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Design of a Unified Power Quality Conditioner (UPQC)

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Abstract- Sagging and swelling of line voltage and harmonic currents are two major problems of power quality. The communication, microcontroller and microprocessor based industry is much more affected by power quality (PQ) problems as their requirement for working and stability is compromised without high quality of power. By mitigation of voltage and current such problems of power quality can be reduced. For optimization and control of power quality in electrical power distribution system, The Unified Power Quality Conditioner (UPQC) is the most complex and versatile power electronic equipment to enhance the power quality of system. This paper presents improvement of power quality through a UPQC placed at load side. The proposed UPQC is integration of shunt and series converters. The series converter can compensate voltage fluctuation in the ac source due fault. Also, it can be used to regulate voltage sag and the under voltage situations. On the other hand, the shunt converter can compensate the current harmonic and improve the power factor. UPQC was simulated and demonstrated at 220V distribution level. Amount of active and reactive power of system can be controlled by installing the UPQC.

Keywords- *Power quality (PQ), Unified Power Quality Conditioner (UPQC), Inverter, Power Flow Controller (PFC), Series and Shunt Converter*

I. INTRODUCTION

Electricity is the most famous form of energy which becomes compromised due to power quality problems. In this era of industrialization, the power quality is important for any power distribution company. Basically the characteristic of voltage (like frequency, waveform, amplitude etc.) are in power quality concerns. On the bases of modern digital devices like microcontroller, microprocessor based equipment have great concern about Power Quality issues. Poor power quality is major problem for both customers as well as power suppliers.

Due to power electronics devices there is serious effect on quality and continuousness of electric supply. Because of power electronics devices there is uninterrupted power supply, flicker, harmonics, voltage fluctuations etc. There is also PQ problems such as voltage rise/dip due to network faults, lightning, switching of capacitor banks. UPQC is an integration of shunt and series converter for limiting PQ problems. Simulation results on MATLAB can be illustrated to find the response of UPQC on different loads. UPQC is used to solve all problems in order to improve power quality. Many modern devices can improve the power quality but in this the focus is on UPQC.

Modern industrial power electronic based equipment offer small size, great efficiency and more controllability but behavior of such devices is nonlinear due to high switching and operational speed. This creates power quality like voltage fluctuations, harmonics, interruption and impulse transient. As these devices are more sensitive to power quality issues, so it results in financial loss (Yash Pal et al., 2008). For modern automated equipment and industry high electrical power quality has become top priority. Now a day's filters and capacitors are used to increase the reactive power and remove harmonics. Pulse width modulators converters are used to control motors but still there is scope and need of improvement. That's the main reason which opened the area of research on series and shunt compensator (Jou H.-L et al., 2008). Shunt compensator have unmatchable ability to remove harmonics from distribution network whereas series compensator utilized to mitigation of voltage. Available equipment provides programmable filtering strategy for removing harmonics and removes up to 20th harmonics. Latest invented FACTS devices provide efficient solution for PQ problems like Static Compensator (STATCOM) used to improve reactive power in distribution system. Shunt compensator improve harmonics caused by load currents and inject equal in magnitude but in opposite harmonic compensating current having phase shift of 180 degree (J. G. Nielsen et al., 2004) (Amit Jain et al., 2006).

Similarly for voltage compensation normally we use FACT device Dynamic Voltage Restore (DVR). DVR inject voltage equal in magnitude and phase angle in order to effectively mitigate voltage sag/swell. Dynamic compensating voltage/current is determined by measuring difference between reference value and required value of voltage/current to run the device safely (J. G. Nielsen et al., 2008).

The present method of compensating current harmonics and voltage fluctuations either sag or swell PQ issues is very costly & complex. The solution technique determines the response of DVR and STATCOM on the power distribution system (Benachaiba C et al., 2008). Until now three phases FACT devices (series and shunt combination) are not so common and rarely used. One of the devices introduced in resent past decade is Unified Power conditioner (UPQC) to improve the power quality of the electric power system and installed in series with the sensitive load. UPQC is combination of Series & Shunt Converters (Inverter) developed in last decade; UPQC can handle power quality problems of voltage & current (Yashomani Y et al., 2007).

