International Journal of Scientific Engineering and Technology Research
www.ijsetr.com
ISSN 2319-8885
Vol.05,Issue.09,
April-2016,
Pages:1800-1807

Unified Power Quality Compensation Scheme for Power Quality Improvement Using Fuzzy Controller with Renewable Energy System

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Abstract: Power quality issue is a biggest problem in today's life. The power consuming is increased day by day. The reduction in amount of fossil fuel and cost of electricity are increased. Which are responsible for us to move towards the renewable sources Consumer always prefers good quality of power. The quality of power can be measured by voltage sag, harmonics and power factor. Shunt compensator's operation is controlled by extracting d axis and q axis current from load current and DC link voltage is maintained through a fuzzy logic controller. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Thus, the combination of weak grids, wind power fluctuation and system load changes produce disturbances in the PCC voltage, worsening the Power Quality stability. In this paper, a fuzzy logic controller with reference signal generation method is designed for UPQC. This is used to compensate current and voltage quality problems of sensitive loads. The results are analyzed and presented using Matlab/Simulink software.

Keywords: Power Quality, Unified Power Quality Conditioner (UPQC), Phase Locked Loop (PLL), Fuzzy Logic Controller.

I. INTRODUCTION

Power Quality (PQ) mainly deals with issues like maintaining a fixed voltage at the Point of Common Coupling (PCC) for various distribution voltage levels irrespective of voltage fluctuations, maintaining near unity power factor power drawn from the supply, blocking of voltage and current unbalance from passing upwards from various distribution levels, reduction of voltage harmonics and current harmonics in the system and suppression of excessive supply neutral current. The power semiconductor devices, generally known as active power filters (APF's), Active Power Line Conditioners (APLC's) etc. are the equipment used to prevent the power quality issues due to their dynamic and adjustable solutions in recent days [1]. Flexible AC Transmission Systems (FACTS) and Custom Power devices like DVR (Dynamic Voltage Restorer), STATCOM (Static synchronous Compensator), and etc. Eliminate the effects of power quality using similar control strategies and concepts. These devices are placed in the different location in a power system where they are deployed and the objectives for which they are deployed. This paper is intended to provide a comprehensive review on the topic of UPQC to get proper idea about different intelligent controller used with UPQC. This paper also discusses the most important concepts which are used to control the UPQC. Many efforts have been taken by utilities to fulfil end user requirement, some Expected level of performance. This implies that the basic requirements, the responsibilities of the different parties, and the methods of characterizing the power quality measures must be taken so that higher levels of Power Quality can be obtained.

Active power filters (APF) have been proposed as efficient tools for power quality improvement. Active power filters can be categorised as shunt and series based to their system configuration. The series APF generally takes care of the voltage based distortions, while shunt APF mitigates current based distortions. The combination of series and shunt active power filter is called the unified power-quality compensator (UPQC). It is a versatile device that can compensate almost all the problems related power quality such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags & swells, current harmonics, current unbalance, reactive current, etc. Recently more researches are going on reduction of sags and swells by using UPQC. The swells are not as common as sags, but the effects of a swell can be very effective than the voltage reduction. The common cause of voltage sag and swell is sudden change of line current flowing through the impedance of the source. The main objective is to maintain the load bus voltage to be sinusoidal and the major concern is the active power and reactive power during the fault conditions. UPQC is commonly connected with back to back to voltage source converters through a DC link capacitor. Twin bridge configuration of inverter is used in series and shunt active power filter for eliminating harmonics. The interfacing inverter is used to compensate load reactive power, current unbalance, and harmonic distortion to active power injection from renewable energy sources. It is useful to the grid to operate power factor at unity. In this fuzzy controller is used to reduction of harmonics. The controlling with fuzzy gives good results. It reduced THD of source current. The fast response is given by the fuzzy controller. [2]

The renewable energy system plays an important role in enhancing the power quality with custom power devices also at point of common of coupling. In custom power devices STATCOM, DVR, UPQC etc. came. In the presence of non linear load it introduces harmonics in the system. In the case absence use of FACTS devices gives poor result. In this, it has observed that the power quality improvement using FACTS is better. FACTS devices are used for reduction in harmonic current and also in the voltage.

