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Reactive Power Compensation of Three Phase System Using Shunt Active Filter and Model Predictive Control with Static var Compensator

[1]N. Balasubramaniam and [2]Dr. J. Devi Shree

[1]PhD scholar, Instructor, Dept. of Instrumentation and Control Engineering, CIT Sandwich polytechnic college, Coimbatore-641014

[2]Assistant Professor (Sr.Grade), Dept. of Electrical and Electronics Engineering, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu - 641014, India

Abstract

This research article mainly focus on power quality parameters like voltage deviation, power factor correction, current harmonics and reactive power compensation with the change of load affects the transmission grid. The above mentioned parameters are fundamental problem even in today's life and grow higher with the power demand, hence power quality is affected. Minimizing these issues must improve a reliable power quality. To improve the power quality current harmonics are to be filtered and reactive power compensation to be done by proper device. In this paper, Model Predictive Controller (MPC) using Shunt Active Power Filter (SAF) and a FACTS device like Static VAR Compensator (SVC) is proposed to filter the current harmonics and to reduce the impact of reactive power in order to improve the power quality. This control technique is implemented in MATLAB/Simulink and the total harmonic distortion (THD) for the system under balanced load and unbalanced load with and without SAF, SVC connected at the load end. The THD for the system under balanced load is zero, where the system without SAF and SVC the THD is 30.27% for both the loads. This method performs better THD value as 1.02% with SAF and SVC when connected with balanced and unbalanced loads.

Keywords: Power quality; Current harmonics; Reactive power; Model Predictive Controller; Static VAR Compensator.

Introduction

Energy has become necessary in our life and as the need increases, demand in energy also increases. Transmission of energy to grid, consumers or to industrial sectors must be supplied with [1] power quality. Voltage sag [2], power factor correction [3, 4], current harmonics [5, 6] are the common problem affects the supply system. The energy supplied to the premises from source to the load must be an uninterrupted, high reliable and stable power. Power quality [7] is the major concern for consumer and to industrial sectors. Fault on three phase system in transmission line generate high current which in turn increases the reactive power, line losses, leads to large voltage drop voltage sag and lower the efficiency of the system. The increase in harmonic current and reactive power in the transmission line increases the power losses in the transmission line and hence the power quality is affected.

There are many devices to control the reactive power [8, 9] which transmits between source and load and to suppress harmonics by injecting harmonic currents at the load end to utilize the apparent power uninterruptedly by the end users. Filters are used to filter the harmonic current and power filters such as active [10, 11] and passive filters [12, 13] are commonly used. Active power filters can be connected in series or in parallel to the load end and are named as series APF and shunt APF respectively [14]. Series APF acts as controlled voltage source and Shunt APF acts as controlled current source. Shunt APF is mostly used in grid to eliminate the harmonic currents present in the transmission line. Poor power quality affects the users at all levels (Power electronic devices, house hold appliances and heavy duty industrial machines). Because of reactive power, load imbalance, overheating of motors, transformers, sudden increase in voltage and line losses, power quality is affected which runs the system insufficiently and affect the system performance. To improve the power quality a proper device should installed at the load end. FACTS devices [15] are one such device to improve the power quality and satisfy the end user requirements.

The main objective is to propose a reactive power control method, Model Predictive Controller (MPC) using shunt active filter with static VAR compensator is implemented to suppress the current harmonics and to improve the power quality for reactive power compensation at the load end (linear or non-linear load) in three phase system.

Related Work

World economic growth over three decades, need of energy with respect to gross domestic product (GDP) and the need to develop renewable energy mainly solar and nuclear power in India [16] . FACTS devices are to minimize the voltage sags in the network buses using genetic algorithm. This device performance was analyzed on 295 bus generic distribution system using static VAR compensator, static compensator and dynamic voltage restorer [2].

Stator current harmonic suppression method was used to eliminate negative sequence, fifth positive sequence and seventh-order current harmonics. Steady state error, dynamic performance, system stability are the parameters taken into account to design a resonant controller to eliminate the harmonics. Distributed negative sequence current sharing method was used for dynamic consensus algorithm which was a dedicated central controller and communication links are not required between distributed generators.

Proposed Method

a. Shunt Active Filter

Shunt active filter produces harmonic current equal in magnitude but opposite in phase to the load current to eliminate the harmonics in higher order.