Due to newly introduced modern electronic devices installation and their massive use generate faults in the power system PQ of system is low due to current harmonics and voltage fluctuations. The communication, microcontroller and microprocessor based industry is much more affected by PQ problems as their requirement for working and stability is compromised without high quality of power. So by using the series and shunt convertors we improve the PQ problems, for compensation of PQ problems like current harmonics caused by Non Linear load we use Shunt on the other side for the PQ problems voltage sag/swell, series convertor is used to mitigate voltage. UPQC deals with all problems related to voltage and current harmonics and improve power quality.

Modern Electronic devices work properly until the voltage (current) of power system remains within a system tolerance range. In-building equipment is major cause of Voltage sags. Domestic consumers usually face voltage dips/sags when they start air conditioner, Water pumps motors and refrigerator. These Voltage Sags affects the Power Quality and often results in financial Loss.

II. UNIFIED POWER QUALITY CONDITIONER (UPQC)

Unified Power Quality Conditioner is a power electronic circuit which is an integration of shunt and series invertors and because of that it can handle any fluctuation when connected to the load. Today all switched mode power supplies are protected by UPQC as it can smartly handle the power quality issues.

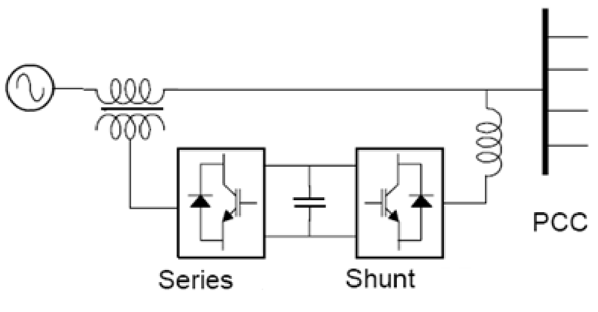

Figure 1. Block Representation of UPQC

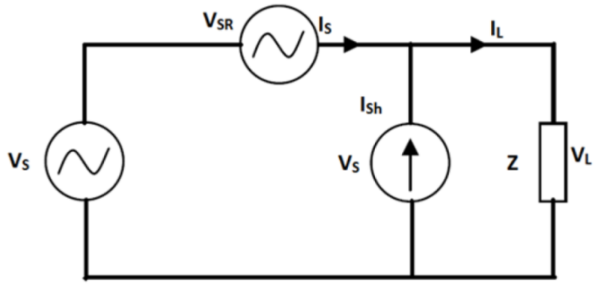

Figure 2. Equivalent Circuit of UPQC

In above given Figure

V_S represent the voltage at power supply

V_{SR} is the series-voltage for voltage compensation

V_L represents the load voltage and

I_{Sh} is the shunt-current for current and V_{SR} compensation

Presence of harmonic components and negative phase sequence are because of the voltage distortion in the supply voltage.

In general, the source voltage in Figure (5) can be expressed as:

$$V_S + V_{SR} = V_L \quad (1)$$

For balanced sinusoidal voltage and fixed amplitude, output of the series compensator is given by the following equation:

$$V_{SR} = (\mathrm{V} - V_{1P}) \sin(\omega t + \theta_{1p}) - V_{Ln}(\mathrm{t}) - \sum_{K=2}^{\infty} V_K(\mathrm{t}) \quad (2)$$

where,

V_{1P}: positive sequence voltage amplitude fundamental frequency

θ_{1P}: initial phase of voltage for positive sequence

V_{1P}: negative sequence component

Because of the presence of inductor at the output of the shunt compensator, shunt inverter acts as the current source which provides desired current to the grid which makes the input voltage sinusoidal. Output current of the shunt compensator is obtained by using the information of load current and fabricated sinusoidal signal obtained from the supply voltage.