II. SUPERCAPACITOR BASED UPQC

The block diagram representation for the proposed system is shown in Fig.1. The dc link of both of these active filters is connected to a super capacitor through a common dc link capacitor. The three-leg voltage source converter based shunt connected active filter is capable of suppressing the harmonics in the source currents, load balancing and correction of power factor. Using a three phase transformer the series connected active filter is placed between the supply and load terminals. The main objective of the series connected filter is to obtain harmonic isolation between the load and supply. A small capacity rated R-C filter is connected in parallel with the secondary of each series transformer and these transformers are also used to inject the voltage to filter the switching ripple content in the series filter. The series voltage source inverter and shunt voltage source inverter are implemented with insulated gate bipolar transistors. The load under a combination of linear and non-linear type is considered.[4]

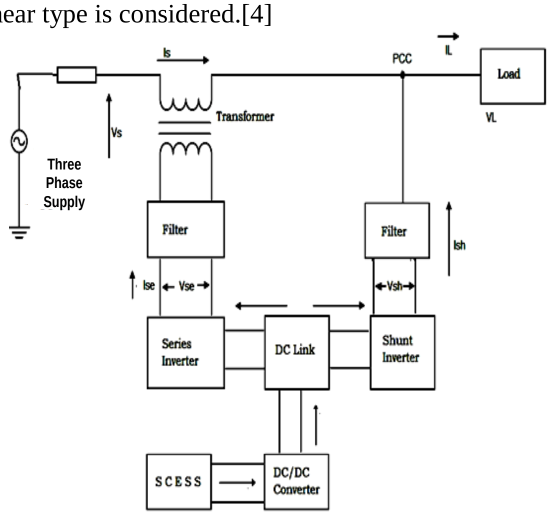

Fig.1. Proposed Block Diagram of UPQC with Super Capacitor.

The super capacitor bank consists of number of series and parallel capacitors to increase the current and voltage at the DC link and the DC/DC converter is used to maintain constant voltage at the DC link irrespective of the voltage at the super capacitor bank. It boosts the voltage level when sag appears in the line, and If voltage suddenly increases i.e. swell in the line consumes energy. UPQC can be utilized to solve power quality problems simultaneously [5]. Proposed method is about the usage of super capacitor instead of conventional energy storage for a UPQC. The UPQC for elimination of harmonic content and compensation of voltage and current simultaneously, which improve the power quality, offered for other harmonic sensitive loads at the point of common coupling. UPQC has the capability of voltage imbalance compensation, voltage regulation and compensation of harmonics at the consumer end. The shunt active power filter is used to reduce harmonics in current and also used to regulation of voltage of the dc-link between both active power filters. The proposed synchronous reference frame based control method for the UPQC system with a DC/DC converter to control voltage at the super capacitor end is used and the system performance is improved in this paper. In the proposed control method, load voltage, source voltage, and source current are measured, evaluated, and tested under unbalanced and distorted load conditions using MATLAB/Simulink software.

III. IMPACTS OF POWER QUALITY PROBLEMS IN DISTRIBUTION NETWORK WITH DGS

In recent years, Distributed Generation (DG) gained much attention due to its widespread use and power injection is due to a developing trend for DG. A parallel trend is now developing with significantly smaller sized generation units connected at the distribution level. The benefits of DG on feeder performance can be significant in reducing the voltage variations on the feeder. This mode of operation requires the DG to operate by delivering real power at times of peak loading for that particular line. There are many possibilities for distributed generation which is based on the size of generator. The main demand is for - Small photovoltaic or wind power for residential or small office applications. Distributed generation has lower capital cost because of the small size, also renewable energy based DGs (such as solar or wind) can produce near zero pollutant emissions. This expansion of distributed generation has the potential to significantly change the nature of the distribution system and the associated power quality issues. There is need to consider their impacts on the distribution system. The study has investigated the power quality issues related to DG integration in distribution networks. Voltage dip transients, harmonics and voltage flicker of distribution systems with DG installed are analyzed to ascertain the DG impact on power quality. The power could be supplied by energy storage technology, which includes two aspects: one is high efficient mass storage, and the other is fast and efficient energy conversion. Energy storage technology applied in power system can realize peak load shifting and system reserve demand reduction.

Super capacitor storage is normally used for smoothing the power of short duration, used in high peak power situation such as high power DC motor starting. When it comes to voltage sags or instantaneous disturbance, Super capacitor storage technology is able to improve the power supply and quality. Thus, this technology is suitable for solving power quality problems in distribution network with high penetration of DGs [6-7] Custom power technology, based on power electronic technology, could provide power supply up to reliability and stability level which users required in MV/LV distribution network system. UPQC, with feature of series compensation and parallel compensation being integrated together, has been considered as the most full featured and effective one of all DFACTS technologies so far. To improve power quality of distribution network with the high penetration of DGs, developing custom power technology based on UPQC, which can inject active power during the voltage regulation and integrate to reactive compensation[3], is a feasible strategy. The system configuration of a single-phase UPQC is shown in Fig. 2. Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus.

