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Modeling of Series Compensator for Enhancement of Power Quality in an Isolated Power System

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Abstract: **In general, maintaining and the operation of sensitive loads is difficult but power electronics and advanced control systems made it possible for solving the power quality problems. The most severe power quality problems which affect the sensitive loads are sag, swells and harmonics. For the mitigation of these disturbances the best suitable method is Series compensation. Due to presence of non liner loads which causes harmonics in the network Series compensator not only mitigates sag but also harmonics in the system. The series compensator plays an important role which avoids the sag and reduces the harmonics. The main components of series compensator are Energy Storage System (ESS), Voltage Source Inverter (VSI), Injection Transformer. ESS act as energy system which injects voltage into system through injection transformer during sag which regulates voltage to appropriate level. By implanting this way, terminal voltage maintained at constant level and sensitive loads are protected. The series compensator is designed in MATLAB SIMULINK work space. The proposed series compensator results were shown thus improved the power quality of an isolated power system. This method gives the effective solution than conventional methods.**

Keywords: **Sensitive loads, Power quality, Harmonics, voltage Sag, ESS (Energy Storage System),VSI (Voltage Source Inverter), Injection Transformer.**

1. INTRODUCTION

Isolated power systems are commonly found in rural and remote areas of the world.These systems represent the alternative to grid connection, where interconnection to a large grid is not viable due to high cost andgeographical obstacles. Isolated power systems are characterized by limiting generating capacity. The sensitive loads which are present in the isolated power systems are much more affected by the power quality problems. Power quality problems encompass a wide range of disturbances such as voltage sags/swells, flickers, harmonics distortion, impulse transient, and interruptions. Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads, because (i) the occurrence of voltage sag in the system can cause devices/process down time effect on product quality, faiure /malfunction of equipments etc., (ii) the occurrence of harmonics in the system can cause excessive losses and heating in motors, capacitors and transformers connected to the system. To avoid those undesirable affects the proposed method mitigates the problems caused by voltage sag and harmonics.

Flexible AC Transmission systems (FACTS) technology is the ultimate tool for getting the most out of existing equipment via faster control action. FACTS is defined as "Alternating Current Transmission Systems incorporating Power Electronic Based and Other Static Controllers to Enhance Controllability and Increase PowerTransfer Capability". The application of FACTS devices to power system security has been an attractive ongoing area of research.

This paper analyses the key issues in the power quality problems, In the proposed system Voltage sag occurs due to the three phase fault in the transmission line and harmonics occurs due to the connection of controlled six pulse converter (rectifier) to the main drive load(non linear load). All these factors affect the sensitive load which is connected in parallel to the main drive load. So the proposed system protects the sensitive load by mitigating the voltage sags and harmonics using series compensation technique.

2. SERIES COMPENSATOR

Series capacitive compensation was introduced decades agotocancela portion of their active line impedance and there by increase the transmittable power. Subsequently, within the FACTS initiative,ithas been demonstrated that variable series compensation ishighly effectivein both controlling powerflow in the lines and in improving stability. The voltage sourced converter based series compensator, called Static Synchronous Series Compensator (SSSC)was proposed by Gyugyi in 1989.SSSC provides the virtual compensation oftransmission line impedance by injecting the controllable voltage in series with the transmission line.The virtualreactance inserted bythe injected voltage source influences electric power flow in the transmission lines independent of the magnitude of the line current. The ability of SSSC to operate in capacitive as well as Inductive mode makes itvery effective in controlling the power flow in the system. The following are the important parts of Series Compensator as explained in below.

Storage Devices/ESS: This is required to provide active power to the load during deep voltagesags. Lead-acid batteries, flywheel or SMES can be used for energy storage. It is also possible 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 compensator need real power for compensation purpose during voltage disturbance in the distribution system. In this case the real power of the 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.

Voltage Source Inverter/VSI: A VSI is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency,magnitude, and phase angle. Either a conventional two level converter (Graetz Bridge) or a three level converter is used. There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT). Each type has its own benefits.

Harmonic filter/Passive filter: The passive filters can be placed either on the high voltage side or the converter side of the injection transformers. Basically filter unit consists of inductor(L) and capacitor(C). In compensator, filters are used to convert the inverted PWM waveform into a sinusoidal waveform. This can be achievedby eliminating the unwanted harmonic components generated by the VSI action. Higher order 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).