$$i_L = I_{1P} \cos(\omega t + \theta_{1p}) sin\varphi_{1P} + i_{Ln}(\mathrm{t}) - \sum_{K=2}^{\infty} i_{LK} \quad (3)$$

$$\emptyset_{1P} = \varphi_{1P} + \theta_{1P} \quad (4)$$

Where,

$\varphi_{1P:}$ Initial phase of current for positive sequence

This equation shows that the negative phase sequence, reactive power and harmonics components are not present in the equation. Thus there are no harmonics present in the supply voltage and their phase angle is in phase with the applied voltage. Hence in this way power factor is improved

$$i_S = i_L + i_{Sh} = I_{1P} \sin(\omega t - \theta_{1p}) cos\varphi_{1P} \quad (5)$$

Unified Power Quality Conditioner is made of shunt & series converter as described. The Series converter is used to overcome voltage fluctuations i-e Sag, Swell or flickers. It compensates the voltage to the desired magnitude taking distribution voltage as reference voltage. Series converter supplies a smooth voltage to the load and improves power quality of the systems. Dc source voltage is the capacitor and at the output of the inverter inductor connects the grid with the inverter.

Shunt converter deals with Power Quality problems related to current generated by power customers having low Power Factor , unbalanced load, harmonic currents etc. it insert current equal in magnitude with the harmonic currents but out of phase (180 Degree) with the harmonic current but remains in phase with grid voltage. Shunt converter injects current on the main line, when large scale current is drawn by the Nonlinear Load. During the fault shunt inverter draws current from the Capacitor bank which is charged during the normal conditions. Inductor acts as first order filter. It improves the power quality and removes harmonics introduced by the nonlinear load.

Transformer implemented to inject the compensation voltages and currents, and for the purpose of electrical isolation of UPQC converters. The UPQC is capable of steady-state and dynamic series and/or shunt active and reactive power compensations at fundamental and harmonic frequencies. However, the UPQC main function is to protect sensitive devices which demand high power quality for operation. Transformers are used in series and shunt configuration to provide isolation to the system. They also provide gain to the duty cycle due to which it is possible to get great voltage from small voltage or small voltage from great voltage. However, UQPC is responsible for improving power quality and removing harmonics form the supply voltage and from the load side. Transformers lower the efficiency of the system however; UPQC is not concerned about this efficiency.

III. SIMULATION DESIGNS

In this research the role of unified power quality conditioner for power quality is simulated on MATLAB/SIMULINK by taking Non-Linear load of 22% THD (Total Harmonic Distortion) and also stimulated by using Induction motor having loads for simulation. Whereas in hardware single phase 1KW UPQC is fabricated & tested in order to improve the power quality of the system.

The model of UPQC in Simulink is shown in below figure. In which we have a programmable grid source to 3-Phase transmission line having V_{ph}-V_{ph} 400V, Nonlinear Load of 22.24% THD, Injection Transformer, UPQC control, Active Power Filters. RC Filter circuit for harmonics and Oscilloscopes for monitoring 3-Phase Voltage and Current during the simulation. The fault of 5 Cycle is generated which results in Voltage Sag as shown in the below figure (6). When the fault arise UPQC control measure the voltage and current and duration and compensate by using Active Power Filter and inject the voltage on the main line so that voltage sag is magnitude. Following parameters and conditions are used during the simulations in MATLAB for testing UPQC in Simulink.

TABLE I. TEST SYSTEM PARAMETER FOR MATLAB

System Quantities	Standards
Source Voltage in Distribution Line	3-phase, 400 v, 50 Hz
Non-Linear RL load	R=500 Ohm L=15*10^{-3} H
DC Voltage	700 V
Voltage Source Converter	IGBT Based, 3-arm, 6-pulse, Carrier Frequency=2LHz
Injection Transformer	3-phase, 400V, 50Hz