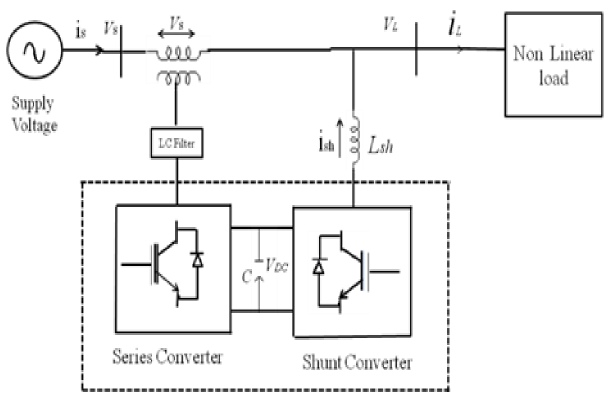

Fig.2. Structure Scheme of UPQC.

IV. OPERATING PRINCIPLE OF UPQC

UPQC is an integration of shunt and series APFs with a common self-supporting dc bus. The series converter of UPQC is controlled in voltage control mode such that it generates a voltage and injects in series with line to get a sinusoidal waveform, free from distortion and at the desired magnitude voltage at the load terminal. In the case of a voltage sag condition, actual source voltage will represent the difference between the reduced supply voltage and reference load voltage, i.e., the injected voltage by the series inverter to maintain voltage at the load terminal at reference value. The series inverter of the UPQC injects a voltage represented by the following equation.

$$V_C = V_L^* - V_S \quad \textbf{(1)}$$

Where VC, V_L^*, and V_S represent the series inverter voltage, reference load voltage, and actual source voltage respectively.

The second unit connected in parallel with load, is termed as Shunt Active Filter. It acts as a controlled current generator. It is used to compensate load reactive power, harmonics and balance the load currents thereby making the source current balanced and distortion free with unity power factor. Voltage rating of dc-link capacitor largely influences the compensation performance of an active filter. Shunt active filter maintains the voltage across the dc link capacitor bank. The shunt inverter should inject a current, thereby cancel the Harmonics generated by a nonlinear load. The injected current given by the following equation

$$I_C = I_L^* - I_S \quad \textbf{(2)}$$

Where I_C, I_L*and I_S represent the shunt inverter current, reference load current, and actual source current respectively.

In addition, it controls dc link current to a desired value [8]. With the series and parallel PWM converter topology, three phase four-leg circuit structure implements both three-phase and single phase structure, as a result, it is more flexible and versatility. And three-phase control systems can drive unbalanced loads as a result of three phases being mutually independent [9]. Therefore, it chooses the three-phase four-leg circuit structure as the topology of power quality improving device. In view of the above, this paper presents a kind of three phase four-wire power quality conditioning device based on fast energy storage named Energy-storage UPQC (EUPQC) aiming for power quality problems in distribution network with high penetration of DGs.

V. POWER CIRCUIT CONFIGURATION OF EUPQC

The power circuit configuration of EUPQC as shown in fig.3. EUPQC includes series converter, parallel converter, booster and discharge unit which consisting of super capacitor energy storage and DC/DC converter, outputting power transformer TsA~TsC of series converter, output filters Ls and Cs of series converter and inductance Lp of parallel converter [10].

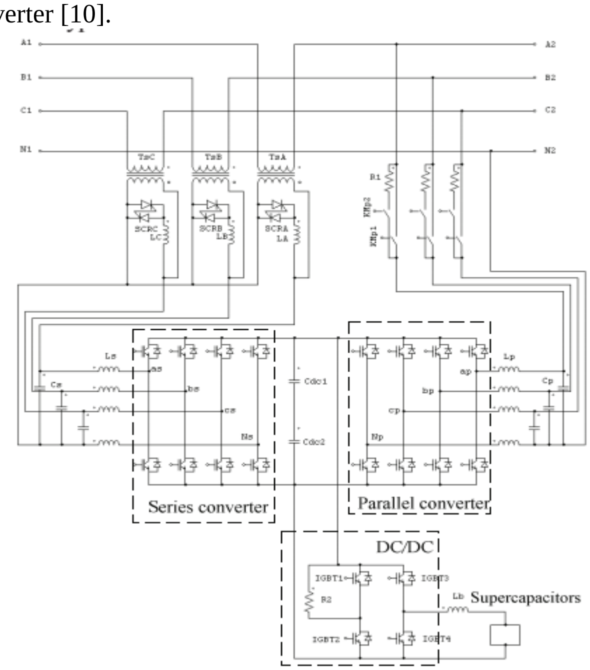

Fig.3.Power Circuit Configuration System of EUPQC.