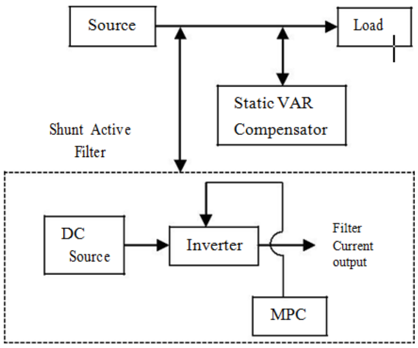

Figure 1: Block diagram of MPC using SAF and SVC

Figure 1 shows the shunt active filter in which the inverter pulse is controlled by Model Predictive Controller (MPC). This is connected at the load end (balanced and unbalanced load) to compensate the reactive power.

b. Static VAR Compensator (SVC)

SVC is a second generation FACTS device and is half controlled device based on compensator consists of thyristor. In three phase transmission line voltage instability occurs at load end. In case of low voltage at heavy load, reactive power must be supplied and if high voltages at low load reactive power must be absorbed. This reactive power compensation must be done to maintain voltage stability and shunt connected device.

c. Model predictive control

Model predictive control (MPC) is a discrete time form of control. Each control decision is obtained by first estimating the system state. This provides the initial condition for prediction (simulation) of subsequent dynamic behaviour. MPC can be implemented to any load model. For reactive power it is denoted as

$$P(V,\lambda) = (1-\lambda)P_0 \left(\frac{V}{V_0}\right)^a \quad \textbf{(1)}$$

Full load corresponds to $\lambda = 0$, complete load shedding is represented by $\lambda = 1$. Let the maximum amount of load at a particular location j is denoted by λ^j_{MAX}. The interval is represented by

$$0 \le \lambda_j + \Delta\lambda_j + \le \lambda^j_{MAX} \qquad (2)$$

Where λ_j the load is shed due to previous MPC step and $\Delta\lambda_j$ is the new load change. Previously shed load can be restored. To avoid excessive voltage steps, all the limits are combined and represented by

$$\Delta\lambda^j_{MIN} \le \Delta\lambda_j \le \Delta\lambda^j_{MAX} \qquad (3)$$

Where, $\Delta\lambda^j_{MIN}$ and $\Delta\lambda^j_{MAX}$ are the most stringent minimum and maximum limits respectively

Results and Discussion

The reactive power compensation is done by injecting harmonic current to the system using shunt active filter, static VAR compensator by MPC to improve the power quality of the system. The results show how the harmonic currents affect the system before and after the filter and SVC connected with balanced, unbalanced load and combination of both using MATLAB/Simulink. The total harmonic distortion is discussed to improve the power quality.

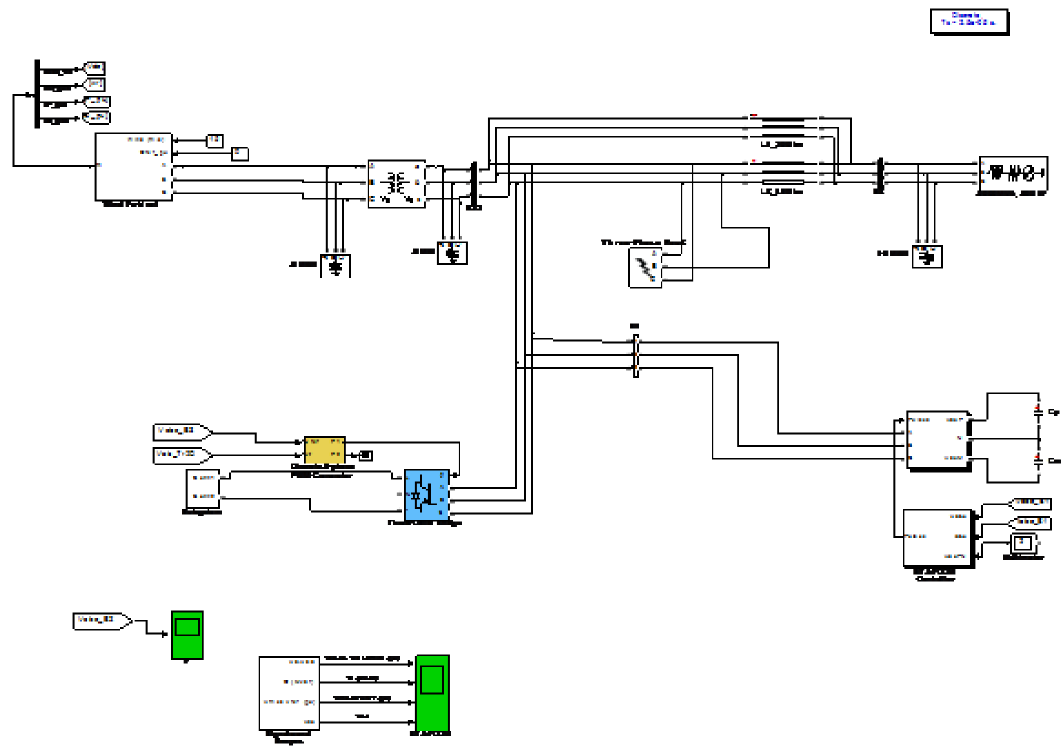

Fig 2 :Functional diagram (MATLAB)

