International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 12, Issue 6 (June 2016), PP.20-26

Voltage Quality Enhancement in an Isolated Power System through Series Compensator

Aniket A. Nakhate[1], Shrikant S. Mopari[2]
[1] P.G. Student, Department of Electrical Engineering, Government College of engineering, Aurangabad, India
[2] Assistant Professor, Department of Electrical Engineering, Government College of engineering, Aurangabad, India

Abstract:- Voltage sag and harmonic mitigation is one of the most challenging issues for utility industry. This paper deals with improving the voltage quality in an isolated power system with the use of series compensator. The proposed method not only mitigates the effect of voltage sag/swell but also significantly reduces harmonic distortion due to presence of sensitive and non linear load in the network. Series compensator (SC) reduces the harmonics to an acceptable level by injecting harmonic current of same magnitude but of opposite polarity. The compensation process cause undesirable variation of voltage across terminal of energy storage system (ESS) of series compensator due to exchange of power with external network. The effect of voltage sag/swell is minimized by phase adjustment of load terminal voltage. The PI controller is used to develop control strategy for SC. Simulation results have confirmed the effectiveness of the proposed method.

Keywords:- Harmonics, series compensator, isolated power system, ESS, voltage sag

I. INTRODUCTION

Today's worldwide growth in digital economy makes widespread usage of power electronic devices not only in commercial and industrial sector but also in domestic sectors. The increase in power demand requires higher level of power quality and reliability (PQR). The reliability of the proper supply offered by utility varies significantly and depends on the several factors such as lightening, non linear loads, large switching loads, faults etc. It can disrupt the electric power grid also. Finally electric power grid is unable to provide consistently digital power supply with high PQR. The power electronic device demand for higher level PQR with low voltage direct current but are highly sensitive to very short duration interruptions, voltage sags/swells, harmonics and distorted waveforms. In the latter case voltage flicker can occur and that can be major concern for power electronic devices.

A traditional method to enhance the voltage quality is to use passive filters connected at the sensitive load terminals [1]. But in usual practice it has some drawbacks such as the source impedance or load conditions changes, it can lead to resonance between the filter and source impedance, finally result get partial deteriorate. To overcome this problem active filters such as that described in [2] may be used. Active filter connected at the sensitive load terminal and injects harmonic currents of the same magnitude but of opposite polarity to cancel the present harmonics. But the problem of voltage sag/swell remains unsolved. The variations in the drive load would result in voltage sag/swell or flickers appearing in the upstream voltage. Thus the challenge is to regulate the sensitive load terminal voltage so that its magnitude remains constant and any harmonic distortion is reduced to an acceptable level.

Isolated power systems [3] can be found on oil exploration areas and remote mining districts. The important feature of isolated power systems is limited generation capacity and comparatively low fault level. The electrical source can be in the form of diesel generator-sets and the source impedance is normally high. The loads are often comparatively large DC or AC drives [4]. The proposed series compensator system mitigates all these three problems simultaneously. Specifically the investigation is done to develop a method to control terminal voltage of sensitive load. The control is achieved by regulating power flow via phase angle adjustment. The proposed scheme also shows that the voltage-sag ride-through capability of the sensitive load can be improved by taking harmonic power from the external system into the series compensator.

II. PROBLEMS ASSOCIATED WITH POWER QUALITY

According to the IEEE (IEEE std. 1100,1999),power quality is defined as, "The concept of powering and grounding electronic equipment in a manner suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment." There are different types of power quality problems such as

- long duration voltage variation
- short duration voltage variation

- voltage sag/swell[5][6]
- interruption and
- Steady state phenomena like harmonics, notching, noise etc.

Among these numerous problems, voltage sags/swells and harmonics are the critical problems which may cause severe damage to the single equipment or whole system.

A. ***Voltage sags***

Voltage sag is a short decrease in the rms voltage at power frequency of 1 to 0.9 pu of the nominal voltage value. The duration of voltage sag is 0.5 to 1 minute. Voltage sags occurs due to system faults and last for durations ranging from 3 cycles to 30 cycles depending on the fault clearing time.