3. CONTROLLING SYSTEM USED IN SERIES COMPENSATOR

The harmonics is generated in the load terminals using six pulse converters with fixed firing angle are connected to the main drive non linear load which is parallel to the sensitive load. Voltage sag is created at load terminals via a three phase fault as shown in the below MATLAB circuit. For compensation purpose the voltage is sensed at the two positions, i.e., at the starting of source and at the load terminals. This gives an error value which is fed to the control circuit. The control circuit consists of discrete PLL, abc to dqo transformation blocks, discrete Proportional Integral (PI) controller, and a Pulse Width Modulator(PWM). The output of the contol circuit is pulses, which is given to the Voltage Source Inverter(VSI) and thus the inverter will operate and injects the required value of voltage for the operation of sensitive load and thus reduced the problem of voltage sag, in the mean while the harmonics which are produced due to the operation of six pulse converter are also mitigated to the acceptable level as mentioned in the below Simulink results. The mitigated harmonics outputs and the voltage sag reduction outputs which are practically obtained using MATLAB software are as shown in the below figures.

Here the inverter circuit may be designed with IGBT, MOSFET, GTO electronic elements for the compensation purpose. Pulse width Modulation (PWM) control technique 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. PI controller input is an actuating signal which is the difference between the V_{ref} and V_{in}. Output of the controller block is of the form of δ.

Output of comparator = $V_{ref} – V_{in}$

Where (1p.u. =Base Voltage)

V_{ref} equal to 1 p.u. voltage

V_{in} voltage in p.u. at the load terminals.

The angle δ is provided to the PWM signal generator to obtain desired firing sequence.

The basic block diagram of the control circuit is as shown in the below figure.

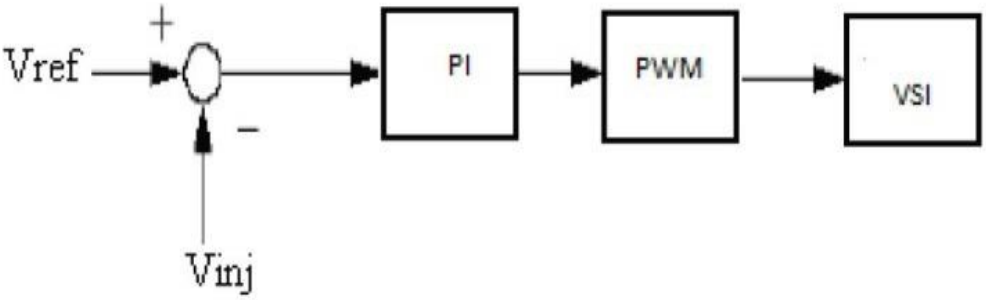

Figure 1: Control circuit of the series compensator for harmonics and voltage sag mitigation

4. SYSTEM PARAMETERS AND VALUES

S.no	Parameters	Values used
1.	Main supply voltage per phase	230v
2	Supply Frequency	50Hz
3	Source impedance	Ls=0.005 mH Rs=0.001 Ω
4	Injection transformer turns ratio	1:1
5	PI controller	K_p =0.1, K_i=1,sample time=50 µs
6	Fault Resistance	0.001 Ω
7	Main Drive Load	500W,15VAR
8	Sensitive Load	1KW,10VAR
9	Inverter	IGBT based 3 arms , 6 pulse,Carrier Frequency=20000 Hz,Sample time= 5 µs
10	Filter circuit	l_f=221mh, c_f=45µf