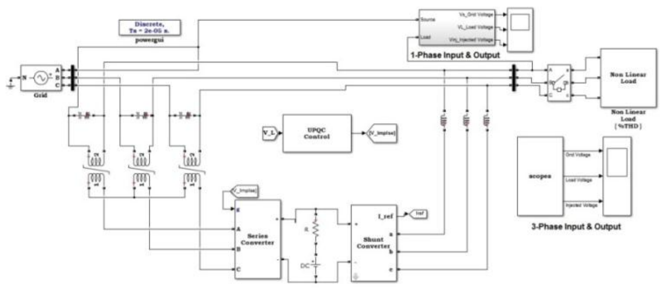

Figure 3. MATLAB/Simulink model of UPQC for 3-Phase Non Linear Load

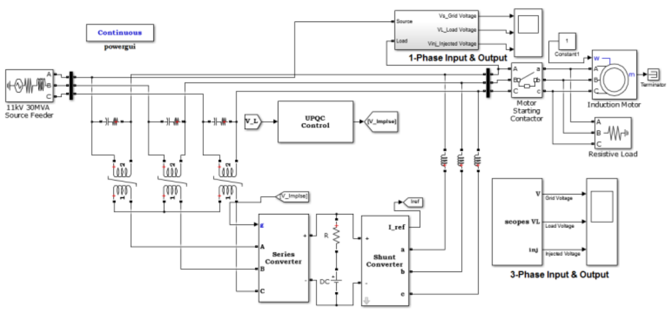

Figure 4. MATLAB/Simulink model of UPQC for 3-Phase Induction Motor Load

Following are simulations results of the proposed model of UPQC custom power compensation device by using PWM techniques in MATLAB software. The simulation is carried out and result is analyzed for voltage sag period and rating of the Non Linear load.