The electric interfaces A1, B1, C1, and N1 connect distribution network source and the A2, B2, C2, and N2 connect various loads. Two sets of three-phase four-leg converter respectively compose the series and parallel converters of the EUPQC. The series converter output enters into distribution network via LC filter and transformer in series, while the parallel device output enters into distribution network with filter inductance in parallel. The switching sequence could be shown in Fig.3. When EUPQC accesses to distribution network and sets to work, the DC bus voltage equals to that of the super capacitor bank. Then close contactors KMp2, 380V AC power supply charges to the dc side via pre-charge resistance R1 and parallel converter. When charging completes, close KMp1, and break KMp2 and DC/DC converter starts to work. Adjust the DC side voltage to nominal reference level 690V. Detect unbalanced degree and harmonic content of mains supply voltage and load current in load side, in order that parallel converter could be put into operation when over ranging problem happens. And when voltage problems like voltage sag and swell happen to mains supply[10], series converter will be put into operation and output compensation voltage until the problems are solved. Then series converter quits working and the SCRA, SCRB and SCRC bypass. The single phase structure schematic diagram of EUPQC is illustrated in Fig. 4. Series converter output voltage vector to compensate voltage unbalance and harmonic of power supply side. Parallel converter is used to solve power quality problems in load side, such as unbalance and harmonic of nonlinear load including reactive compensating and current harmonic. Super capacitor energy storage and DC /DC converter buffer reactive power, exchange and provide energy for voltage compensation. As a result, decoupling series converter and parallel converter is implemented. Moreover, voltage quality problems of power interruption[4], which beyond the reach of traditional UPQC, can be resolved successfully.

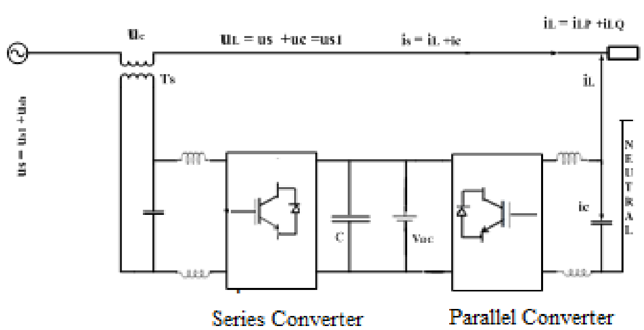

Fig. 4.The Single Phase Structure Schematic of EUPQC.

The ultimate purpose of EUPQC control is to keep load voltage on a constant level and be sinusoidal feature, compensate load reactive power and harmonic and ensure power supply has unity power factor characteristic in all circumstances. As is the control schematic of EUPQC shown in Fig.5. series converter works as a non-sinusoidal voltage source, outputting compensation voltage u_c which offsets grid voltage distortion and fundamental deviation, accordingly it ensures load voltage u_L being rated sinusoidal voltage. Meanwhile, shunt converter works as a non-sinusoidal current source, outputting reactive power and harmonic current I_c which offset reactive load power and load harmonic current, accordingly it could make the injected current Is be sinusoidal by compensating reactive power and harmonic current. And the angle between the injected voltage and the injected current is zero at the moment, namely the power factor in grid side is unity.

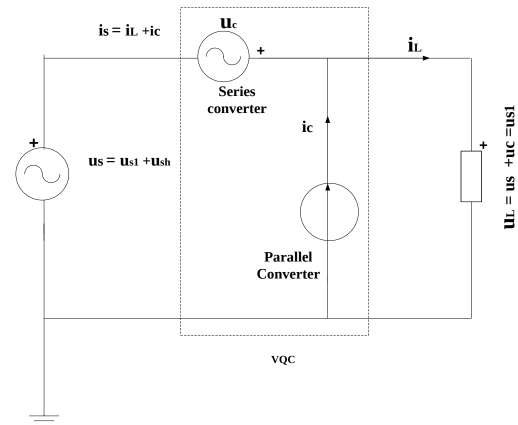

Fig.5.Control Schematic of EUPQC.

VI. CONTROL SCHEMES OF EUPQC

The control of EUPQC mainly includes three aspects: the control of series converter, the control of parallel converter and the control of DC bus voltage. In control strategy diagram of series converter shown in Fig.6. In this technique, only the voltage magnitude is compensated [11]. VDVR is in-phase with the left hand side voltage of DVR.

$$VDVR = V_{inj} \quad \textbf{(3)}$$

$$|V_{inj}| = |V_{pre\ sag}| - |V_{sag}| \quad \textbf{(4)}$$

$$\angle V_{inj} = \theta_{inj} = \theta_s \quad \textbf{(5)}$$

In this paper, hysteresis voltage control is used to improve the load voltage and determine switching signals for inverters gates. A basic of the hysteresis voltage control is based on an error signal between an injection voltage (V_{inj}) and a reference voltage of DVR (V_{ref}), which produces proper control signals [12]. There is Hysteresis Band (HB) above and under the reference voltage and when the difference between the reference and inverter voltage reaches to the upper (lower) limit, the voltage is forced to decrease (increase) as shown in Fig.7.

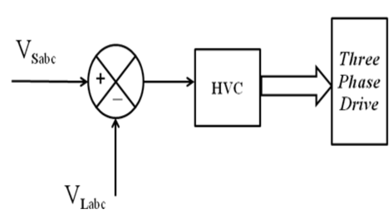

Fig.6. Series Converter Control Strategy Diagram.

