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Improvement of Power Quality Using Fuzzy Based 3-Phase UPQC under Reduced VA Rating

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Abstract—
During the past several years, fuzzy control has emerged as one of the most active and fruitful areas for research in the applications of fuzzy set theory, especially in the realm of industrial process, which do not lend of quantities data regarding the input-output relations. This paper deals with Minimum VA rating handled by a Unified Power Quality Conditioner, which consists of Series and Shunt Active Power Filter. The Series Active Filter is Dynamic Voltage Restorer (DVR), which regulates the voltage at the point of common coupling with minimum VA loading. The Shunt Active Filter is Distribution Static Compensator(DSTATCOM) which compensates the reactive power and eliminates the load current harmonics from the source current. In this paper, Fuzzy based controller is used to extract the harmonic component in the source current. The proposed compensator compensates the harmonics and reactive power in all three phases. To regulate the dc capacitor voltage, a current control method using hysteresis controller is proposed. In this proposed method the total power handled by UPQC is minimum than the other conventional methods and it has been investigated by simulation using MATLAB/SIMULINK.

Index Terms: Unified Power Quality Conditioner (UPQC), Dynamic Voltage Restorer (DVR), Static Compensator (STATCOM), Minimum VA, Optimum angle, injection voltage and voltage sag.

I. INTRODUCTION

Fuzzy control is based on fuzzy logic; it is much closer in spirit to human thinking and natural language than traditional logical systems application to many industries and residential usages. Electric Power quality is a term which has captured increasing attention in power engineering in the recent years. Even though this subject has always been of interest to power engineers; it has assumed considerable interest in the 2003's. The measure of power quality depends upon the needs of the equipment that is being supplied. What is good power quality for an electric motor may not be good enough for a personal computer. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. Electric power quality (EPQ) problems mainly include unbalance voltage and current, flicker, harmonics, voltage sag, dip, swell, and power interruption [1],[2]. These power quality problems may cause abnormal operations of facilities or even trip protection devices. Hence, the maintenance and improvement of electric power quality has become an important scenario today. Even though the power generation is fairly reliable, the quality of power is not always so reliable. Fuzzy control is based on fuzzy logic; it is much closer in spirit to human thinking and natural language than traditional logical systems application to many industries and residential usages. Hence supply of reactive power at the load ends becomes essential [3-5]. 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 and current harmonics in the system.[6-7].

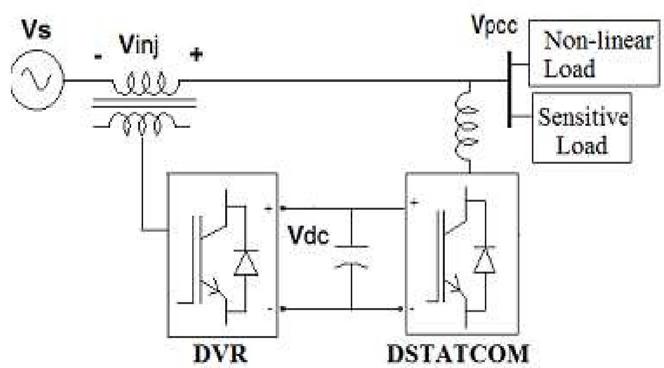

Fig.1. Schematic diagram of UPQC

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UPQC is a modern CUSTOM power device [9]-[11], which is used to solve almost all types of power quality problems. The UPQC consists of series and shunt active filter as shown in fig.1. Series active filter is used to mitigate the voltage sag and swell problems and shunt active filter is used to improve the power factor and eliminate the load harmonics. In series active filter the voltage will be injected at an optimum angle. In that optimum angle total VA requirement of UPQC will be less than the UPQC-P (series injected voltage is in phase with the source current) and the UPQC-Q (series injected voltage is in $90^0$with the source current) method. Therefore, the active power requirement will be less than the UPQC-P and an injected voltage magnitude is less than the UPQC-Q. The minimum VA method is one of the effective methods among others.

II.SEVERAL SAG COMPENSATION METHODS

A. IN-PHASE COMPENSATION METHOD (UPQC-P):

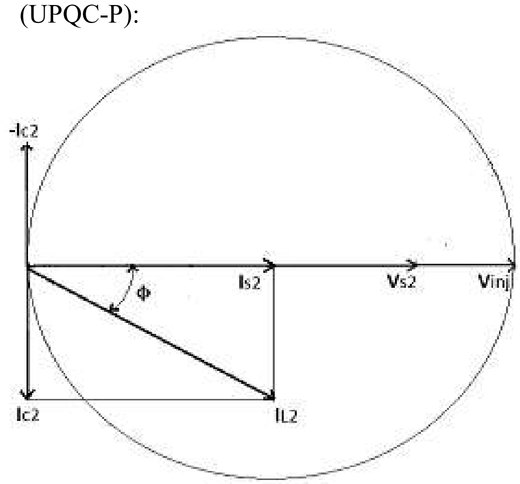

Fig. 2. Phasor diagram of In-phase compensation method

In this method the injected voltage (V_{inj}) from the series active filter is in-phase with the post-sag source voltage (V_{s2}) and the post sag source current (I_{s2}) as shown in figure 2. The assumption here is the shunt active filter is always maintaining the unity power factor. So the angle between the injected voltage and the post sag source current will be zero. So that the active power requirement will be more in this case. But the reactive power requirement will be zero. In this method, the magnitude of injected voltage will be less when compare to other methods. Even though it takes less injected voltage, the additional active power requirement drawn from the source. It adds the further burden to the source. This is the main drawback of the UPQC-P method.