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5. MATLAB MODELING CIRCUIT

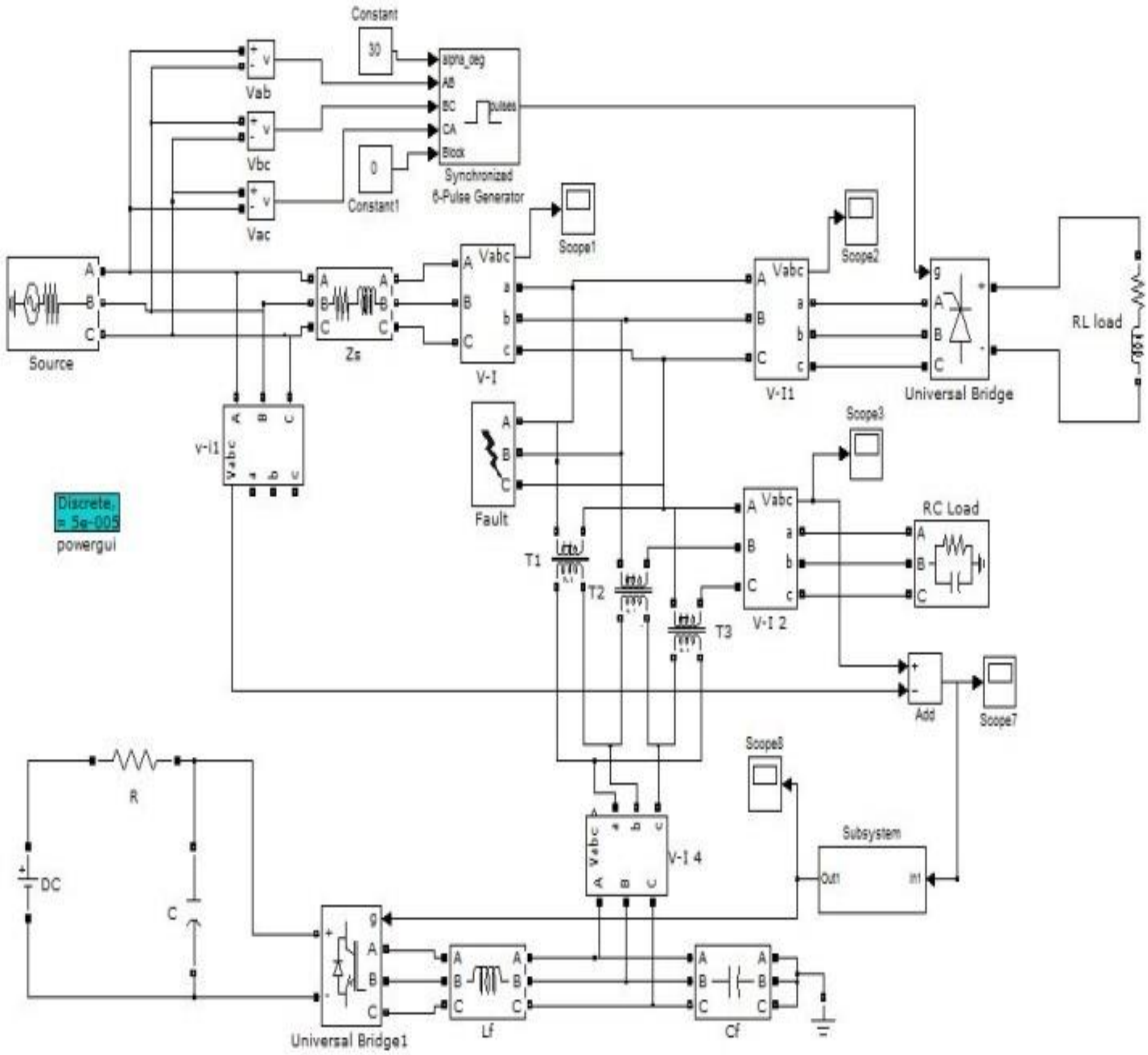


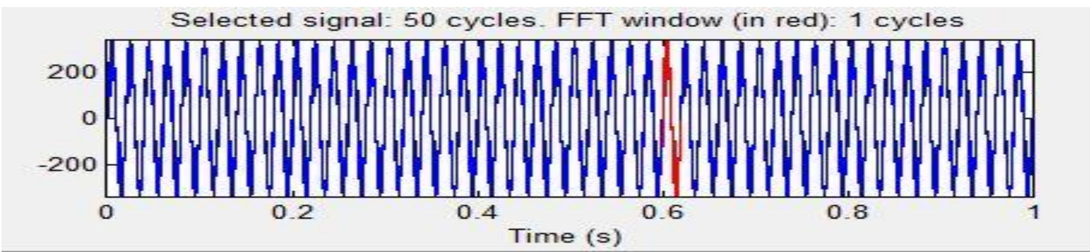
Figure 2: MATLAB SIMULINK Modeling of SeriesCompensator

