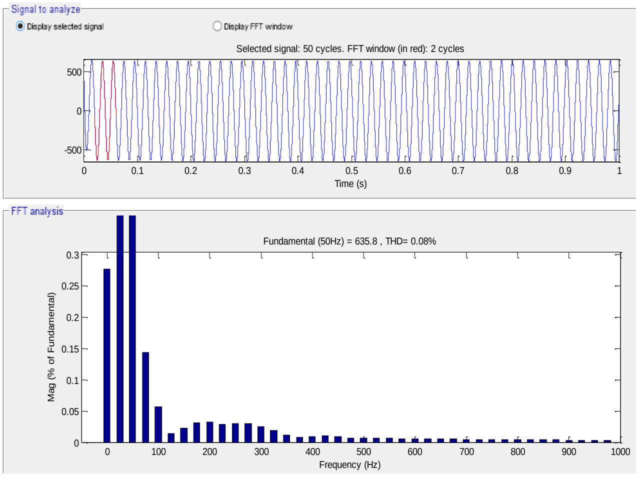


Fig. 19: Output THD having No Harmonics and Interruption

V. CONCLUSIONS

In this paper, the simulation results shows that UPQC can be employed to reduce the distortion level and highly improve the power quality of the system. Due to its reliability, it was adopted as the optimal solution for the compensation of voltage and current. This paper investigated the application of UPQC for power quality improvement and implementation of a flexible control strategy to enhance the performance of UPQC. In order to protect critical loads from more voltage harmonics, UPQC is suitable and satisfactory. The objectives have been successfully realized through software implementation in MATLAB/SIMULINK.

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