B. QUADRATURE COMPENSATION METHOD (UPQC-Q)

In this method the injected voltage (V_{inj}) from the Series active filter is in quadrature with the post sag source voltage (V_{s2}). So the angle between the injected voltage and the post sag source current (I_{s2}) will be 90^0 as shown in figure. 3. From this it can identify that the active power requirement will be zero in this method [4]. But the reactive power requirement will be more. Though it takes zero active power, the magnitude of injected voltage will be more. That is the main drawback of this method. Hence, the minimum VA method is used to overcome the drawbacks of both the UPQC-P and the UPQCQ method.

C. PROPOSED -UPQC MINIMUM VA METHOD

In this minimum VA method the voltage injection will be based on an optimum angle α. A is an angle between the post-sag source voltage and the load voltage shown in figure.4.Optimum angle is an angle in which the VA requirement of the UPQC will be minimum[5]. Based on this optimum angle, the magnitude of injected voltage and the injection angle will be derived. In that particular magnitude of injected voltage and an injection angle, the active power requirement of the UPQC will be less than the UPQC-P method and the reactive power requirement of the UPQC will be less than the UPQC-Q method. So the total VA requirement of the UPQC will be less compare to the other two methods. And also the magnitude of injected voltage will be less than the UPQC-Q method. So the minimum VA.

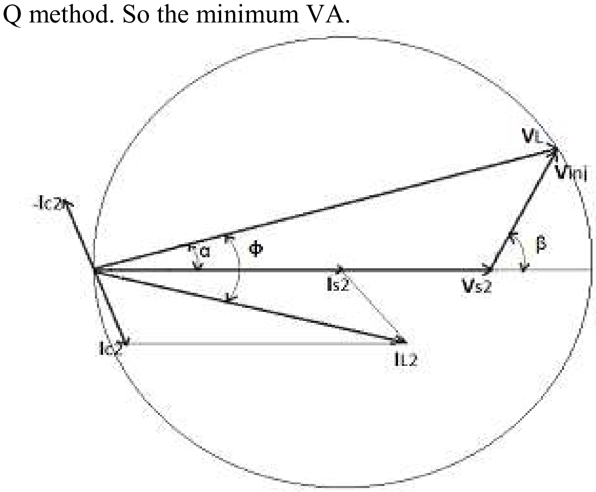

Fig. 3. Phasor diagram of Quadrature compensation method

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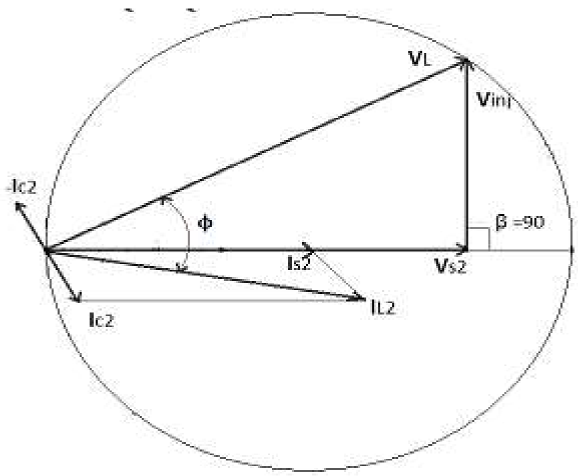

Fig. 4. Phasor diagram of Minimum VA method

method is one of the very efficient method. The injected voltage and the power limitation in the minimum VA