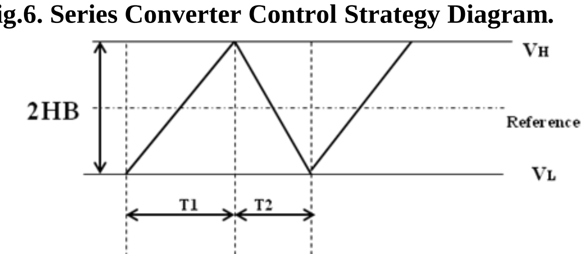

Fig. 7. Hysteresis Band voltage control.

As parallel converter control strategy diagram shown In Fig.8. Perform dq transform on three phase load current i_{La}, i_{Lb}, i_{Lc}. Then let the transformed current pass low-pass filter to generate active component id and reactive component iq. Perform dq inverse transform on these two components to get fundamental component of three phase load current. Subtract load current from this standard current to get three phase reference compensation current. Compare the reference currents with three phase actual compensation current i_{ca}, i_{cb}, i_{cc}, and constitute closed loop control by using a Fuzzy controller [14]. In SPWM mode three phase driving pulse signal of parallel converter is generated, consequently parallel converter is controlled to output corresponding current vector to compensate. The control of the forth leg of shunt converter is aiming to keep load zero sequence current to zero, which function is implemented through closed loop control constituted by a Fuzzy controller[12]. Symbols i_{sa}, i_{sb}, i_{sc} in Fig.8. Represent three-phase power supply current respectively. Parallel converter can realize reactive compensation by controlling reactive component i_q. If i_q=0, then all reactive power of the load is provided by parallel converter.

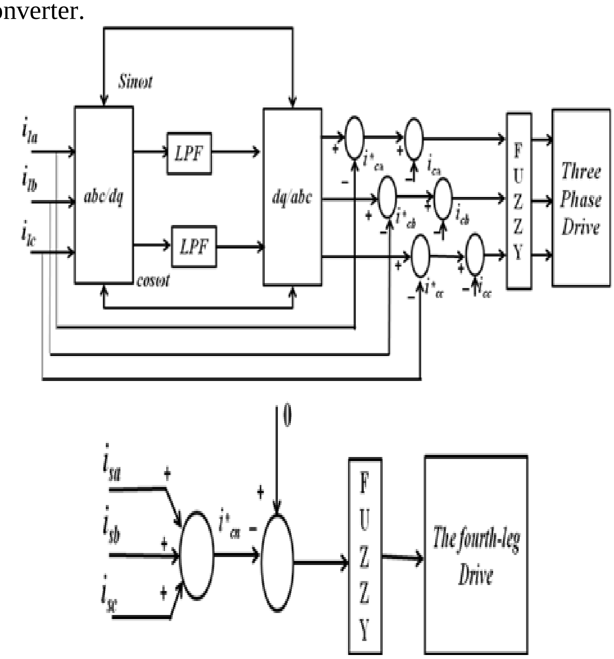

Fig.8.Parallel Converter Control Strategy Diagram.

DC side of EUPQC, consisting of bi-directional DC-DC converter based on super capacitor fast energy storage, is able to solve problems of deeper voltage sag and voltage instantaneous interruption. Fig.9. Illustrates control strategy of DC/DC converter. After comparing reference voltage U_{def} with DC bus voltage U_d, the two voltages pass through closed loop Fuzzy controller and then compared by limited driver to generate PWM signal[13]. They could drive IGBT3 and IGBT4 Respectively to implement the control of DC/DC converter. And then use the output to maintain U_d at a stable level. The function of discharge circuit comprising IGBT1 and IGBT2 could avoid over tension happens to DC bus voltage U_d.

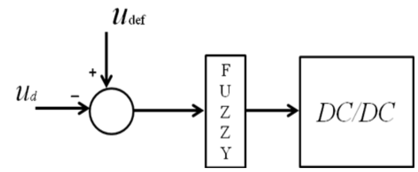

Fig.9. DC/DC Converter with Fuzzy Logic Control Strategy Diagram.

VII. PHOTOVOLTAIC (PV) SYSTEM

In the crystalline silicon PV module, the complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Fig. 10. For that equivalent circuit, a set of equations have been derived, based on standard theory, which allows the operation of a single solar cell to be simulated using data from manufacturers or field experiments.

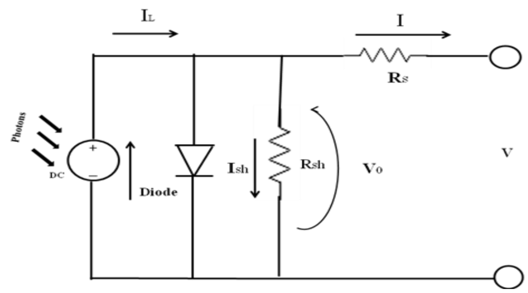

Fig.10. Equivalent Electrical Circuit of a PV Module.