B. ***Voltage swells***

A voltage swell is an increase in rms voltage at the power frequency between 1.1 and 1.8p.u. for duration between 0.5 cycles to 1minute. A swell can occur on the healthy phases during a single line to ground fault. Swell can also be caused by switching off large load, energizing a large capacitor bank or incorrect setting of tap changer.

C. ***Steady state phenomena***

Waveform Distortion-

This is defined as steady state deviations from an ideal sine wave of power frequency. There are four type of waveform distortion.

a. DC offset
b. Harmonic
c. Inter harmonics
d. Notching

III. CAUSES OF DIPS, SAGS AND SURGES

1. Rural location remote from power source
2. Long distance from a distribution transformer with interposed loads
3. Unreliable grid system
4. Switching of heavy loads and nonlinear load
5. Unbalanced load on a three phase system
6. Equipment not suitable for local supply

IV. GENERAL BENEFITS OF POWER QUALITY IMPROVEMENT

1. Improvement in power factor and avoided penalty for low power factor or incentive for high power factor
2. Improvement in voltage profile and consequent efficient operation of power equipment
3. Reduction in losses and hence lower energy bills
4. Reduction in harmonic distortion and consequent reduction in copper loss, core loss and stray loss
5. Prevention of malfunction of equipment and avoided loss of production
6. Reduction in failure of equipment due to reduced electrical and thermal stress
7. Enhanced life / reliability of equipment due to lower operating temperature due to lower losses

V. SYSTEM MODEL

In order to overcome the power quality problems the concept of series compensator devices is introduced recently. There are several power quality problems among which voltage sags and harmonics are the most severe. The function of the proposed series compensator is to ensure that the voltage across the sensitive load terminals is of superior quality. The central part of the Compensator is an energy storage system (ESS) and a VSI where a PWM switching scheme is often used. The ESS can be a capacitor of suitable capacity. Because of the switching, harmonics are generated, and filtering is required.

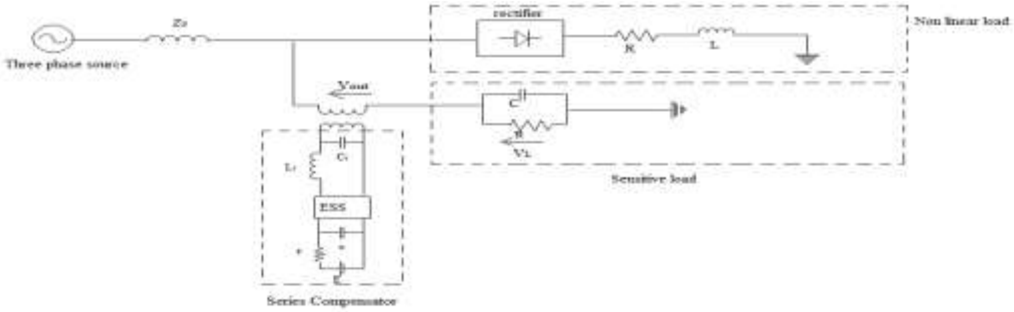

Fig.1: Typical isolated power system with proposed series compensator

The general configuration of the series compensator consists of:
1) An Isolation Transformer
2) A Harmonic filter/ passive filter
3) Energy Storage Devices
4) A Voltage Source Inverter (VSI)
5) By-pass switch
6) A Control and Protection system

a. An Isolation Transformer

An isolation/booster/injection transformer may either three single-phase transformer units or one three phase transformer unit can be used for voltage injection purpose. The Isolation transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from one side to another side. It consists of two side voltages namely the high voltage side and low voltage side. The basic function of the injection transformer is to isolate the compensator circuit from the distribution network. The proposed system mitigates the voltage Sag and reduces harmonic of an isolated power system.

