Enhancement of Power Quality with Fuzzy Based Unified Power Quality Conditioner with Fast Energy Storage

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Abstract: One of the major concerns in electricity industry today is power quality. It becomes especially important with the introduction of advanced and complicated devices; whose performance is very sensitive to the quality of power supply. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage sags, voltage flickers, harmonics and load unbalance etc. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator, dynamic voltage restorer and unified power quality conditioner which is based on the VSC principle are used for power quality improvement. 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, UPQC, Voltage Sag, Fuzzy Logic Controller.

I.INTRODUCTION

Here has been a continuous rise of nonlinear loads over the years due to intensive use of power electronic control in industry as well as by domestic consumers of electrical energy. The utility supplying these nonlinear loads has to supply large vars. Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous VAR control with fast dynamic response and on-line elimination of load harmonics. To satisfy these criterion, the traditional methods of VAR compensation using switched capacitor and thyristors controlled inductor coupled with passive filters are increasingly replaced by active power filters (APFs). The APFs are of two types; the shunt APF and the series APF. The shunt APFs are used to compensate current related problems, such as reactive power compensation, current harmonic filtering, load unbalance compensation, etc. The series APFs are used to compensate voltage related problems, such as voltage harmonics, voltage sag, voltage swell, voltage flicker, etc. The unified power quality conditioner (UPQC) aims at integrating both shunt and series APFs through a common DC link capacitor. The UPQC is similar in construction to a unified power flow controller(UPFC).

The UPFC is employed in power transmission system, whereas the UPQC is employed in a power distribution system. The primary objective of UPFC is to control the flow of power at, fundamental frequency. On the other hand the UPQC controls distortion due to harmonics and unbalance in voltage in addition to control of flow of power at the fundamental frequency. The schematic block diagram of UPQC is shown in Fig. 1. It consists of two voltage source inverters (VSIs) connected back-to-back, sharing a common DC link in between. One of the VSIs act as a shunt APF, whereas the other as a series APF. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Control schemes of UPQC based on PI controller has been widely reported. The PI control based techniques are simple and reasonably effective. However, the tuning of the PI controller is a tedious job. Further, the control of UPFC based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows. In this work, the conventional PI controller has been replaced by a fuzzy controller (FC). The FC has been used in APFs in place of conventional PI controller for improving the dynamic performance. The FC is basically nonlinear and adaptive in nature. The results obtained through FC are superior in the cases where the effects of parameter variation of controller are also taken into consideration.

The FC is based on linguistic variable set theory and does not require a mathematical model. Generally, the input variables are error and rate of change of error. If the error is coarse, the FC provides coarse tuning to the output variable and if the error is fine, it provides fine tuning to the output variable. In the normal operation of UPQC, the control circuitry of shunt APF calculates the compensating current for the current harmonics and the reactive power compensation. In the conventional methods, the DC link capacitor voltage is sensed and is compared with a reference value. The error signal thus derived is processed in a controller. A suitable sinusoidal reference signal in-phase with the supply voltage is multiplied with the output of the PI controller to generate the reference current. Hysteresis band is normally (most often but not always) is imposed on top and bottom of this reference current. The width of the hysteresis band is so adjusted such that the supply current total harmonic distortion (THD) remains within the international standards. The function of the series APF in UPQC is to compensate the voltage. The control circuitry of the series APF calculates the reference voltage to be injected by the series APF by comparing the terminal voltage with a reference value of voltage