6. HARMONICS MITIGATION USING SERIES COMPENSATOR

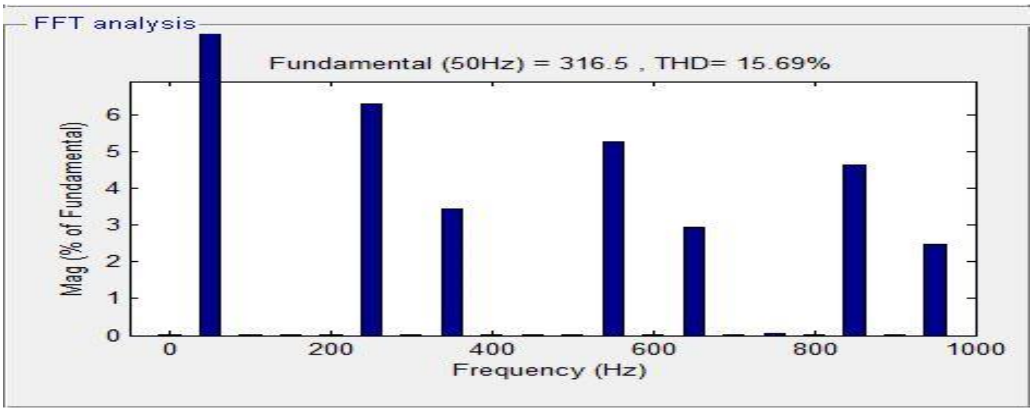
The harmonics are generated in the transmission line using six pulse converter connected to the main drive non linear load which is connected in parallel to the sensitive load. The percentage of total harmonic distortion in the sensitive load side is, in phase1 15.69%, in phase2 16.56%, in phase3 15.62%.

When Matlabsimulation is carried out **with compensation technique**, the percentage of total harmonic distortion in the sensitive load side is, in phase1 0.60%, in phase2 0.60%, in phase3 0.60%.

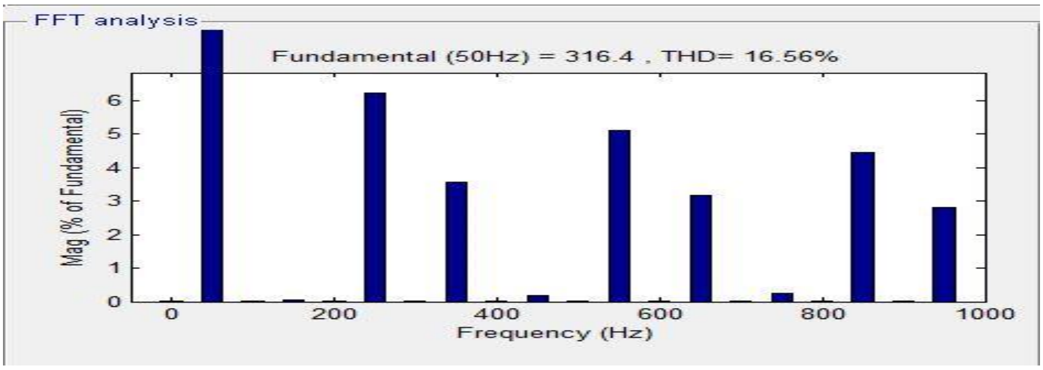
The simulation results carried out without compensation are as shown in the below figures.



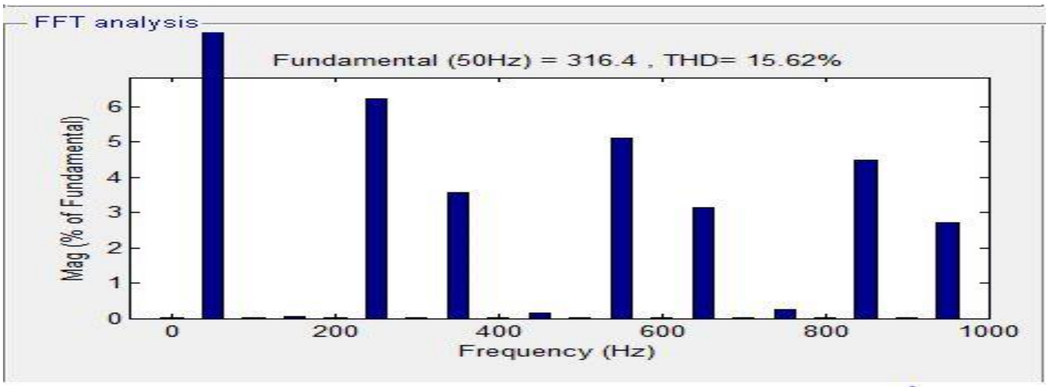
(a)