b. A Harmonic filter

Harmonic filter unit comprises of inductor and capacitor. The harmonic filters are generally placed either on the high voltage side or the converter side of the injection transformers. In this system filters are used for eliminating the unwanted harmonic components generated by the VSI action. Higher orders harmonic components distort the compensated output voltage. The unnecessary switching harmonics generated by the VSI must be removed from the injected voltage waveform in order to maintain an acceptable Total Harmonics Distortion (THD) level.

c. Storage Device

During deep voltage sags active power should be provided to the load. Lead-acid batteries, flywheel or capacitor can be used for energy storage. It is also promising to provide the required power on the DC side of the VSI by an auxiliary bridge converter that is fed from an auxiliary AC supply. The series compensator need real power for compensation purpose during voltage disturbance in the distribution system. In this case the real power of the series compensator must be supplied by energy storage when the voltage disturbance occurs. The energy storage such as battery is responsible to supply an energy source in D.C form.

D. ***A Voltage source Inverter***

VSI is a power electronic system consists of a storage device and switching devices. It generates a sinusoidal voltage at any required frequency, magnitude, and phase angle. This voltage source inverter system is used to convert from dc storage to ac. Rating of the VSI Converter is of low voltage and high current type due to injection transformer in the series compensation technique.

E. ***By-pass Switch***

During voltage sag appearance in the power system, By-pass switch play very significant role. It is used to protect the inverter from high current. Whenever any fault or short circuit occur on downstream of distribution system, the series compensator change in to the bypass condition where the VSI inverter is protected against over current flowing through the power semiconductor devices.

F. ***A Control and Protection System***

The main function of the control and protection system is to maintain constant voltage magnitude under the disturbances at the point where a sensitive load is connected.

VI. HARMONIC COMPENSATION

Due to commutation action of the converter connected to the main drive load, distorted voltage V_L will appear on the upstream source-side of the sensitive load and the phase voltages can be expressed as,

$$V_{La}(t) = \sum_{n=1}^{n} [\mathrm{V_{0n}} + \mathrm{V_{1n}} \sin(\mathrm{nwt} + \emptyset_{1n}) + \mathrm{V_{2n}} \sin(\mathrm{nwt} + \emptyset_{2n})] \quad \text{... (1)}$$

$$V_{Lb}(t) = \sum_{n=1}^{n} [\mathrm{V_{0n}} + \mathrm{V_{1n}} \sin(\mathrm{nwt} + \emptyset_{1n} - 2n\pi/3) + \mathrm{V_{2n}} \sin(\mathrm{nwt} + \emptyset_{2n} + 2n\pi/3)] \quad \text{... (2)}$$

$$V_{Lc}(t) = \sum_{n=1}^{n} [\mathrm{V_{0n}} + \mathrm{V_{1n}} \sin(\mathrm{nwt} + \emptyset_{1n} + 2n\pi/3) + \mathrm{V_{2n}} \sin(\mathrm{nwt} + \emptyset_{2n} - 2n\pi/3)] \quad \text{... (3)}$$

Where, *n* is the harmonic order; *V0n* is the zero phase sequence voltage component; V_{1n} and ; V_{2n} are the magnitude of the positive phase sequence and negative phase sequence voltage components; $\emptyset_{1n}$ and $\emptyset_{2n}$ are the phase of the positive and negative phase sequence voltage components.

This voltage contains harmonic components which is harmful and unwanted. The desired voltage at the sensitive load terminal is the fundamental components of voltages given by equation (1)-(3). The proposed voltage injection method is to compensate for the difference between V_L and the desired voltage. This is achieved by injecting an ac voltage component in series with the incoming three-phase network. Hence the desired injection voltages are-