II. POWER QUALITY PROBLEMS IN DISTRIBUTION NETWORK WITHHIGHPENETRATION OF DGs

In distribution network with high penetration of DGs, enough power support is used to restraint output power fluctuation. 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. Meanwhile, it would provide technical support for reducing network power loss and improving power quality. Super capacitor storage is normally used for smoothing the power of short duration, high power load or used in high peak power situation such as high power DC motor starting and dynamic voltage restorer. 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. 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, is a feasible strategy. Traditional UPQC used in power distribution system, integrating series compensation voltage principle and parallel compensation voltage principle in one device, can compensate three-phase asymmetric and harmonicon both mains supply voltage and nonlinear loads. UPQC is composed of the main circuit shown in Fig.1, including series and parallel PWM converter, and the control circuit. There are two basic control strategies, i.e. direct control scheme and indirect control scheme. Direct control scheme meansseries converter is controlled as sinusoidal current source to isolate voltage disturbance comes from grid and load. And parallel converter is controlled as sinusoidal voltage source to avoid load reactive power, load harmonic current and unbalance from being injected into grid. On the other side indirect control scheme means series converter works as a non- sinusoidal voltage source, outputting compensation voltage which offsets grid voltage distortion and fundamental deviation, accordingly it ensures load voltage being rated sinusoidal voltage.

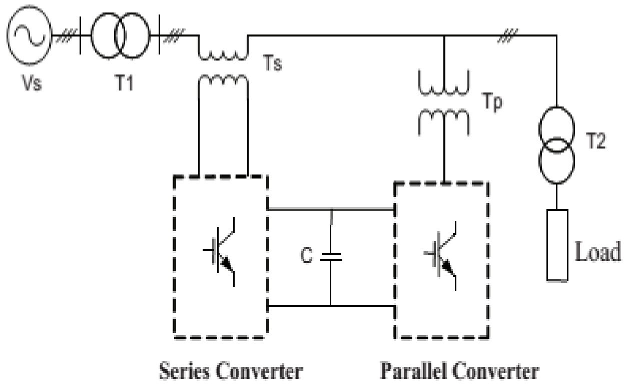

Fig.1. Structure scheme of UPQC.

Meanwhile, parallel converter works as an non-sinusoidal current source, outputting reactive power and harmonic current which offset reactive load power and load harmonic current, accordingly it could make the injected current be sinusoidal and running under unit power factor by compensating reactive power and harmonic current. Indirect control scheme by researched more common is mainly discussed in this paper. 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. 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 (UPQC) aiming for power quality problems in distribution network with high penetration ofDGs.

III. STRUCTURE OF UPQC

As shown in Fig. 2, the main circuit system structure of UPQC includes series converter, parallel converter, booster and discharge unit which consisting of super capacitor energy storage and DC/DC converter, outputting power transformer TsA~TsCof series converter, output filters Ls and Cs of series converter and inductance Lp of parallel converter. 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 UPQC. 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.2.

When UPQC 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, 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.

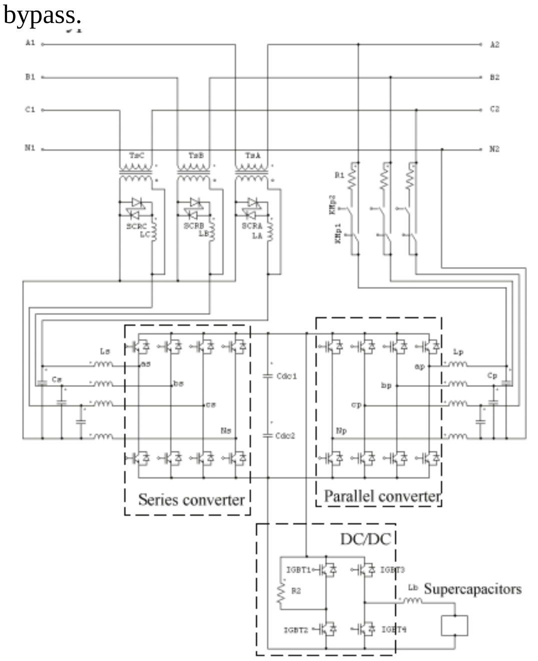

Fig.2. Main circuit system structure of UPQC.

The single phase structure schematic diagram of UPQC is illustrated in Fig. 3. 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, which beyond the reach of traditional UPQC, can be resolved successfully. The ultimate purpose of UPQC 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 UPQC shown in Fig.4, series converter works as a non-sinusoidal voltage source, outputting compensation voltage uc which offsets grid voltage distortion and fundamental deviation, accordingly it ensures load voltage u_L being rated sinusoidal voltage.