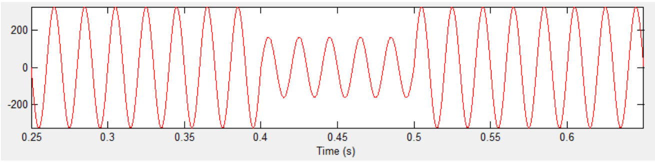

Figure 5. Voltage Sag Period 0.4 to 0.5 sec for Non Linear load

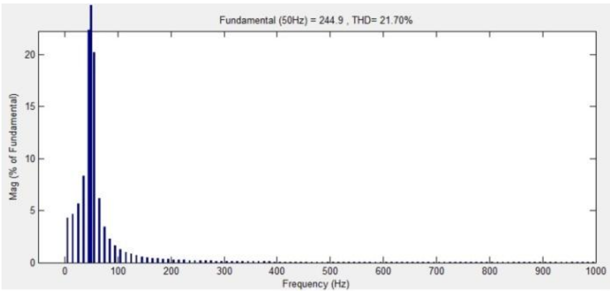

Figure 6. FFT analysis for Total Harmonic Distortion THD of Non Linear Load

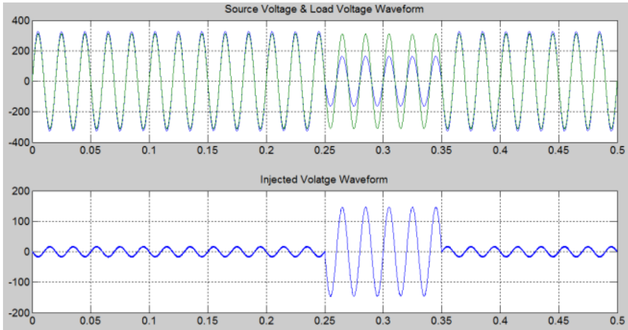

Figure 7. Voltage mitigation by UPQC for Non Linear Load

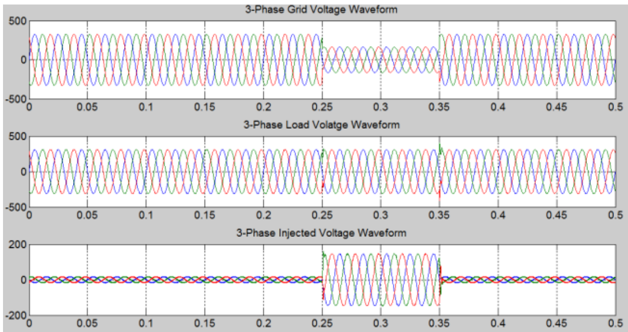

Figure 8. Voltage mitigation by UPQC for Non Linear Load

TABLE II. VOLTAGE AND SAG LOAD COMPARISON -INDUCTION MOTOR LOAD

Sr. No	Load (HP)	Load (KW)	Voltage Sag Starting Time	Voltage Sag End Time	Voltage Sag Duration (ms)	Frequency	No of Cycles	Reference Voltage	Instanteneous Voltage	% Voltage Sag	% Voltage Drop
1	5.4	4	0.1	0.165	0.065	50	3.25	230	190	82.6	17.4
2	10	7.5	0.1	0.185	0.085	50	4.25	230	183	79.6	20.4
3	20	15	0.1	0.215	0.115	50	5.75	230	130	56.5	43.5
4	50	37.5	0.1	0.37	0.27	50	13.5	230	75	32.6	67.4
5	100	75	0.1	0.52	0.42	50	21	230	45	19.6	80.4
6	150	113	0.1	0.65	0.55	50	27.5	230	30	13.0	87.0