(b)



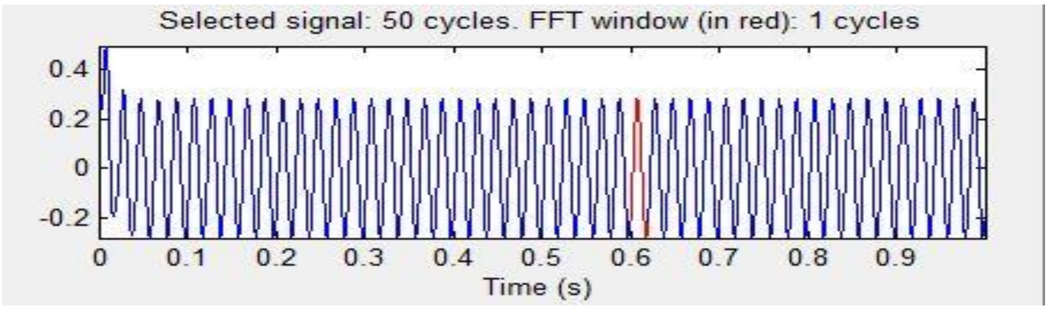
(c)



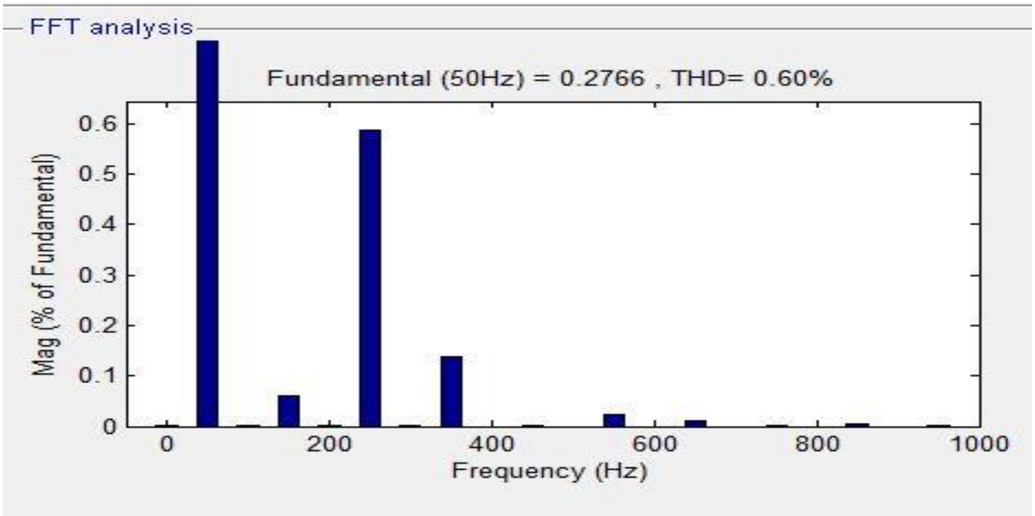
(d)

Figure 3: (a) Selected signal without compensating for FFT analysis, (b) Total harmonics distortions in phase1 without compensation,(c) Total harmonics distortions in phase2 without compensation, (d) Total harmonics distortions in phase3 without compensation.