$$V_{inj-a} = V_{fa}(t) - V_{La}(t)$$
$$= \sum_{n=1} V_{0n} + \sum_{n=2} V_{1n} \sin(nwt + \emptyset_{1n}) - \sum_{n=1} V_{2n} \sin(nwt + \emptyset_{2n}) \quad ...(4)$$
$$V_{inj-b} = V_{fb}(t) - V_{Lb}(t)$$
$$= \sum_{n=1} V_{0n} + \sum_{n=2} V_{1n} \sin(nwt + \emptyset_{1n} + 2\pi/3) - \sum_{n=1} V_{2n} \sin\left(nwt + \emptyset_{2n} + \frac{2n\pi}{3}\right) \quad ...(5)$$
$$V_{inj-c} = V_{fc}(t) - V_{Lc}(t)$$
$$= \sum_{n=1} V_{0n} + \sum_{n=2} V_{1n} \sin(nwt + \emptyset_{1n} - 2\pi/3) - \sum_{n=1} V_{2n} \sin(nwt + \emptyset_{2n} - 2n\pi/3) \quad ...(6)$$

Therefore, from the above equations the injected voltage of the compensator would be-

$$\overrightarrow{V^*} = V_f - V_L = -\overrightarrow{V_{Lh}} \quad \ldots (7)$$

Where, V_f is the fundamental voltage and V_{Lh} is the vector containing all harmonic component in (1)-(3). V_L is measured online and the fundamental voltage is obtained by phase locked loop (PLL) scheme. So the injection voltage V^* is obtained online which is implemented to mitigate the harmonics in the sensitive load terminal.

VII. VOLTAGE SAG/ SWELL MITIGATION

The principle of compensation for upstream voltage sag/swell using series compensator has been discussed in [7]. Voltage sag/swell is generated due to the load change. The above voltage problems are sensed separately and passed through the sequence analyser. The magnitude component is compared with reference voltage (Vref). Pulse width Modulation (PWM) control technique [8] is applied for inverter switching so as to produce a three phase 50 Hz sinusoidal voltage at the load terminals. The IGBT inverter is controlled with PI controller in order to maintain 1 per unit voltage at the load terminals. PI controller (Proportional Integral Controller) is a closed loop controller which drives the plant to be controlled with a weighted sum of the error (difference between the output and the desired set point) and the integral of that value. One advantage of a proportional plus integral controller is that the integral term in a PI controller causes the steady-state error to be zero for a step input.

The energy exchange between the SC and the external power system over the time interval '*T*' is

$$E = \frac{T}{2} \sum_{K=2}^{\infty} V_K I_K cos\emptyset_k \quad \ldots (8)$$

The SC supplies energy to the external system when *E>0*. As the only significant source of energy storage in the SC is the ESS, the export of the energy to the external system will result in a decrease in the voltage V_{DC}. Hence V_{DC} has to be controlled within certain range. In order to achieve this, there must be control on the energy flow. This can be achieved by adjusting the phase of the fundamental component of the reference voltage of the SC. If a phase shift α is introduced to the reference voltage then we get

$$V_L(t) = V_1 \sin(wt + \emptyset_1 + \propto) \quad \ldots (9)$$

The intention is not to change the magnitude of the fundamental component of the load-side voltage V_L. Hence V_L has the same magnitude as without the phase shift. With an assumed constant impedance load model, I_1 will also remain constant following the phase shift. It then follows that the new injection voltage is

$$V_{inj}(t) = V_1 sin(\omega t + \emptyset_1 + \alpha) - V_1 \sin(\omega t + \emptyset_1) - V_{Lh} \quad .... (10)$$

Referring above equations, the energy flow between the ESS and the external power system becomes

$$E = \frac{T}{2}\left(V_1 I \cos(\emptyset_1 + \alpha) - \sum_{k=2}^{\infty} V_k I \, cos\emptyset_k\right) \quad \ldots. (11)$$

From eq^n (11) E will be zero if $\propto$ will be $\propto_0$

The control strategy of α for different load condition can be designed. V_{DC} is monitored continuously and no sooner than it is outside a set range, α is adjusted in a manner to bring the voltage within the set range. In this way constant voltage is maintained and voltage sag/swell will be mitigated.