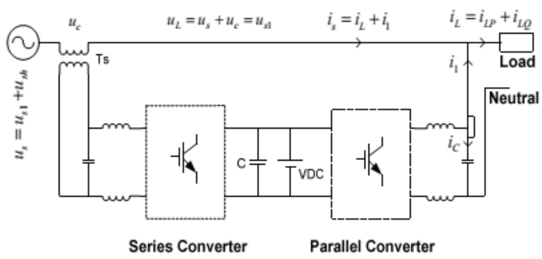

Fig. 3.The single phase structure schematic of UPQC.

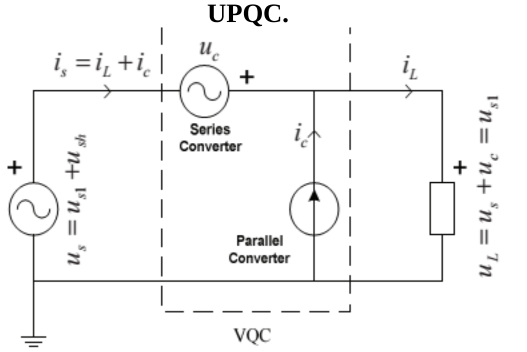

Fig.4. Control schematic of UPQC

Meanwhile, shunt converter works as a non-sinusoidal current source, outputting reactive power and harmonic current Ic 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 us and the injected current is is zero at the moment, namely the power factor in grid side is unity.

IV.THE CONTROL STRATEGY OF UPQC

The control of UPQC 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. 4.5, u_{sa}, u_{sb}, u_{sc} are distribution network three-phase voltage respectively. Through software phase-locked loop, we could get ωsint and ωcost, which is essential to d_q rotary transformation. And then we perform d_q transform and dq inverse transform on three phase standard voltage to make it in-phase with mains supply voltage. Then subtract the distribution network unbalance voltage from this standard voltage to get three phase reference compensation voltage Compare reference voltages with three phase actual compensation voltage u_{ca} , u_{cb} , u_{cc}, and constitute closed loop control by using a PI regulator. Specifically, in SPWM mode three phase driving signal of series converter is generated, consequently series converter is controlled to output corresponding voltage vector to compensate. The control of the forth leg of series converter is aiming to keep load zero sequence voltage to zero, which function is implemented through closed loop control with feed-forward control for voltage constituted by a PI regulator. Symbols u_{La}, u_{Lb}, u_{Lc} in Fig.5 represent three-phase load voltage respectively.

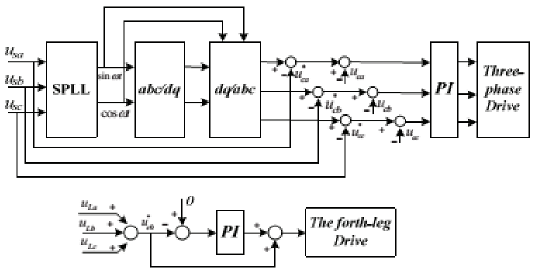

Fig. 5. Series converter control strategy diagram.

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 i_{ca}, i_{cb}, i_{cc}. Compare the reference currents with three phase actual compensation current ica, icb, icc, and constitute closed loop control by using a PI regulator. The same as the series converter control mode, 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 PI regulator. Symbols isa, isb, iscin Fig.6 represent three-phase power supply current respectively. Parallel converter can realize reactive compensation by controlling reactive component iq. If iq=0, then all reactive power of the load is provided by parallel converter

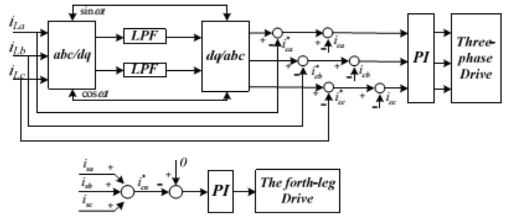

Fig.6.Parallel converter control strategy diagram

DC side of UPQC, 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.7 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 PI control and then compared by limited driver to generate PWM signal. They could drive IGBT3 and IGBT4 in Fig.2 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

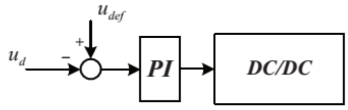

Fig.7.DC/DC converter control strategy diagram.

