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Unified Power Quality Conditioner for Power Quality Improvement with Induction Motor Drive

Yangala Pedda Lalaiah
M-Tech student scholar Department of Electrical & Electronics Engineering, Laqshya Institute of Technology & Sciences, Telangana, India
Mail: lalaiahyangala@gmail.com

Mr. Raghunam Laveen
Asst. Professor Department of Electrical & Electronics Engineering, Laqshya Institute of Technology & Sciences, Telangana, India
Mai:laveen.raghunam@gmail.com

Abstract— *In this paper presents Three-phase unified Power Quality (UPQC) to improve power quality. The UPQC is realized by the integration of series and shunt active power filters (APF) sharing a common dc bus capacitor. The realization of shunt APF is carried out using a three-phase Voltage Source Inverter (VSI), The performance of the applied control algorithm is evaluated in terms of power-factor correction, source neutral current mitigation, load balancing, and mitigation of voltage and current harmonics in a three-phase, four-wire distribution system for different combinations of linear and non-linear loads. Dynamic Voltage Restorer (DVR) is presented to improve the Power quality in distribution system by injecting voltage in series for the protection of sensitive loads against voltage sags and voltage swells. The performance of the DVR depends on control technique involved .This circuit consists of capacitor in series with the interfacing inductor of the shunt active filter. The series capacitor enables reduction in dc-link voltage requirement of the shunt active filter and simultaneously compensating the reactive power required by the load, so as to maintain unity power factor, without compromising its performance. This allows us to match the dc-link voltage requirements of the series and shunt active filters with a common dc-link capacitor. AC induction motor has a fixed in the output side to run the ac machine with required speed. The proposed topology enables UPQC to compensate voltage sags, voltage swells and current harmonics with a reduced DC-link voltage without compromising its compensation capability by implementing the circuit in MATLAB/SIMULINK software.*

Index Terms: Power quality, UPQC, Load balancing, voltage sags, voltage swells, AC Induction motor, APF.

I.INTRODUCTION

Electric power system is considered to be composed of three functional blocks generation, transmission and distribution. For a reliable power system, the generation unit must produce adequate power to meet customer's demand, transmission systems must transport bulk power over long distances without overloading or jeopardizing system stability and distribution systems must deliver electric power to each customer's premises from bulk power systems [13]. Distribution system locates the end of power system and is connected to the customer directly, so the power quality mainly depends on distribution system. The reason behind this is that the electrical distribution network failures account for about 90% of the average customer interruptions [15]. In the earlier days, the major focus for power system reliability was on generation and transmission only as these more capital cost is involved in these. In addition their insufficiency can cause widespread serious consequences for both society and its environment. But now a day's distribution systems have begun to receive more attention for reliability assessment.

Initially for the improvement of power quality or reliability of the system FACTS devices like static synchronous compensator (STATCOM), static synchronous series compensator(SSSC), interline power flow controller (IPFC), and unified power flow controller (UPFC) etc are introduced [12]. These FACTS devices are designed for the transmission system. But now a day's more attention is on the distribution system for the improvement of power quality, these devices are modified and known as custom power devices. The main custom power devices which are used in distribution system for power quality improvement are distribution static synchronous compensator (DSTATCOM), dynamic voltage Restorer (DVR), active filter (AF), unified power quality conditioner (UPQC) etc.

II.UNIFIED POWER QUALITY CONDITIONER

The best protection for sensitive loads from sources with inadequate quality, is shunt-series connection i.e. unified power quality conditioner (UPQC) .Recent research efforts have been made towards utilizing unified power quality conditioner (UPQC) to solve almost all power quality problems for example voltage sag, voltage swell, voltage outage and over correction of power factor and unacceptable levels of harmonics in the current and voltage The basic configuration of UPQC is shown in fig.1. The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics [14]. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity sensitive loads to voltage flicker/imbalance. Unified Power Quality Conditioner (UPQC) for non-linear and a voltage sensitive load has following facilities:

- It eliminates the harmonics in the supply current, thus improves utility current quality for nonlinear loads.
- UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase, therefore, no additional power factor correction equipment is necessary.
- UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag.
- The voltage injected by UPQC to maintain the load end voltage at the desired value is taken from the same dc link, thus no additional dc link voltage support is required for the series compensator.

The UPQC consists of two three phase inverters connected in cascade in such a manner that Inverter I is connected in series with the supply voltage through a transformer inverter II is connected in parallel with the load. The main purpose of the shunt compensator is to compensate for the reactive power demanded by the load, to eliminate the harmonics and to regulate the common dc link voltage. The series compensator is operated in PWM voltage controlled mode. It injects voltage in quadrature advance to the supply voltage (current) such that the load end voltage is always maintained at the desired value. The two inverters operate in a coordinated manner.