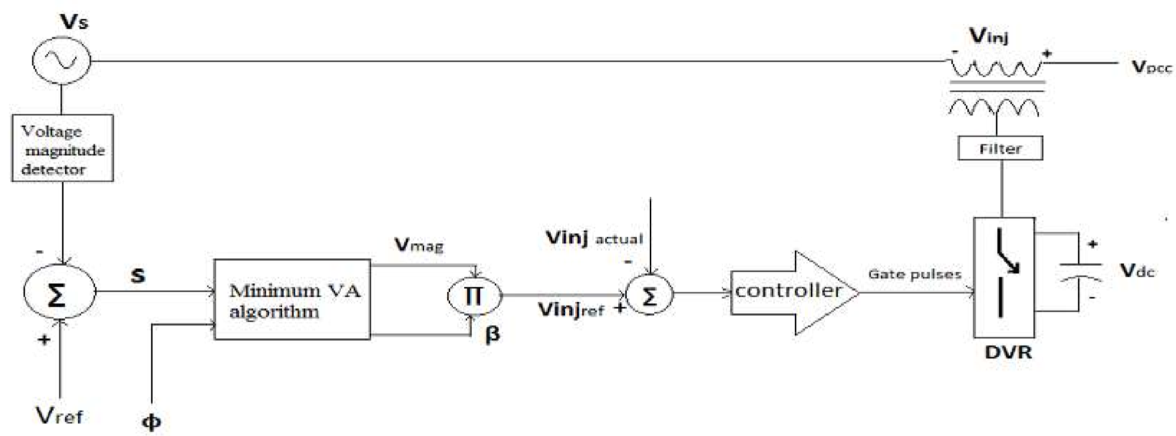

Fig. 5. Block diagram of DVR

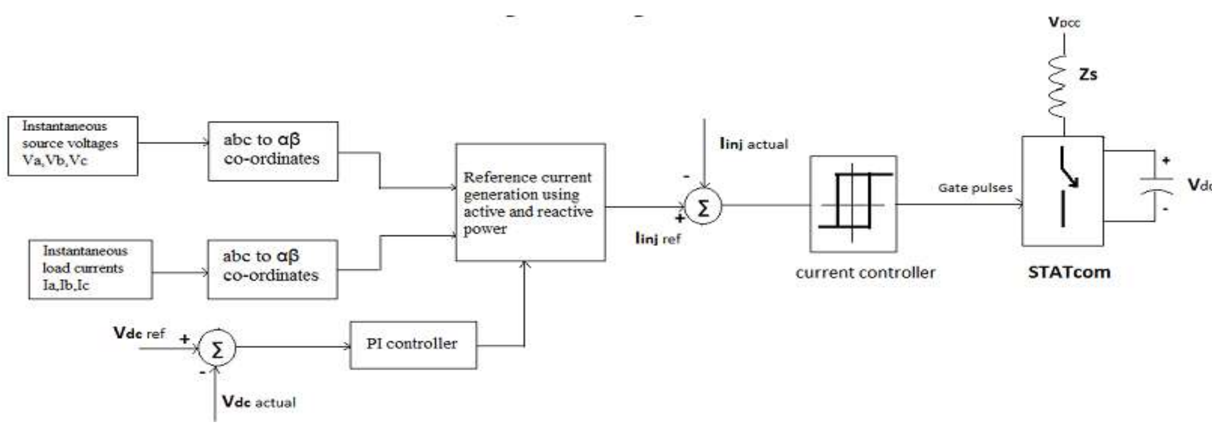

Fig. 6. Block diagram of STATCOM

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method (V,P,Q and S indicates injected voltage, real, reactive and apparent power and subscripts such as In, Quad, Min indicates UPQC-P,UPQC-Q, Minimum VA method) will be,

$$V_{In} < V_{Min} < V_{Quad}$$
$$P_{Quad} < P_{Min} < P_{In}$$
$$Q_{In} < Q_{Min} < Q_{Quad}$$
$$S_{Min} < S_{In} < S_{Quad}$$

III.SCHEMATIC CONFIGURATION OF STATCOM & DVR

The total VA requirement of the DVR is based on the injected voltage and the post-sag source current [3],[6]. An injected voltage and the post-sag source current are depending on the sag, the load displacement power factor and an optimum angle. For calculating the sag, the instantaneous source voltage is compared with the reference voltage. That difference is taken as sag (in p.u.). The load active and reactive power is used to calculate the load displacement power factor. With these two parameters, the optimum angle is varying till power factor angle for finding an optimum VA. At the minimum VA angle the magnitude of injection voltage and the injection angle is determined. The injection voltage is considered as a reference voltage. This reference voltage is compared with the actual injection voltage. That error signal is going to the PWM generator or hysteresis comparator for producing the gate signals. Finally the gate pulses are given to the gate terminal of the converter IGBTs [12]. By tuning the value of LC filter, we can reduce the switching noises in the actual injected voltage. The block diagram of DVR is shown in figure.5.

Instantaneous Reactive Power Theory (IRPT) is used to calculate the reference shunt compensated currents. As per IRPT, the instantaneous source voltage and load currents is used to find the instantaneous active and reactive power [7],[8]. And also the voltage across dc capacitor (Vdc) needs to be maintaining as constant. In order to maintain Vdc constant, the actual dc voltage is compared with the dc reference voltage. The difference is given to the PI controller for regulating the dc link voltage. Based on the values, the instantaneous active and the reactive power reference currents will be generated. Further these reference currents compared with the actual injected currents. This error signal is given to the hysteresis current controller. The hysteresis current controller will generate the required gate signals. The gate signals are given to the converter circuit of the STATCOM as shown in Figure.6.