V. FUZZY LOGIC CONTROLLER In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC. The FLC comprises of three parts: Fuzzification, interference engine and de-Fuzzification. The FC is characterized as; i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani"s „min" operator. v. Defuzzification using the „height" method.

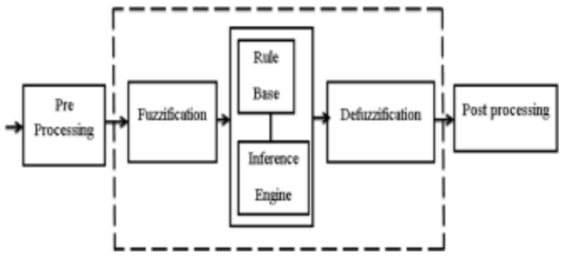

Fig.8. Fuzzy Logic Controller

A. Fuzzification Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB

(Positive Big). The partition of fuzzy subsets and the shape of membership function adapt the shape up to appropriate system. The value of input error E(k) and change in error CE(k) are normalized by an input scaling factor shown in Fig. 8

Change In Error	Error						
	NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset. The input error E(k) for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}}$$

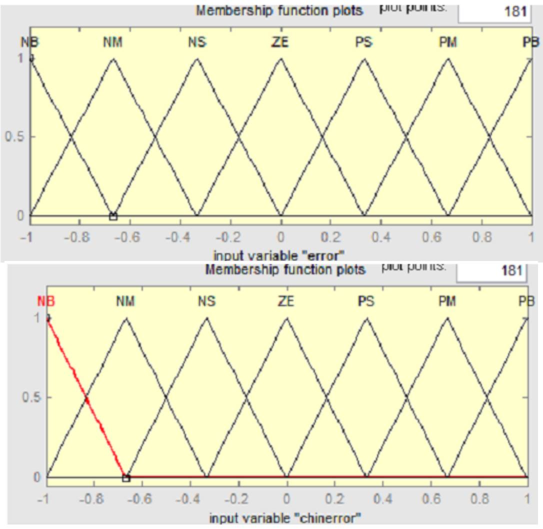

Fig. 9(a) & (b) Membership functions

B. Interference Method

Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

C. Defuzzification

As a plant usually requires a non-fuzzy value of control, a Defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output as shown in Figs. 9(a), (b) In the present work, for Fuzzification, non-uniform fuzzifier has been used. If the exact values of error and change in error are small, they are divided conversely and if the values are large, they are divided coarsely.

$$u=-[\alpha E + (1-\alpha)*C]$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state. Overshoot plays an important role in the system stability. Less overshoot is required for system stability and in restraining oscillations. C in (12) plays an important role, while the role of E is diminished. The optimization is done by α. During the process, it is assumed that neither the UPQC absorbs active power nor it supplies active power during normal conditions. So the active power flowing through the UPQC is assumed to be constant. The set of FC rules is made using Fig. 4 is given in Table 1.