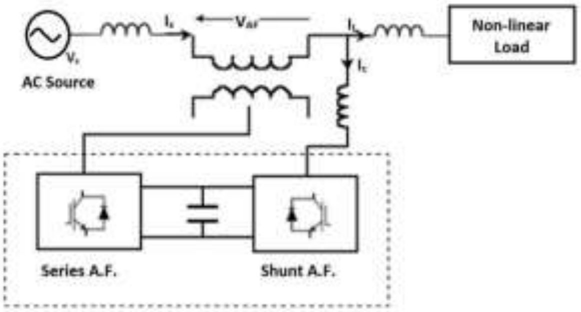

Figure 1: Unified power quality conditioner.

There are three principle elements to the custom power concept; these are:

- The Dynamic Voltage Restorer (DVR), it provides series compensation by voltage Injection for power system sags and swells.
- The Distribution Static Compensator (D-STATCOM), it provides continuously variable Shunt compensation by current injection for eliminating voltage fluctuations and obtaining correct power factor in three-phase systems. An ideal application of it is to prevent disturbing loads from polluting the rest of the distribution system.
- Unified Power Quality Conditioner (UPQC), it provide series and shunt compensation i.e. Inject voltage in sag and swell condition and inject current for elimination of voltage fluctuations, correct power factor, avoid pollution to rest of the distribution system. The proper selection of necessary custom power strategies in addition to accurate system modeling and appropriate protection devices will increase the power quality.

III. VARIOUS SAG COMPENSATION METHODS

A. In-phase compensation method (upqc-p):

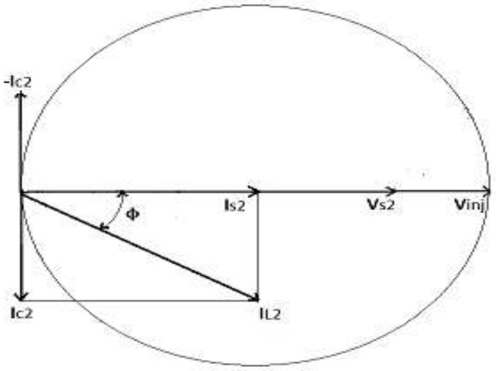

Fig. 2. Phasor diagram of In-phase compensation method.

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. α 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 method is one of the very efficient methods.

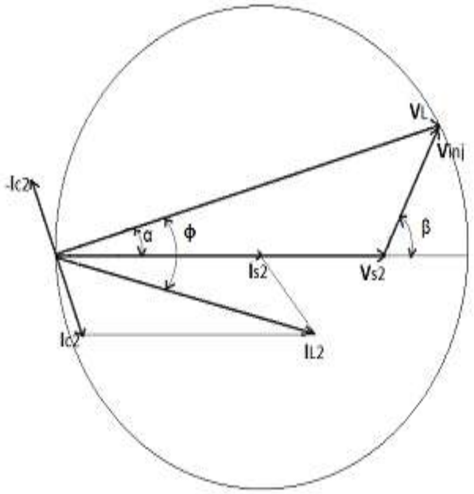

Fig. 3. Phasor diagram of Quadrature compensation method.

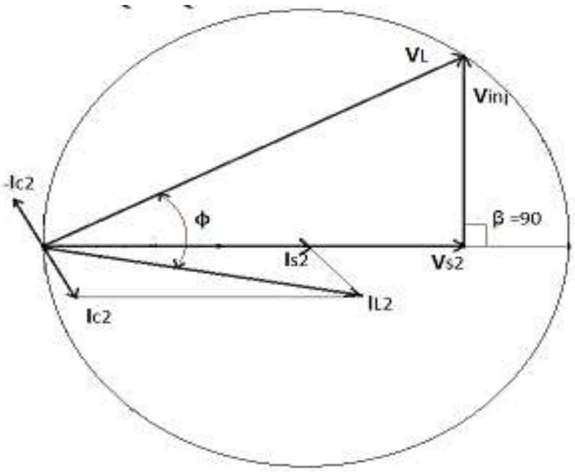

Fig.4. Phasor diagram of Minimum VA method.

The injected voltage and the power limitation in the minimum VA 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,

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

IV. BLOCK DIAGRAM EXPLANATION OF 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.

V. BLOCK DIAGRAM EXPLANATION OF STATCOM

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) need to be maintain 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.