VIII. ILLUSTRATIVE EXAMPLE

Consider the generator supplying loads, as main drive load and sensitive load is a three phase 440-V voltage source. The main drive load converter is assumed to be a six-pulse controlled rectifier. The rating of the dc load is 0.5 kW and it is also the base value chosen for the system. The current of the motor is controlled and load change is simulated by changing the reference current of the motor. The capacity of the sensitive load is assumed to be 1 kW and its power factor at the fundamental frequency is 0.75 leading. The sensitive load level is assumed to be at full load in this example. The compensator is modelled as a PWM inverter. A battery and capacitor is used as the ESS. The simulation is accomplished using MATLAB. The voltage at the sensitive load terminals is distorted because of the harmonics generated due to commutation action of the converter supplying DC to the main drive load and the THD level is 22.26%. The distorted voltage at the sensitive load terminals without using compensator is as shown in fig.2. The proposed series compensator compensates these harmonic contents and reduced THD level to 2.32%. The waveform of the terminal voltage at sensitive load with implementation of series compensator is shown in fig.4. To investigate the effect of voltage sag/swell, load change is applied for the time duration of 0.18 to 0.3 sec. Voltage sag/swell may occur due to the fault. The voltage sag generated at sensitive load is as shown in fig.3. This voltage sag is strong enough to damage the sensitive loads. Proposed series compensator compares voltage change with respect to reference voltage and corrects the value of $\propto$. PI controller minimizes error signal and gives pulses to inverter which in turn supplied the required voltage from ESS to the sensitive load during sag period and in turn mitigate the sag. Fig.5.shows mitigated voltage sag at the sensitive load terminal with the use of series compensator. Proposed series compensator mitigates the voltage sag to up to 95.45% of reference nominal voltage. Hence the efficiency of the proposed series compensator is 95.45%.

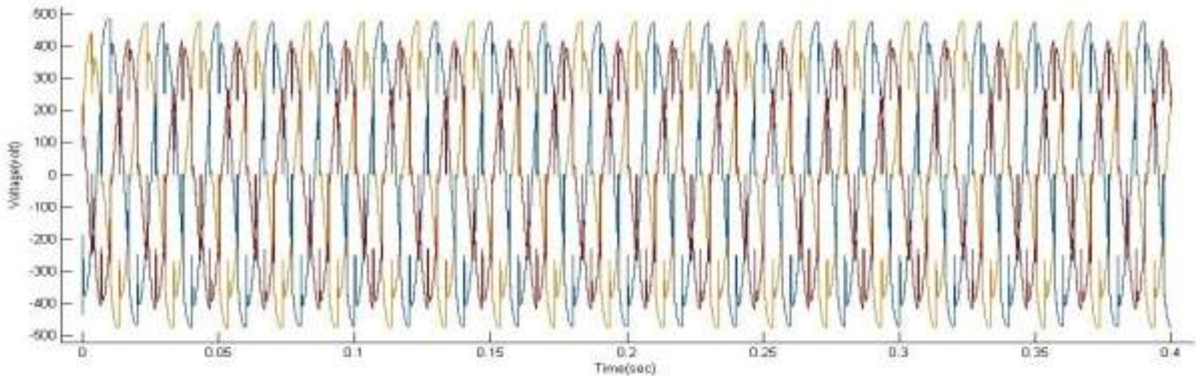

Fig.2: Distorted terminal voltage across sensitive load without series compensator