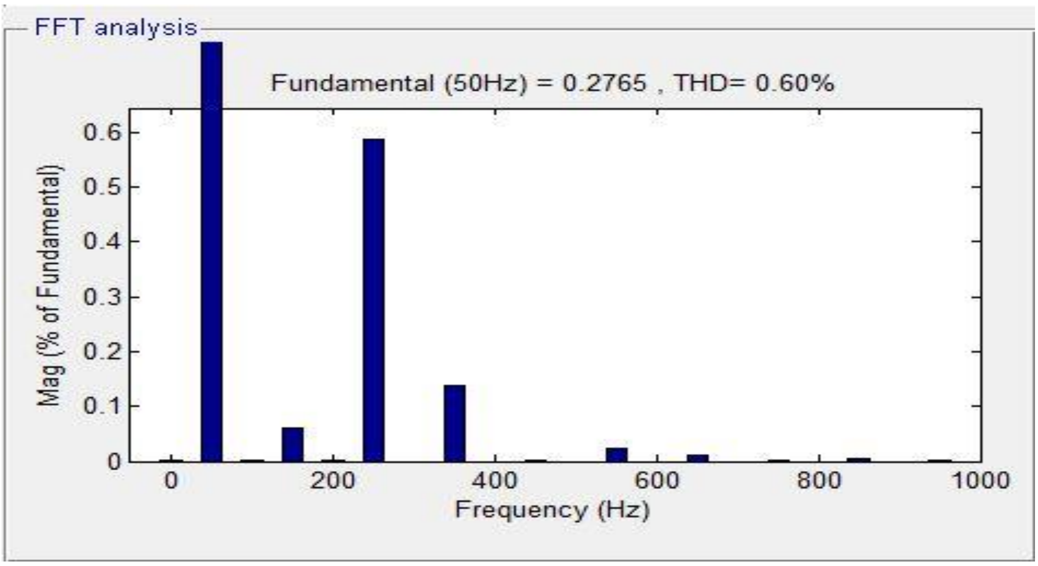
The simulation results after compensation are as shown in the below figure.



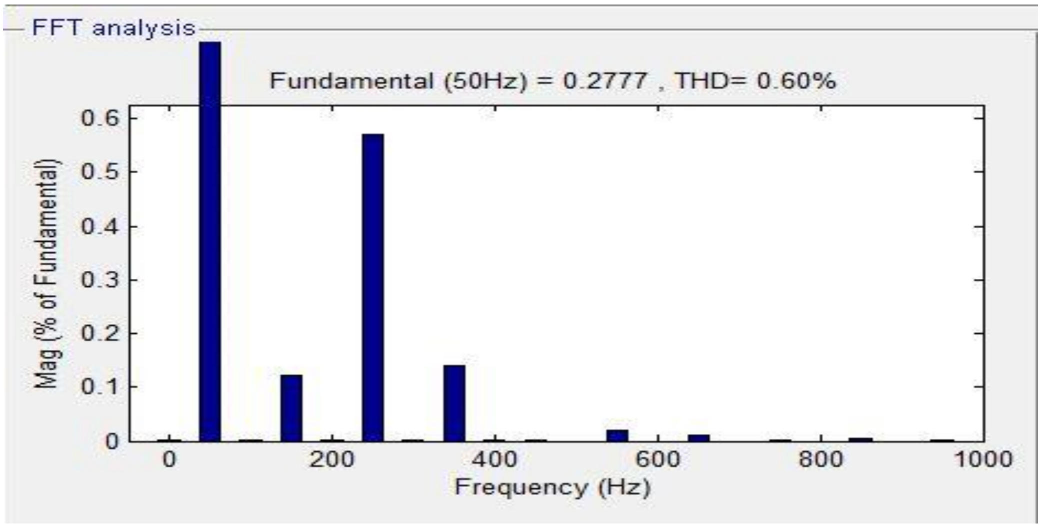
(a)



(b)



(c)



(d)

Figure 4: (a) Selected signal after compensation for FFT analysis, (b) Total harmonic distortion in phase1 with compensation, (c) Total harmonic distortion in phase2 with compensation, (d) Total harmonic distortion in phase3 with compensation.

The simulation results carried out with series compensator, generated harmonics are reduced. The reducedharmonics distortions in all the three phases are shown in the above figures using FFT analysis.

The following tables show the simulation result carried out with and without using series compensator inmitigating harmonics.

THD in sensitive load before compensation

S.NO	PHASE	%THD
1.	PHASE 1	15.69%
2.	PHASE 2	16.56%
3.	PHASE 3	15.62%

THD in sensitive load after compensation

S.NO	PHASE	%THD
1.	PHASE 1	0.60%
2.	PHASE 2	0.60%
3.	PHASE 3	0.60%

A thyristor based six pulse converter used in this system is a power electronic device (fast switching device)adds harmonics in the system voltage and increases the total harmonics distortion of the system. The above two tables show simulation results carried out with and without using series compensator respectively. This harmonics affects the operation of sensitive load. Then the series compensator is brought into the service for harmonic mitigation, the sensitive load is protected against the distortion introduced by the main drive load in the above explained way.