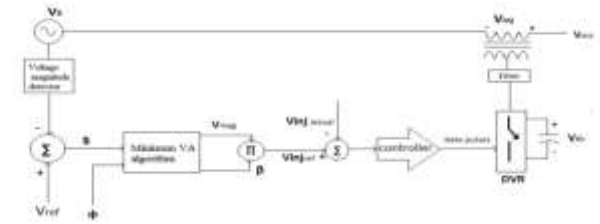

Fig.5. Block diagram of DVR

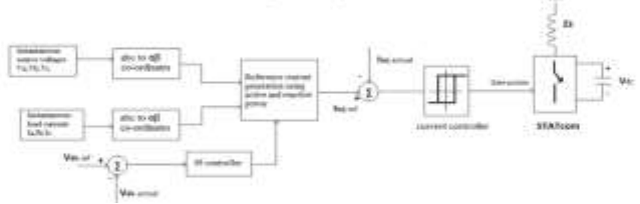

Fig.6. Block diagram of STATCOM.

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.

VI. MINIMUM VA CALCULATION

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.

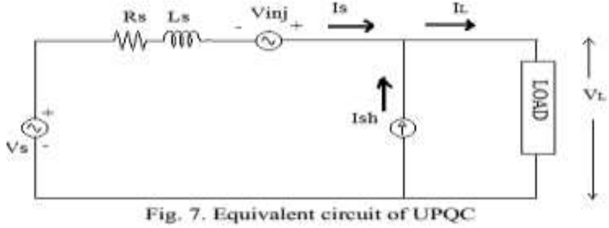

Fig.7. Equivalent circuit of UPQC

$$S_{Upqc} = S_{Sr} + S_{Sh} \tag{1}$$

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.

$$S_{Sr} = V_{inj} I_{S2} \tag{2}$$

The injected voltage is,

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

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,

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

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

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

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

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

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

$$I_{S1} = I_{L1} \cos\phi \tag{7}$$

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

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

B. The apparent power calculation of the shunt active filter

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

$$S_{Sh} = I_{c2}V_L + I_{c2}^{\,2}Z_S \tag{10}$$

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

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,

$$S_{Upqc} = V_{inj}I_{S2} + I_{c2}V_L + I_{c2}^{\,2}Z_S \tag{12}$$

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

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

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.

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

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

VII.MATLAB/SIMULINK RESULTS

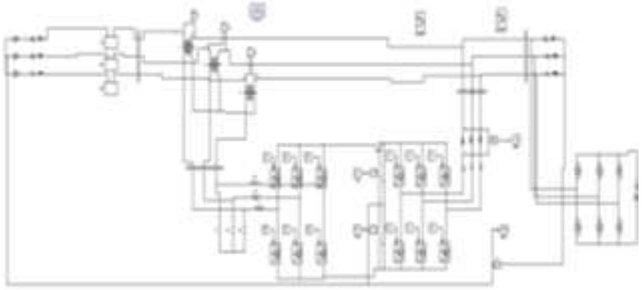

Fig 8.Matlab/Simulink Diagram of The System With Proposed UPQC.

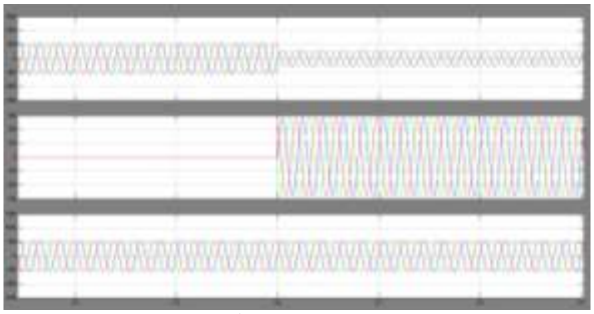

Fig. 9. Source, series active filter and load voltages with minimum VA method.

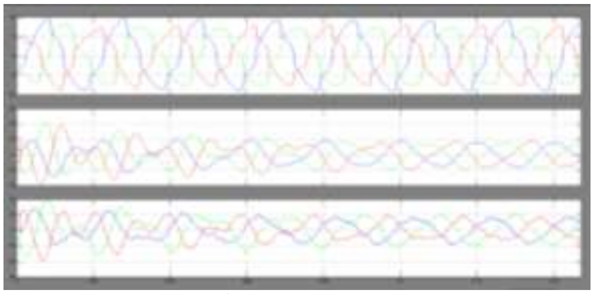

Fig. 10. Load, shunt active filter and source currents with minimum VA method.

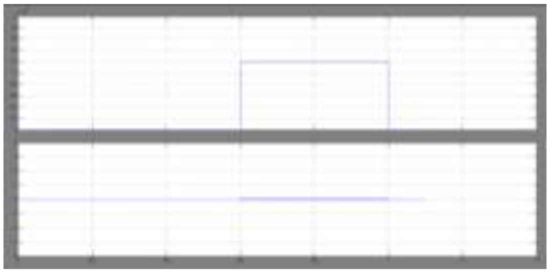

Fig. 11. Power handled by UPQC in minimum VA method.