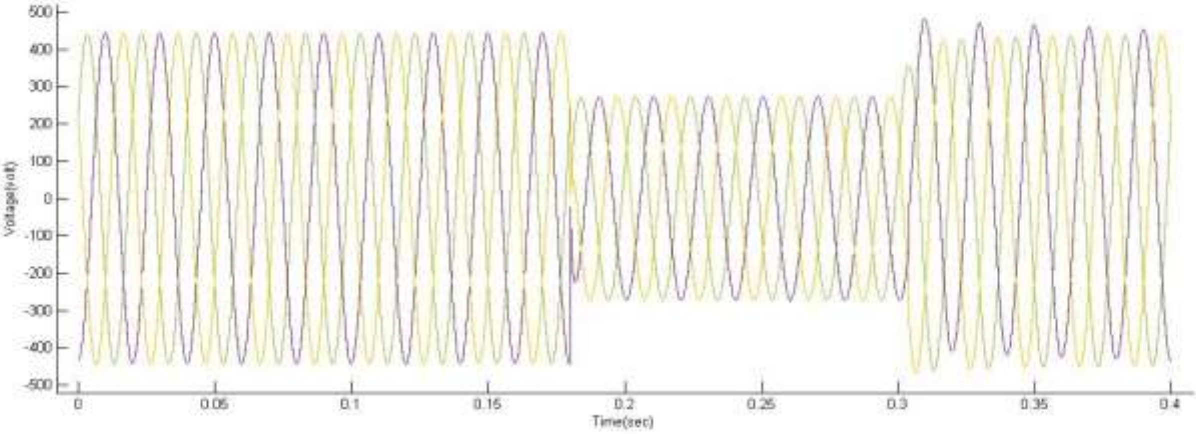

Fig.3: Voltage sag at sensitive load during load change without series compensator