The series resistance R_S represents the internal losses due to the current flow. Shunt resistance R_{sh}, in parallel with diode, this corresponds to the leakage current to the ground[7]. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behaviour of the PV cell [15]. The equation for the output current is given by,

$$I = IL - ID \quad (6)$$

$$I_D = I_{SC}[\exp(\frac{V}{AV_T}) - 1] \quad (7)$$

$$I = I_L - I_{SC}[\exp\frac{(V + R_s I)}{V_T} - 1] - \frac{(V + R_s I)}{R_{sh}} \quad (8)$$

Where $V_T = Ns*K*Tq$

The number of PV modules connected in parallel and series in PV array are used in expression. V_T is the thermal voltage of a PV module having Ns cells connected in series; q is the electron charge; k is the Boltzmann constant; T is the temperature of the p-n junction and A the diode ideality factor. V_T is also defined in terms of the ideality factor of PN junction (n). Applied a dynamical electrical array reconfiguration (EAR) strategy on the photovoltaic (PV) generator of a grid-connected PV system based on a plant-oriented configuration, in order to improve its energy production when the operating conditions of the solar panels are different. The EAR strategy is carried out by inserting a controllable switching matrix between the PV generator and the central inverter, which allows the electrical reconnection of the available PV modules.

VIII. FUZZY LOGIC CONTROLLER

The control framework is in light of fuzzy logic. FL controller is an one sort non straight controller and programmed. This kind of the control drawing closer the human thinking that makes the utilization of the acknowledgement, vulnerability, imprecision and fluffiness in the choice making procedure, figures out how to offer an exceptionally tasteful execution, without the need of a definite numerical model of the framework, just by fusing the specialists' learning into the fluffy. The basic structure of fuzzy logic controller is shown in fig.11. Fuzzy-logic system is inflected in three basic elements: Fuzzification, Fuzzy inference, and Defuzzification. Degrees of membership in the fuzzifier layer are calculated according to IF-THEN rules. They base their decisions on inputs in the form of linguistic variable derived from membership functions which are formulas used to determine the fuzzy set to which a value belongs and the degree of membership in that set. The membership functions are shown in fig.12. The variables are then matched with the specific linguistic IF-THEN rules and the response of each rule is obtained through fuzzy implication. The Fuzzy rule base table is shown in Table I. To perform compositional rule of inference, the response of each rule is weighted according to the impedance or degree of membership of its inputs.

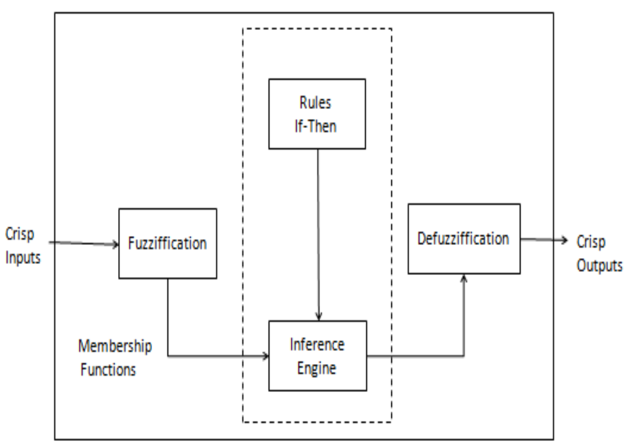

Fig.11. Block Diagram of Fuzzy Logic Controller.

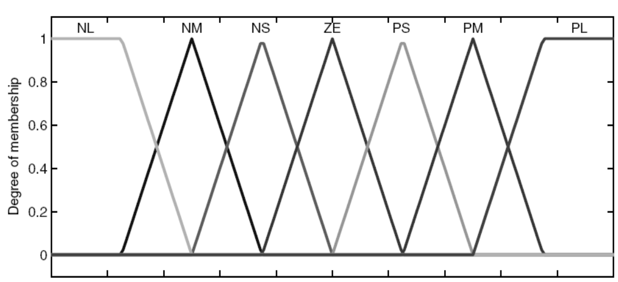

Fig.12. Membership functions of Fuzzy Controller.