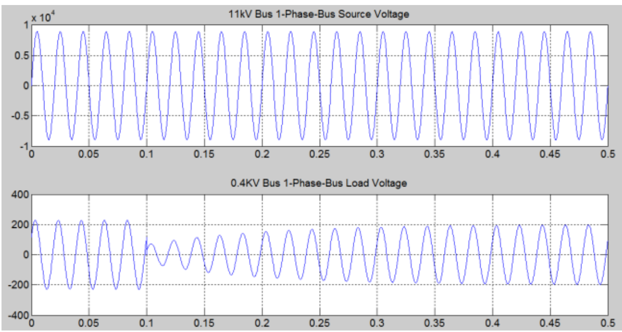

Figure 9. 1-Phase Load & Source Voltage with Motor Load

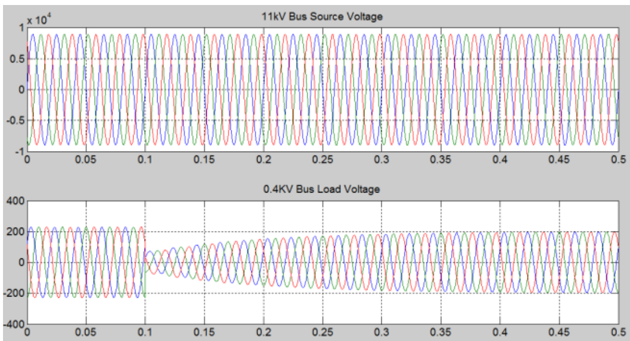

Figure 10. 3-Phase Load & Source Voltage with Motor Load

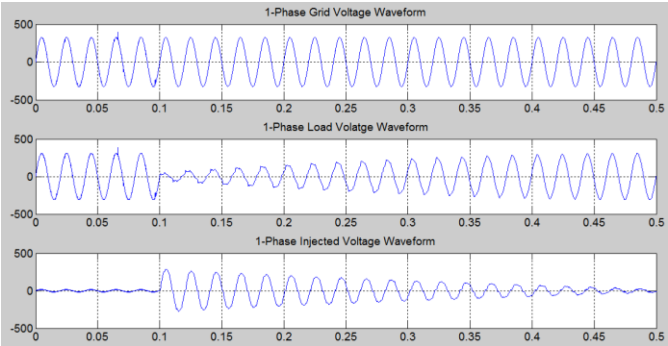

Figure 11. 1-Phase Voltage mitigation by UPQC for Motor Load

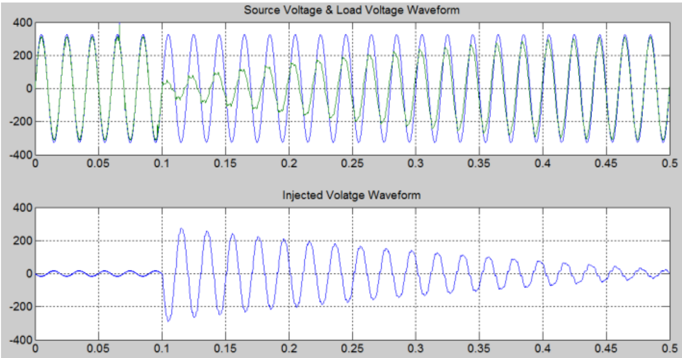

Figure 12. Voltage mitigation by UPQC for Motor Load

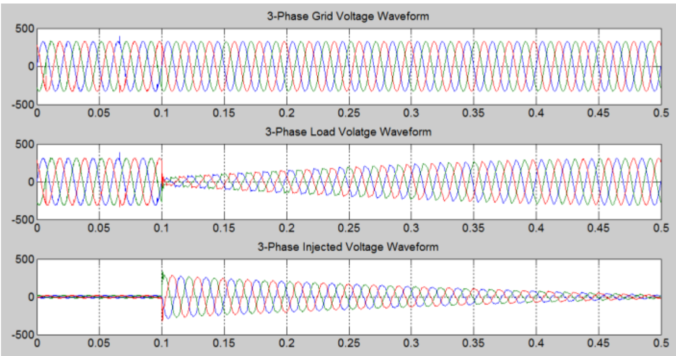

Figure 13. 3-Phase Voltage mitigation by UPQC for Motor Load

IV. HARWARE IMPLEMEMENTATION

To achieve fundamental objectives of any project/device are properly selection of components is necessary part of it, lot of research and time required for selection of suitable things which fulfill project objectives too. All objectives center on the economic objectives, which` mean maximization of profits.

Shunt converter during compensation of load current system required stored energy so DC Capacitor bank is used for instantaneous supply of current during distortion. Capacitors bank current storage can be estimated by change in current with respect to duration. Thus the bank is installed according to maximum current requirement during fault time. The voltage ripple generated by nonlinear behaviour of load can be controlled by increasing the capacitor bank size.

Figure 14. Capacitor Bank

So the capacitor bank work as backup of power source to improve the PF as it is providing the real power equal to difference between source power and load power. In this way it compensates Power Factor.

For compensation of voltage sag caused by the fault we need the power which is drawn from capacitor bank and used to mitigate voltage sag. So the inverter is used to produce 12V AC from 12V DC of Capacitor bank. The output voltage (AC) wave form of our inverter module is sine wave and it is suitable for UPQC voltage injection to compensate Voltage sag.

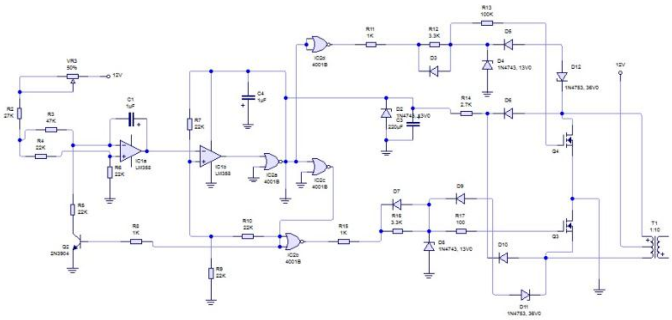

Figure 15. Inverter Circuit

For Mitigation of voltage sag in UPQC series injection transformer is used. Such transformer gives isolation between inverter circuit and main line from DC noise and used for impedance matching between main line and Series converter. Reliability and effectiveness of the system depends on this transformer. In this UPQC project used single-Phase 1KVA transformer for voltage injection for 1KW (1.34 HP) load.

Figure 16. UPQC Working inline with Sensitive Load

Figure 17. UPQC working at 50% Voltage Sag

V. CONCULUTION

The main theme of his research was to design a device for consumers in order to increase the power quality, Mitigation of voltage sag and controlling the current harmonics by using capacitor bank. In order to control voltage and current harmonics UPQC can be installed which can mitigate the voltage sag by Series converter and for current harmonics used Shunt converter. It is a reliable and optimal solution for compensation of current and voltage due to its satisfactory performance and improving the power quality of the systems.

For simulations and studies MATLAB/Simulink gave the user friendly environment for research, development and testing new methodologies. Therefore, UPQC is considered to be an efficient available solution for protection of sensitive equipment like PLC's, Microcontroller and microprocessor based digital devices.

This research work can be utilized for other following related areas like UPQC can be modeled for other load types like Turbine load etc. UPQC can be integrated with renewable power generation model to increase the stability of power flow like Wind & Solar due to uncertainty in their power generation production. UPQC can be controlled by latest control techniques and methods like Fuzzy controller and artificial neural networks to increase the system efficiency and reliability.

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