IV.MINIMUM VA CALCULATION METHOD

The total VA requirement of the UPQC (S_{Upqc})from fig.7. is depending on the VA requirement of both the series(S_{Sr}) and shunt active filter(S_{Sh})[5]. By considering the pre sag source voltage and the post sag load voltage (V_L) are 1 p.u, we can write the total VA requirement is in terms of the load displacement power factor (cosφ), the sag in p.u, and an optimum angle. Here, R_s, L_s is series resistance and inductance respectively.

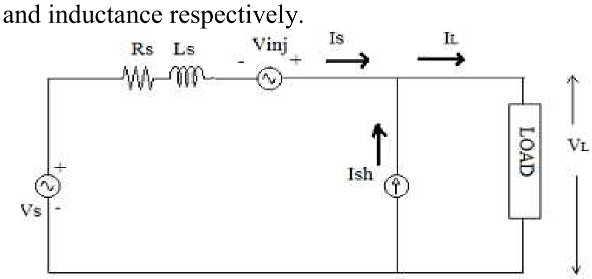

Fig. 7. Equivalent circuit of UPQC

Fig. 7. Equivalent circuit of UPQC

$$S_{Upqc} = S_{Sr} + S_{Sh} \quad (1)$$

In this case we are taking the load current as constant in both the normal and the sag condition. So the load current is considered as 1 p.u.

A. THE APPARENT POWER CALCULATION OF THE SERIES ACTIVE FILTER

Total VA requirement of Series active filter depends on the injected voltage and the post sag source current.

$$S_{Sr} = V_{inj} I_{S2} \quad (2)$$

The injected voltage is,

$$V_{inj} = \sqrt{\left((V_L \cos\alpha - V_{S2})^2 + (V_L \sin\alpha)^2\right)} \quad (3)$$

Similarly the post sag source current in terms of sag and power factor can be found(refer proof in appendix(b)). The post sag source voltage is (1-s)V_{S1} p.u and the pre sag source voltage is V_{S1} So we can write the post sag voltage as follows,

$$V_{S2} = (1-s) \times V_{S1} \quad (4)$$

We are maintaining the active power as constant in both the normal and during the sag condition

$$V_{S1} I_{S1} = V_{S1}(1-s) \times I_{S2} \quad (5)$$

Substitute the value of V_{S2} in the above equation we can get the post sag source current

$$I_{S2} = \frac{I_{S1}}{(1-s)} \quad (6)$$

The shunt active filter is always maintaining unity power factor, So the presag source current(I_{S1}) is equal to the active component of the load current(I_{L1})

$$I_{S1} = I_{L1}\cos\phi \quad (7)$$

$$I_{S2} = \frac{(I_{L1}\cos\phi)}{(1-s)} \quad (8)$$

$$S_{Sr} = \frac{V_{inj}(I_{L1}\cos\phi)}{(1-s)} \quad (9)$$

B. THE APPARENT POWER CALCULATION OF THE SHUNT ACTIVE FILTER

Shunt VA requirement (S_{Sh}) depends on the postsag injected filter current (I_{c2}) and load voltage and also the losses present due to synchronous link impedance(Z_s p.u.)

$$S_{Sh} = I_{c2}V_L + I_{c2}^2 Z_S \quad (10)$$

$$I_{c2} = \frac{\sqrt{\left((1-s)^2 + \cos^2\phi + 2(1-s)\cos\phi\cos(\phi-\alpha)\right)}}{(1-s)} \quad (11)$$

C. TOTAL APPARENT POWER OF THE UPQC

From the shunt active filter and the series active filter's VA requirement, the total VA requirement is given below,

$$S_{Upqc} = V_{inj}I_{S2} + I_{c2}V_L + I_{c2}^2 Z_S \quad (12)$$

By substituting the equation (3), (11),

$$S_{Upqc} = \sqrt{\left((V_L\cos\alpha - V_{S2})^2 + (V_L\sin\alpha)^2\right)} \times \frac{(I_{L1}\cos\phi)}{(1-s)} + I_{L2}\sqrt{\frac{\left((1-s)^2 + \cos^2\phi + 2(1-s)\cos\phi\cos(\phi-\alpha)\right)}{(1-s)^2}} \times V_L + I_{L2}^2\frac{\left((1-s)^2 + \cos^2\phi + 2(1-s)\cos\phi\cos(\phi-\alpha)\right)}{(1-s)^2} \times Z_S \quad (13)$$

By substituting the values for the known variables, the total VA requirement is derived in terms of φ ,α and s. In this equation α is variable quantity which is varying between 0° to load displacement power factor angle. At optimum angle between 0 and the VA requirement will be minimum. This angle is considered as α. Based on this angle the injected voltage and angle as follows .

$$\beta = \tan^{-1}(V_L\sin\alpha)/(V_L\cos\alpha - V_{S2}) \quad (14)$$

$$Vinj = \sqrt{\left((V_L\cos\alpha - V_{S2})^2 + (V_L\sin\alpha)^2\right)} \quad (15)$$

V. FUZZY CONTROLLER

Figure 8shows the internal structure of the control circuit. The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage V_{dc} and the input reference voltage V_{dc-ref} have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current I_{max}. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Figure 9.