VI. MATLAB/SIMULINK RESULTS

Case 1: by using PI controller

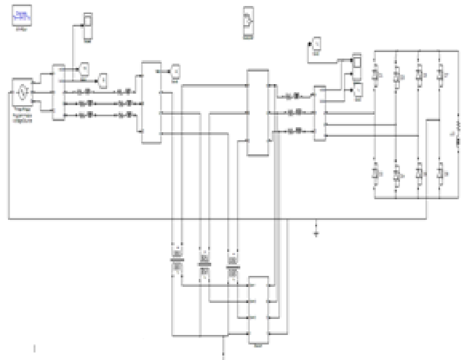

Fig.10. Matlab/Simulink Model of UPQC Based on fast energy storage

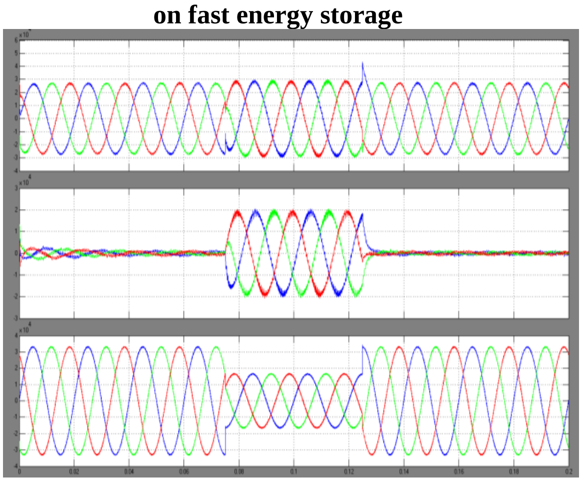

Fig.11. shows load voltage, DVR injected voltage and source voltage

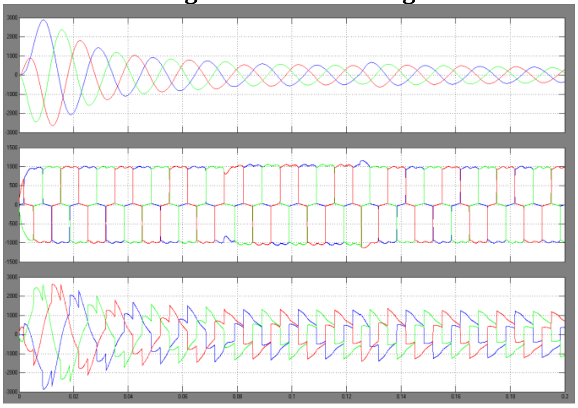

Fig.12. shows source current, load current and compensating current.

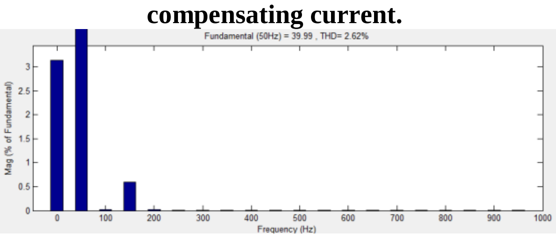

Fig.13. Harmonic Spectrum for Source Current

Case 2: by using fuzzy controller

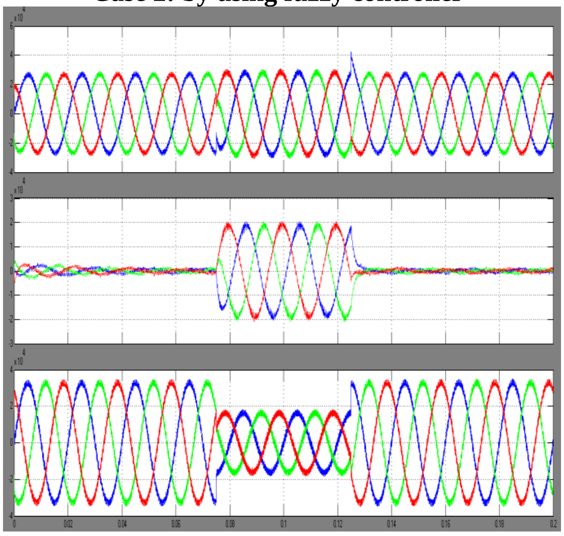

Fig.14.Simulation results for load voltage, dvr injected voltage and source voltage.

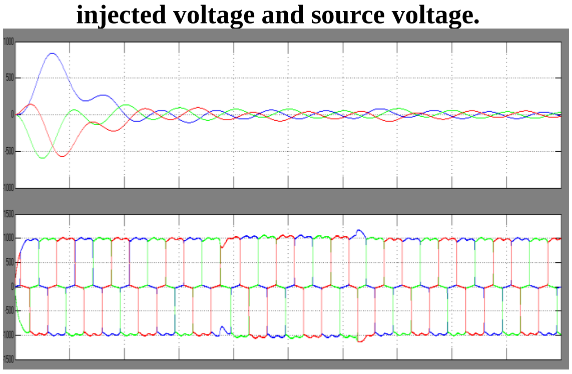

Fig.15. Simulation result for source current and load current.