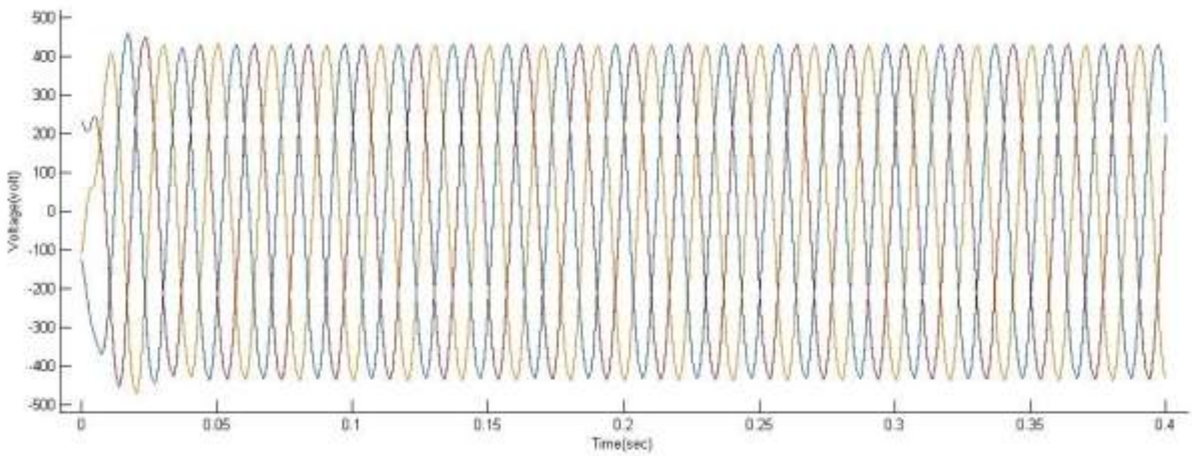

Fig.4: Terminal voltage at sensitive load with series compensator

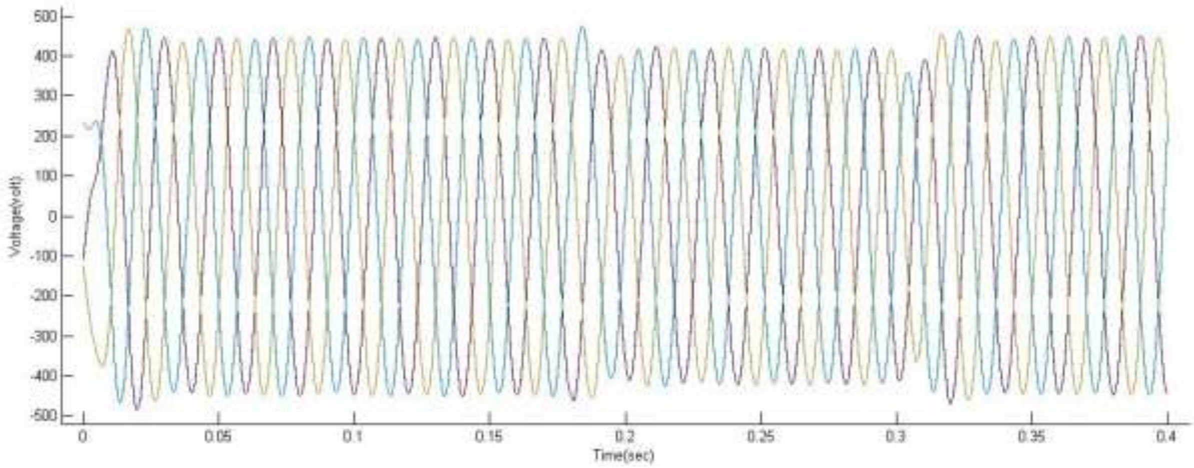

Fig.5: Voltage sag mitigation at sensitive load with series compensator

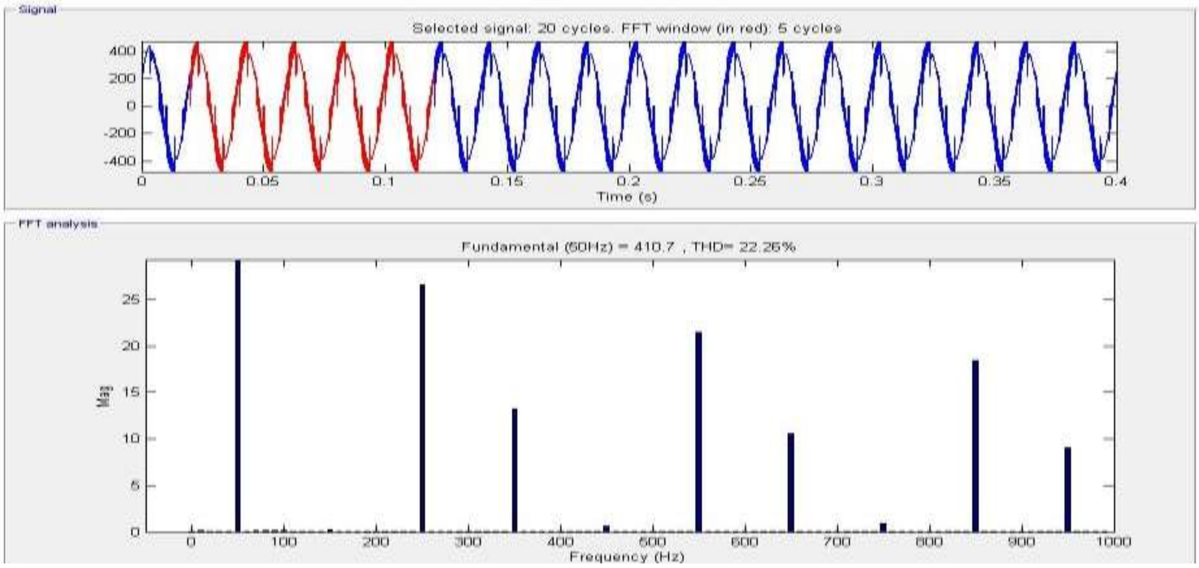

Fig.6: THD in voltage across sensitive load terminal without series compensator

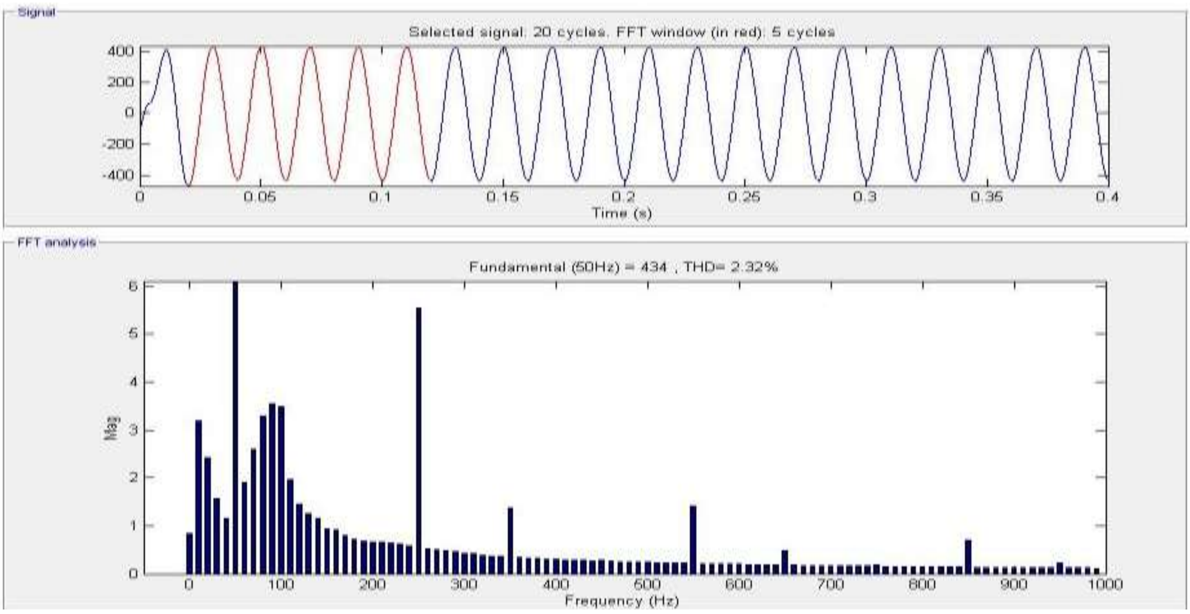

Fig.7: THD in voltage across sensitive load terminal with series compensator

IX. CONCLUSION

Enhancement of voltage quality in an isolated power system by series compensator has been investigated. The control system is designed for the SC which introduces feedback scheme. This scheme is further connected with an inductive filter used to mitigate higher order harmonics generated by VSI of the series compensator. The proposed method gives harmonic reduction with an acceptable level 2.37%. In this method power exchange exists between SC and external network. Such exchange of power produces variation in terminal voltage of ESS. The proposed new control strategy maintains the terminal voltage of ESS by phase adjustment of load terminal voltage. The SC absorbs harmonic real power during power exchange which improves load ride through capability of SC during voltage sag. Simulation results have proved the effectiveness of the proposed method.