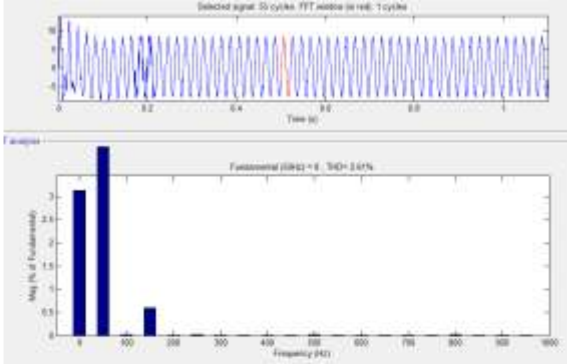

Fig. 12. THD analysis of source current.

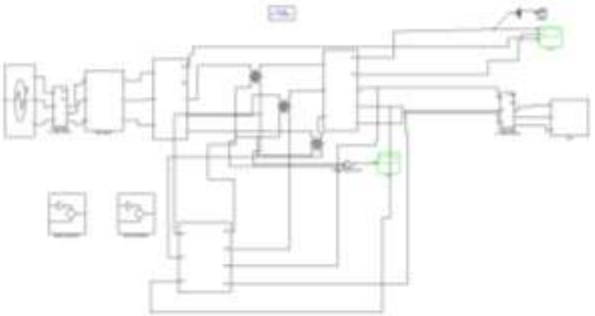

Fig 13.Matlab/Simulink Diagram of the System with Proposed UPQC and Induction Motor Load.

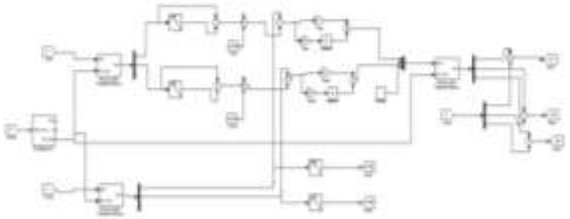

Fig 14.Series Compensator

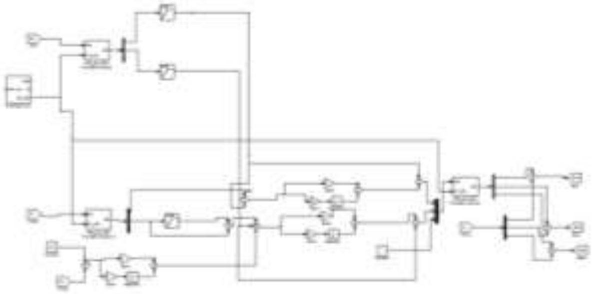

Fig 15.Shunt Compensator.

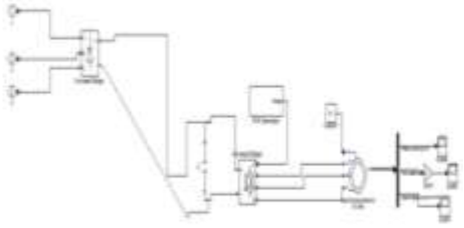

Fig 16.Induction Motor Load.

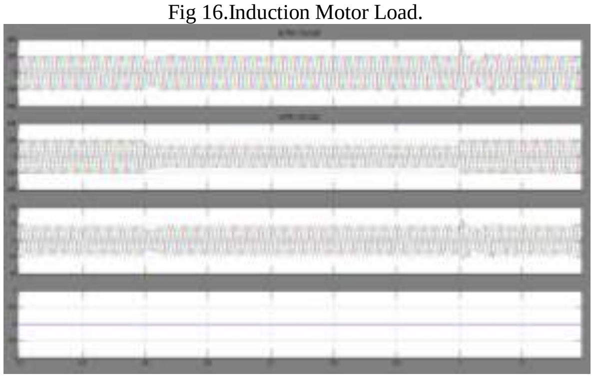

Fig.17. Source, series active filter and load voltages with minimum VA method with induction motor.

VIII.CONCLUSION

In this paper 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.

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Author's Profile:

YANGALA PEDDA LALAIAH M.TECH (ELECTRICAL POWER SYSTEMS) PURSUING In Laqshya Institute of Technology Sciences ,TANIKELLA(V) ,KHAMMAM(D), TELANGANA, INDIA. EMail id: lalaiahyangala@gmail.com

Mr. RAGHUNAM LAVEEN was born in India in the year of 1985.He received B.Tech degree in Electrical and Electronics Engineering in the year of 2006 & M.Tech PG in Electrical power systems in the year of 2013 from JNTUH, Hyderabad. He is expert in Control Systems, Electrical circuits, Power system Subjects. He is currently working as An Assistant Professor in EEE Department in Laqshya Institute of Technology and Sciences, Khammam, Telangana State ,India.