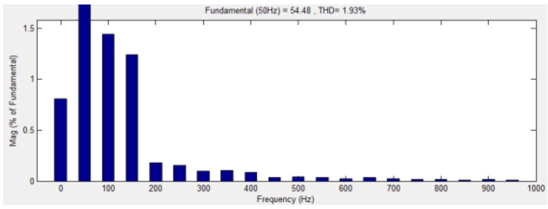

Fig.16. Harmonic Spectrum for Source Current.

VII. CONCLUSION

UPQC using Fuzzy Controller(FC) has been investigated for compensating reactive power and harmonics. It is clear from the simulation results that the UPQC using FC is simple, and is based on sensing the line currents only. The THD of the source current using the proposed FLC is well below 5%, the harmonic limit imposed by IEEE-519 standard.

VIII. REFERENCES

[1] Han Yingduo, Yan Gangui, Jiang Qirong, Huang Mincong. Electric Power in Information Society And FACTS & DFACTS [J] . Automation of Electric Power System, 2000, 24(19): 1-7.

[2]Wu Shan, Mei Tianhua, Gong Jianrong, Gan Deqiang. Voltage Fluctuation and Flicker Caused by Distributed Generation[J]. Energy Engineering, 2006(4) : 54-58.

[3]Bai Qian. Mechanism of Voltage Regulation by Distributed Generation on Distribution Network [D]. Hebei : North China Electric Power University Baoding, 2007.

[4]Zhang Guorong. Research on Control Strategies of Unified Power Quality Conditioner (UPQC) [D]. Hefei: Hefei University of Technology; 2008.

[5] VinodKhadkikar, AmbrishChandra.UPQC-S: A Novel Concept of Simultaneous Voltage Sag/Swell and Load Reactive Power Compensations Utilizing Series Inverter of UPQC [J]. IEEE Transactions on Power Electronics, 2011, 26(9):2414-2425.

[6] Liang Zuquan, Shu Hongchun, Liu Zhijian, Yu Jilai. Completely Decoupled Direct Control Strategy of UPQC [J]. Electric Power Automation Equipment, 2009, 29(4): 27-31.

[7]Wang Yunling, Zeng Jie, Zhang Buhan, Mao Chengxiong. Dynamic Voltage Conditioner Based on Ultracapacitor Energy Storage System [J]. Power System Technology, 2007, 31(8): 58-62.

[8]K. V. Govardhan Rao, P. Babu Rao. A Novel Hybrid PV/FC Energy Management Scheme for Grid-Connection And Islanded Operation Capabilities, International Journal of Scientific Engineering and Technology ResearchVolume.05, IssueNo.40, November-2016, Pages: 8228-8234

[9] CHENG Shi-jie芈YU Wen-hui芈WEN Jin-yu芈SUN Hai-shun芈WANG Hai-feng. Energy Storage and its Application in Power System Stability Enhancement [J]. Power System Technology芈2007,31(20) : 97-108.

[10] Tang Xisheng, Wu Xin, Qing Zhiping. Study

on A Stand-alone PV System With Battery/Ultracapacitor Hybrid Energy Storage [J]. Acta Energiae Solaris Sinica, 2007, 28(2): 178-182.

[11] Xingtian Feng, Tongzhen Wei. Study on Voltage Quality of distribution Network with High Penetration of DG [C]. Power System Technology, Hangzhou, China, 2010

[12] Zhang Wenliang, Qiu Ming, Lai Xiaokang. Application of Energy Storage Technologies in Power Grids [J]. Power System Technology, 2008, 32(7): 1-9.

[13] Li Xun. Analysis and Control of Uinfied Power Quallity Conditioner (UPQC) [D]. Wuhan: Huazhong University of Science And Technology, 2006.

[14] Yunwei Li, D. MahindaVilathgamuwa, Poh Chiang Loh.Microgrid Power Quality Enhancement Using a Three-Phase Four-Wire GridInterfacing Compensator [J]抵IEEE Trans on Industry Application. 2006, 41(6): 1707-1719抵

[15] Fu Songping, Gao Qinxiang Yu Weiwei. Research on Series Convertor of Unified Power Quality Conditioner Based on Improved d-q-0 Transformation.