The fuzzy controller is characterized as follows:

1) Seven fuzzy sets for each input and output;
2) Fuzzification using continuous universe of dis-course;
3) Implication using Mamdani's 'min' operator;
4) De-fuzzification using the 'centroid' method.

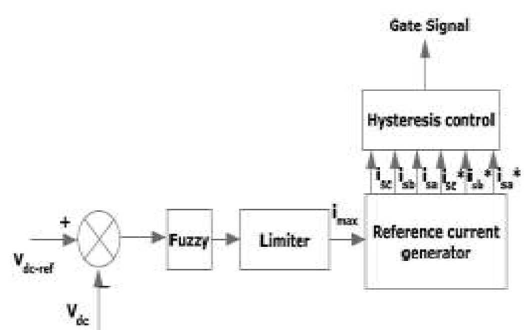

Fig.8.Conventional fuzzy controller

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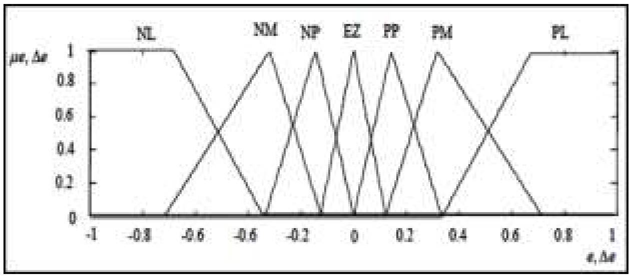

Fig.9. (a) Input Vdc normalized membership function; (b) Input Vdc-ref Normalized Membership Function; (c) Output Imax Normalized Membership Function.

Fuzzification: the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

De-fuzzification: the rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).
Database: the Database stores the definition of the membership Function required by fuzzifier and defuzzifier.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with'V_{dc}' and '$V_{dc\text{-}ref}$' as inputs.

Table 1: Rules for Fuzzy System

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

VI.MATLAB/SIMULINK RESULTS

Here simulation is carried out in several cases, in that 1) Minimum VA Rating of UPQC method for compensation of Harmonics & Voltage sag-swells using Pi Controller, 2) Minimum VA Rating of UPQC method for compensation of Harmonics & Voltage sag-swells using Fuzzy Controller.

Case 1: Minimum VA Rating of UPQC method for compensation of Harmonics & Voltage sag-swells using PI Controller.

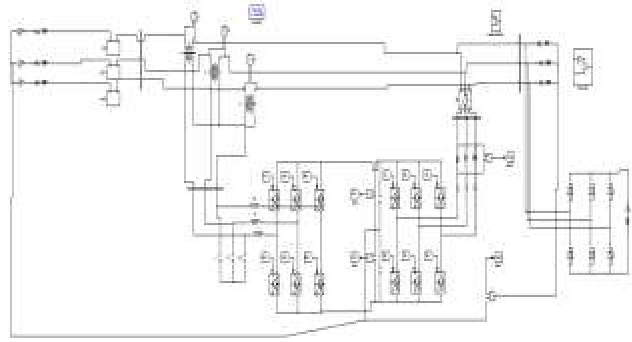

Fig.10 Matlab/Simulink Model of proposed Minimum VA Rating of UPQC method for compensation of Harmonics & Voltage sag-swells using PI Controller.

Fig.10 shows the Matlab/Simulink Model of proposed Minimum VA Rating of UPQC method for compensation of Harmonics & Voltage sag-swells using PI Controller using computer simulation tool.

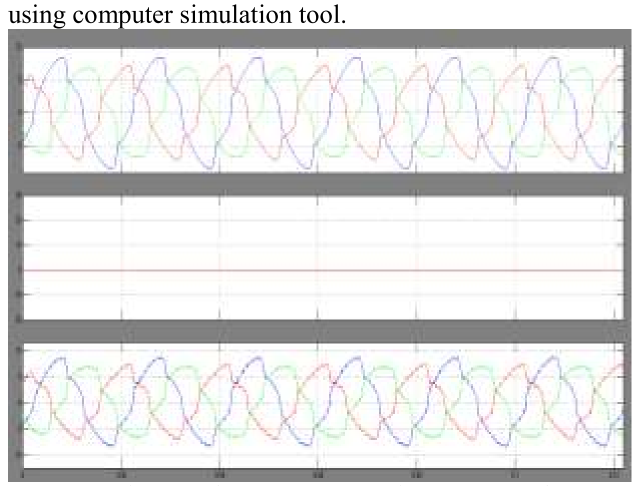

Fig.11 Load Current, Compensation Current, Load Current under No Compensation Scheme