TABLE I: Fuzzy Rule Base

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

TABLE II: The Meanings of the Symbols

Symbols	Meaning
Vca, Vcb, Vcc	Three phase compensation voltage
VLa, VLb, VLc	Three phase load voltage
Vsa, Vsb, Vsc	Three phase source voltage
Ud	Super Capacitor DC bus voltage
ica, icb, icc, ic0	Three phase compensation current and The neutral compensation current
iLa, iLb, iLc, iL0	Three phase load and neutral current
isa, isb, isc, is0	Three phase source and neutral current
Ish	Shunt resistance
Ise	Series Resistance
IL	Light generated current
Isc	Short circuited current

IX. MATLAB/SIMULINK RESULTS

According to above EUPQC As we can see from the simulation waveforms shown in Fig13, when three phase source voltage is unbalance, series converter starts to compensate load voltage to maintain the original voltage characteristics. If nonlinear loads are contained, parallel converter will restrain current harmonic to reduce source current harmonic considerably. If unbalanced loads are contained, parallel converter will regulate three phase source current to keep it balanced. Thus the waves of three phase load voltage and three phase source current tend to the standard three phase sine wave, and they are nearly in-phase as shown in fig.14. And fig.15. From which we can know that in this condition, when load voltage maintains normal amplitude THD of source current is 0.86% is shown in fig.16. This is enough to meet requirement. Meanwhile, the grid side power factor angle is higher and the source provides active power only. As a result, the level of distribution network voltage quality is improved significantly.

B. By using fuzzy controller

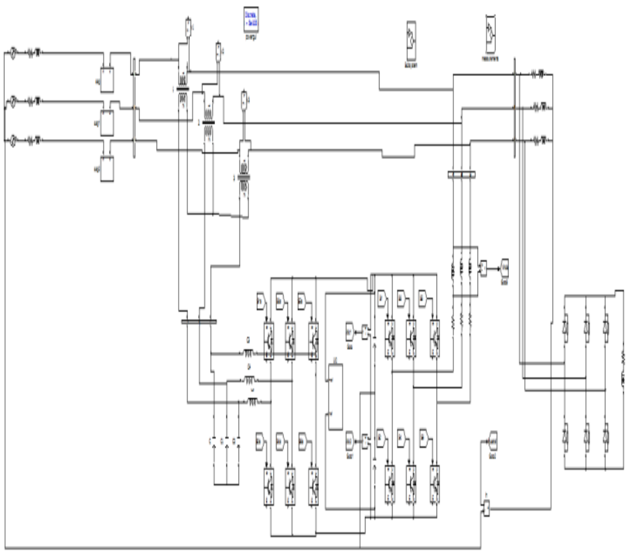

Fig.13. Matlab/Simulink Model of UPQC Based on Fast energy storage.

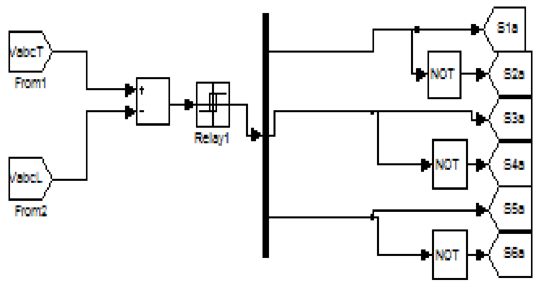

Fig.14.Control Diagram for Series Converter.

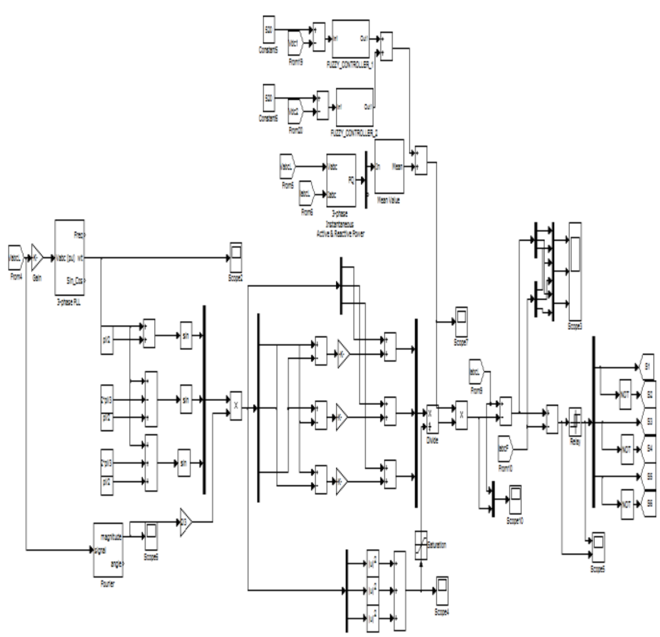

Fig.15.Control Diagram for Parallel Converter UPQC based Fuzzy Logic Controller.