7. VOLTAGE SAG MITIGATION USING SERIES COMPENSATOR

The main advantage of series compensator is not only to mitigate harmonics but also to solve voltage sag problems. In simulink model when the fault is introduced at the point of common coupling, sag appears at certain time period as required in all the three phases as shown in the below figures. When the series compensator is connected to thesystem the appeared voltage sag is mitigated as shown in the below figure.

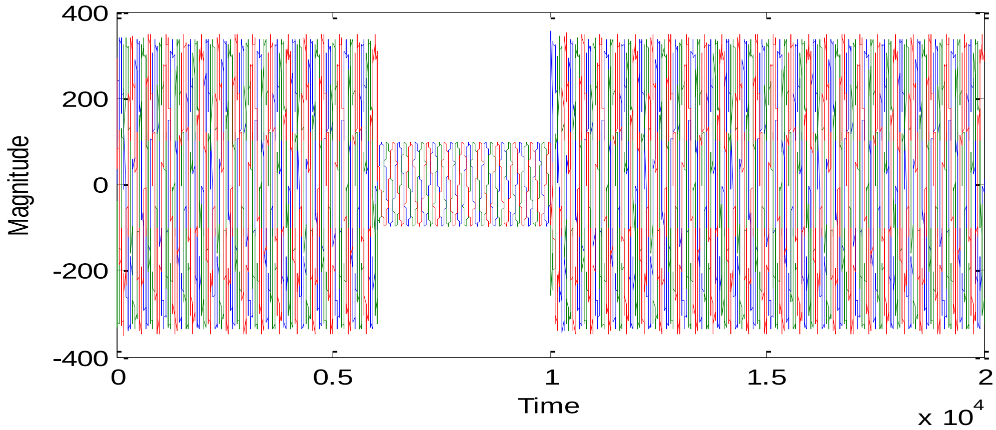


Figure 5: (a) Voltage sag appeared when three phase fault is introduced into the system before compensation

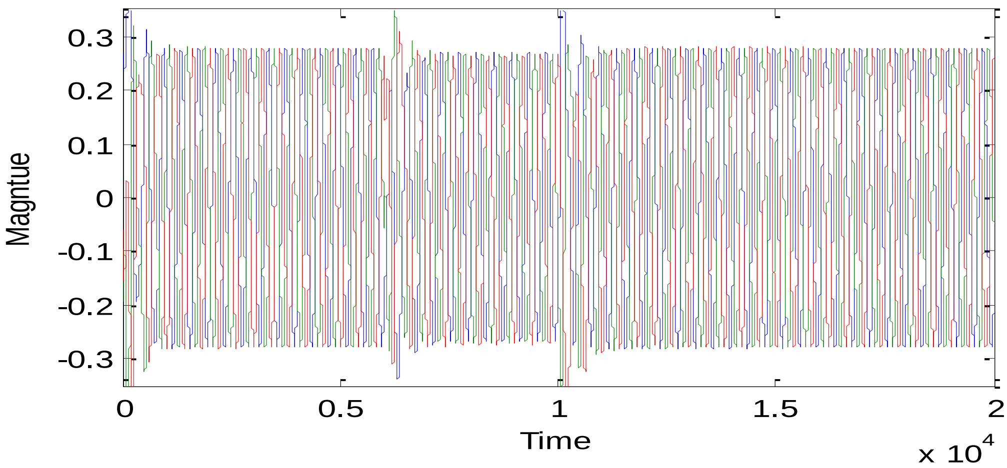


Figure 5: (b) Voltage sag removed from the system after compensation.

8. CONCLUSION

This paper has presented the power quality problems such as voltage sag, distortions and harmonics. The design and applications of series compensator for voltage sags, harmonics and comprehensive results were presented. A Pulse Width Modulator-based control scheme was implemented in this proposed series compensator. The performance of the proposed topologies and an improvement of suggested controller can be observed through simulation and experimental results. The THD and the amount of unbalances in load voltage are decreased with this application of series compensator. The proposed system performs better than the traditional methods in mitigating harmonics and voltage sags.

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