a. Balanced load

The figure 3 shows the waveforms of voltage and current under balanced load and it's a pure sine wave with neutral current zero and hence the total harmonic distortion (THD) under balanced load is zero as in figure 3.

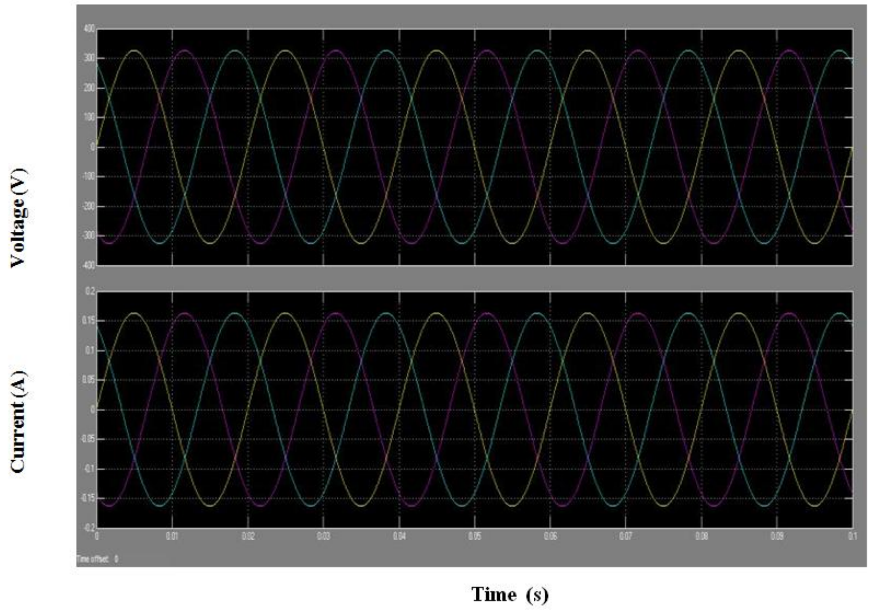

Fig 3: System connected with balance load

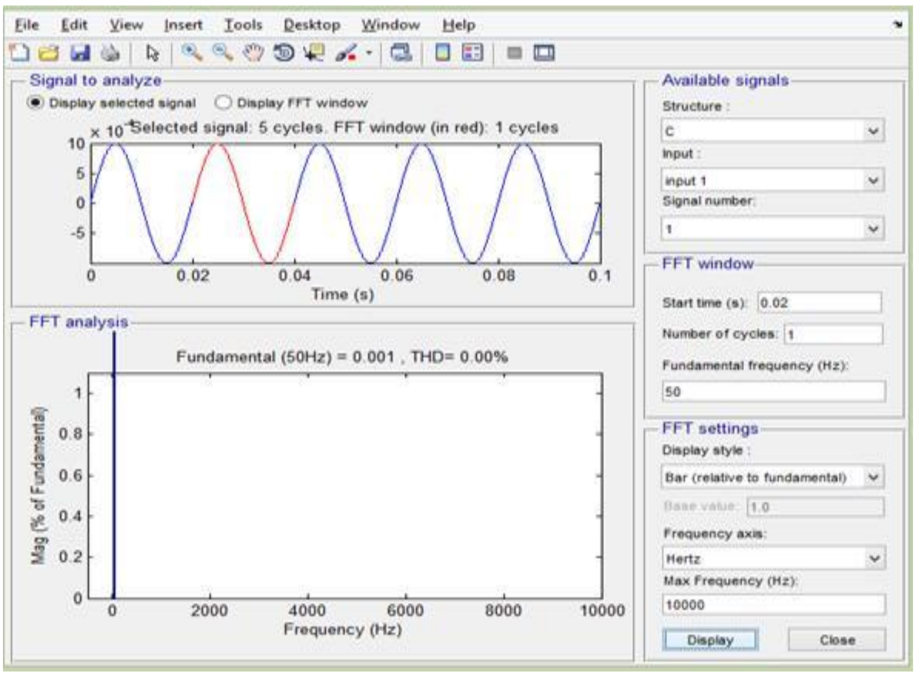

Figure 4: Total harmonic distortion for balanced load

b. Unbalanced load

The system is connected under unbalanced load condition to determine the sharing of electrical power. The system with unbalanced load show large voltage drop and may damage the system. Hence the unbalanced load system must be converted to balanced load system in order to avoid the above issues. The figure 5 and figure 6 shows the voltage, current waveform and source current under unbalanced load condition respectively. The total harmonic distortion is zero for unbalanced load system as in figure 7.