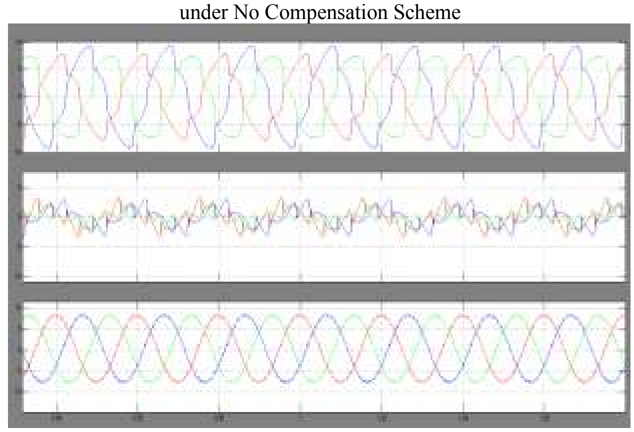

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Fig.11 Load Current, Compensation Current, Load Current under Proposed Compensation Scheme

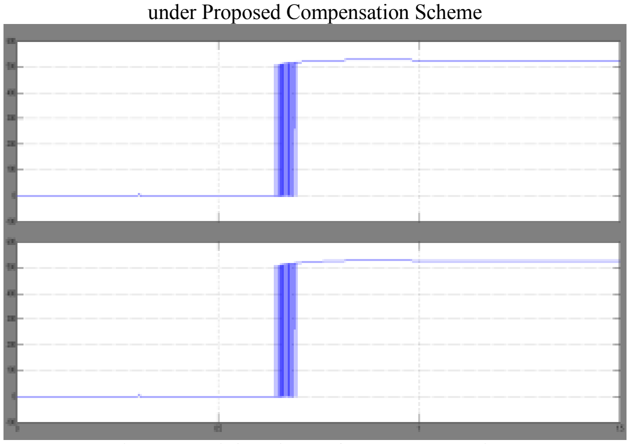

Fig.12 DC Link Voltage of C1 & C2 Capacitors

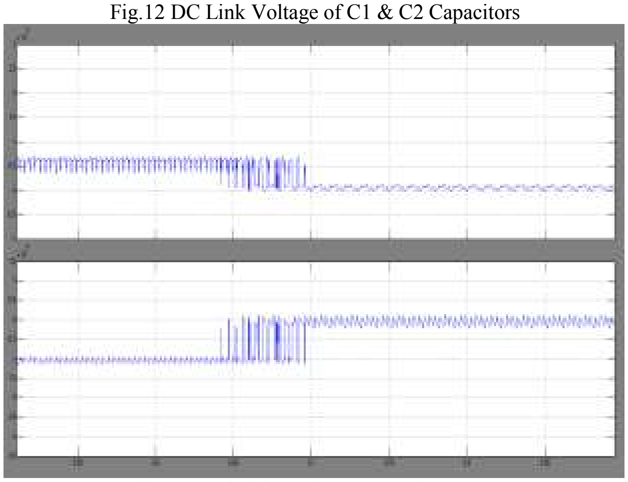

Fig.13 Load Side Active & Reactive Power

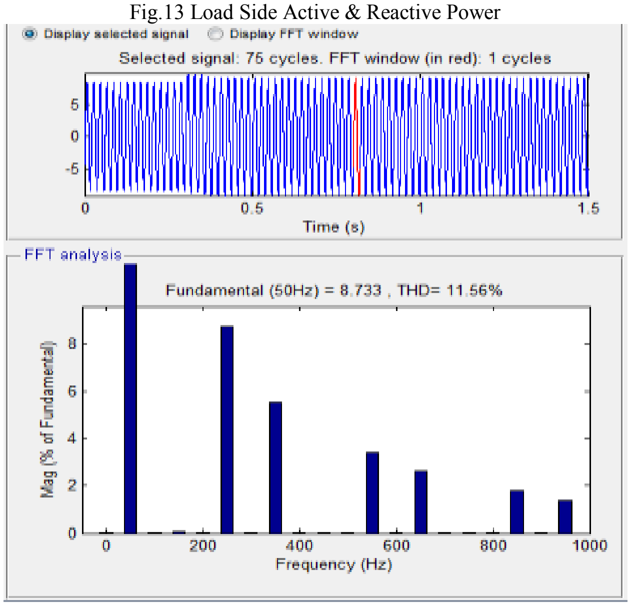

Fig.14 THD Analysis of Source Current under no compensation scheme attains 11.56%.