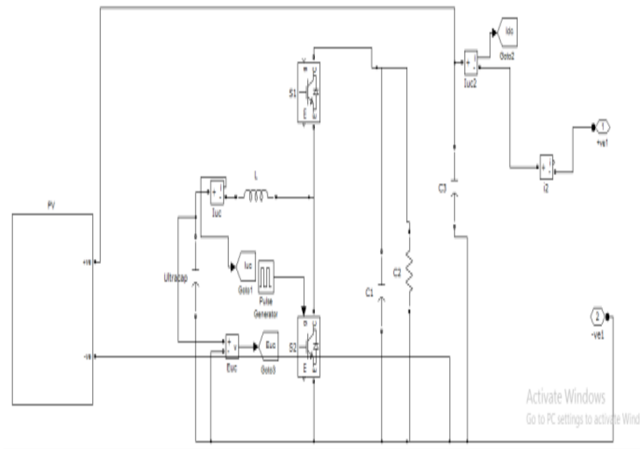

Fig.16.PV with Ultra Capacitor.

Let us consider that voltage waveform. The voltage contains sag between duration of 0.8<t<1sec.The EUPQC is switched on at t = 0.8 s continues injecting voltage up to 1sec. The voltage, the corresponding compensation voltage injected by VSC and finally load voltage are shown in Figs.17 to 19.

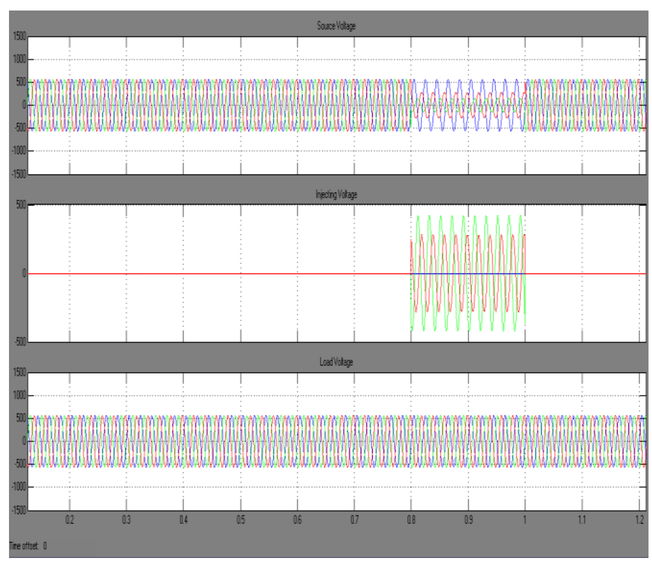

Fig.17.Shows Source Voltage, DVR Voltage and Load voltage.

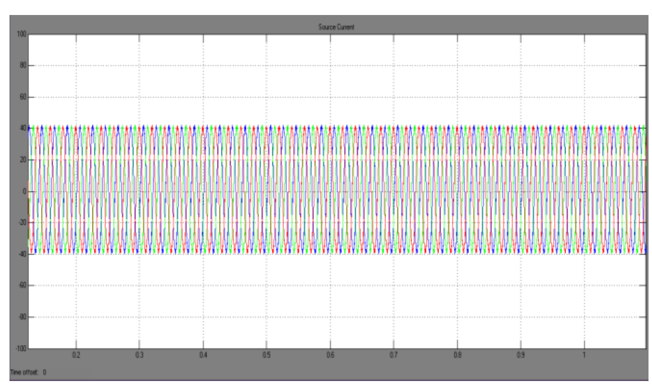

Fig.18.Shows Source Current.

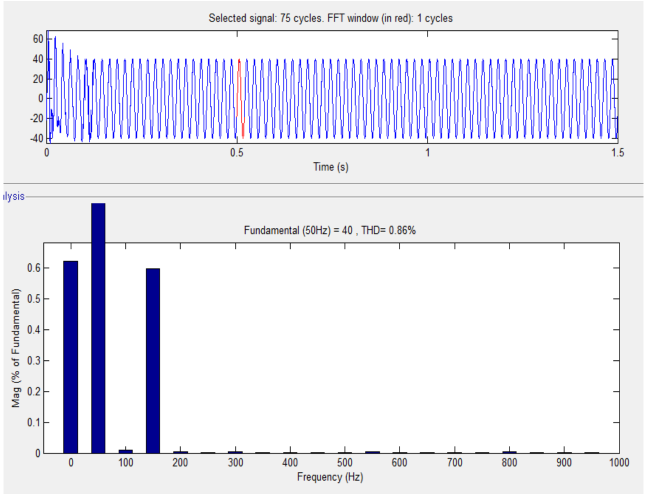

Fig.19. Harmonic Spectrum for Source Current.

X. CONCLUSION

Hybrid is the best solution for meeting the demand of coming years of electricity. As in future reduction of fossil fuel are diverting us to move towards renewable. This literature survey gives complete knowledge about power quality technique used for hybrid sources system. This paper has dealt with the unified power quality conditioner, the aim of which is not only to compensate for current harmonics produced by nonlinear loads but also to eliminate voltage flicker/imbalance appearing at the receiving terminal from the load terminal. The performance of UPQC was tested with fuzzy controller under voltage sag and harmonics are analyzed in MATLAB. From the result THD value is reduced satisfactorily.

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