REFERENCES

[1]. J. C. Das, “Passive filter—Potentialities and limitations,” IEEE Trans. Ind. Appl., vol. 40, no. 1, pp. 232–241, Jan. 2004.
[2]. H. Akagi, “New trends in active filter for power conditioning,” IEEE Trans. Ind. Appl., vol. 32, no. 6, pp. 1312–1322, Nov. 1996.
[3]. I. Jonasson and L. Soder, “Power quality on ships-a questionnaire evaluation concerning island power system,” in Proc. IEEE Power Eng. Soc. Summer Meeting, Jul. 2001, vol. 15–19, pp. 216–221.
[4]. K. S. Smith and L. Ran, “Voltage stability assessment of isolated power systems with power electronic converters,” Proc. IEE, Gen., Transm. Dist., vol. 141, no. 4, pp. 310-314, July 1994.
[5]. Surya Prakash Singh , Prof. R.K. Tripathi “Voltage Sags and Their Characterization,” IEEE 2010.
[6]. Muhamad Mansor , Prof. Dr. Nasrudin Abdul Rahim “Voltage Sag Detection – A Survey ,”
[7]. E. K. K. Sng, S. S. Choi, and D. M. Vilathgamuwa, “Analysis of series compensation and dc link voltage controls of a transformer less selfcharging dynamic voltage restorer,” IEEE Trans. Power Del., vol. 19, no. 3, pp. 1511–1518, Jul. 2004.
[8]. Leela.S, Dash. S.S., “Control of Three Level Inverter Based Dynamic Voltage Restorer” Journal of Theoretical and Applied Information Technology, Vol.8, No. 1, 2009. Pp-13-17