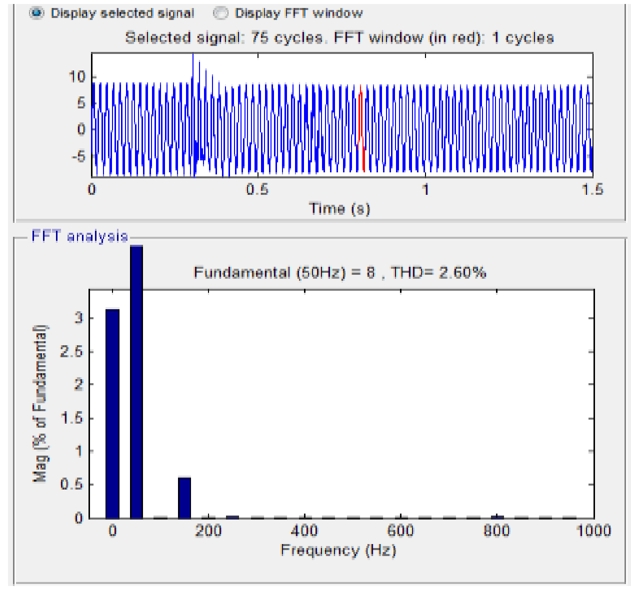

Fig.15 THD Analysis of Source Current under proposed compensation scheme attains 2.60%.

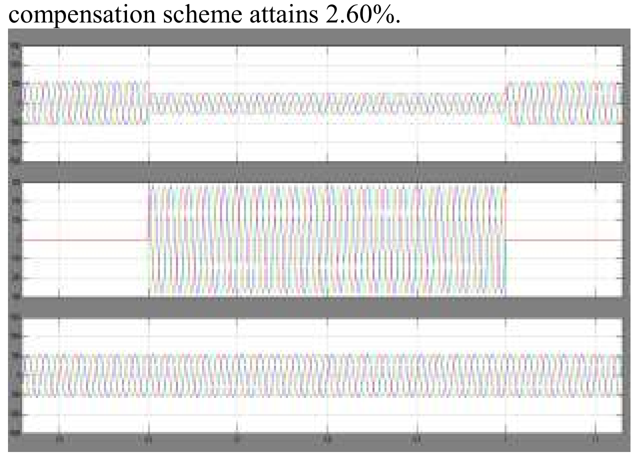

Fig.16 Source Voltage, Compensation Voltage, Load Voltage under proposed compensation scheme.

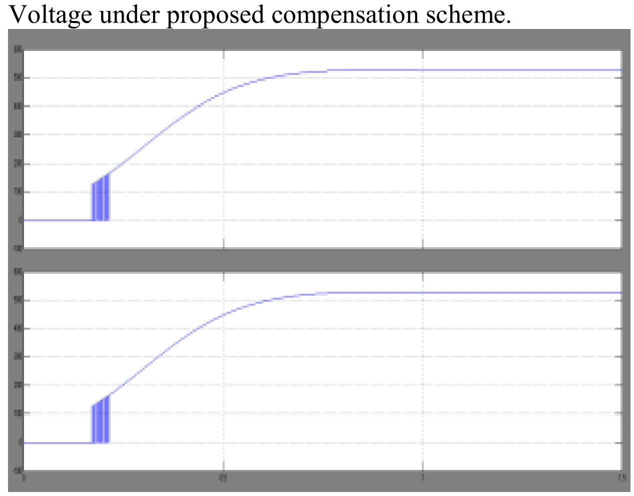

Fig.17 DC Link Voltage of C1 & C2 Capacitors

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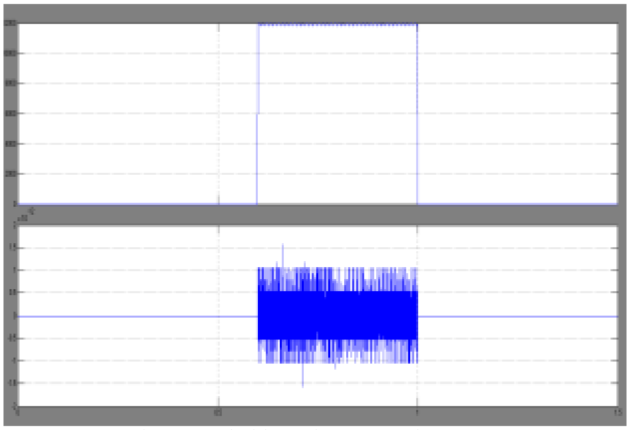

Fig.18 Load Side Active & Reactive Power

Case 2: Minimum VA Rating of UPQC method for compensation of Harmonics & Voltage sag-swells using Fuzzy Controller

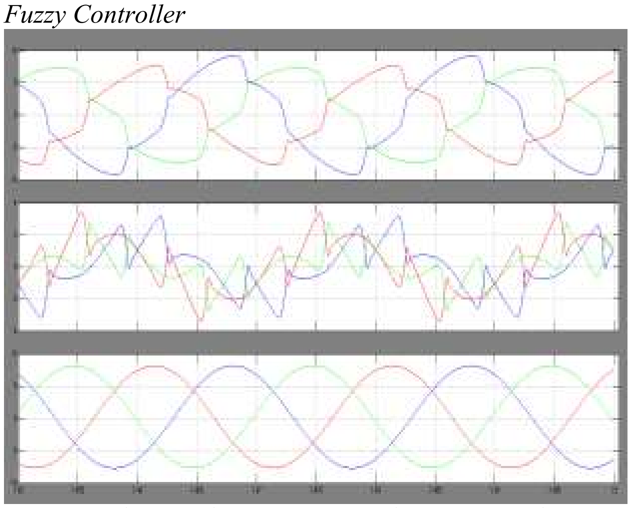

Fig.19 Load Current, Compensation Current, Load Current under Proposed Compensation Scheme using Fuzzy Control Scheme

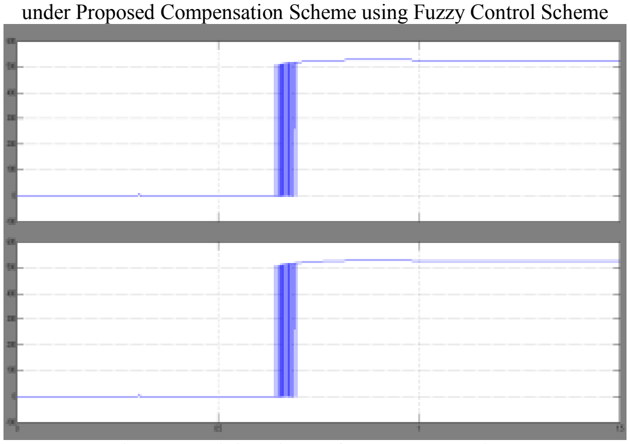

Fig.20 DC Link Voltage of C1 & C2 Capacitors

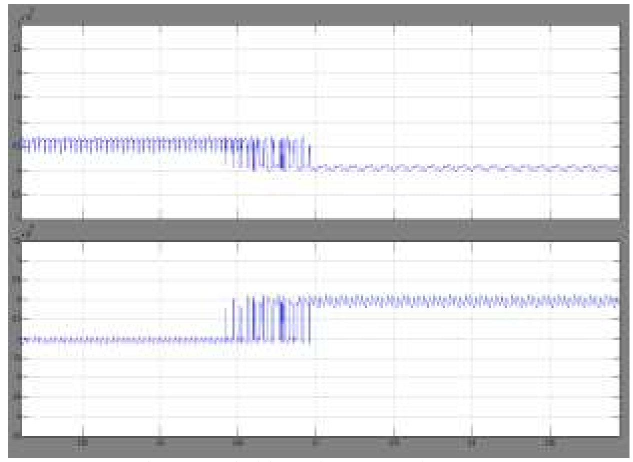

Fig.21 Load Side Active & Reactive Power

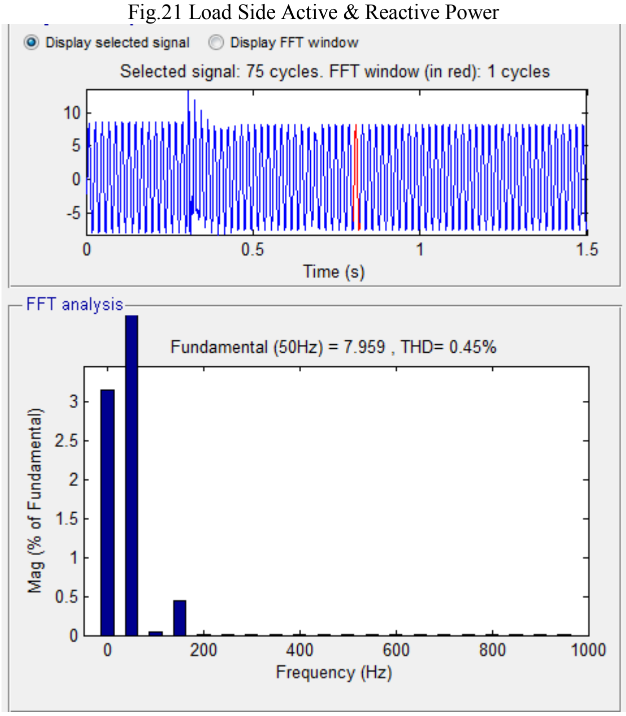

Fig.22 THD Analysis of Source Current under proposed compensation scheme using fuzzy control scheme attains 0.45%.

VII CONCLUSION

Both PI controllers based and fuzzy logic controller VSI based UPQC are implemented for harmonic and reactive power compensation of the non-linear load, voltage sag compensation. In this work the sag of the load voltage has been compensated by using the UPQC with minimum VA loading. And the total harmonic distortion of the source current has been reduced with the improved power factor. The results of various sag compensation methods are obtained separately and that results are compared with this method. The total VA obtained by this method is less than the other conventional methods. And also the active power handled by the UPQC is less than the UPQC-P and the injected voltage through the series active filter is less than the UPQC-Q. Finally a new intelligent application is preferred for getting high stability factor, low error values, better THD values by using fuzzy logic controller.

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