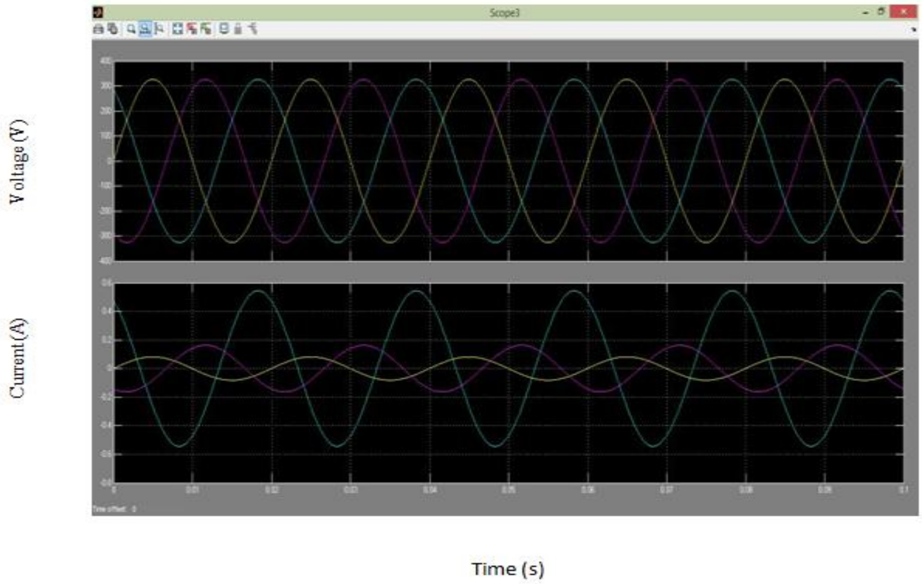

Figure 5: Voltage and current waveform under unbalanced load.

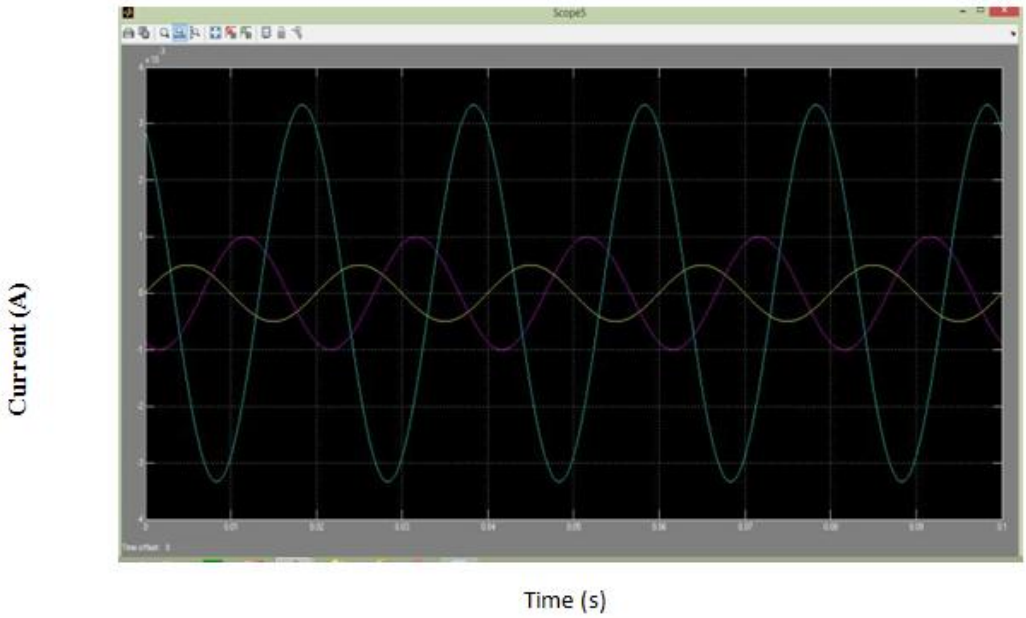

Figure 6: Source current under unbalanced load.

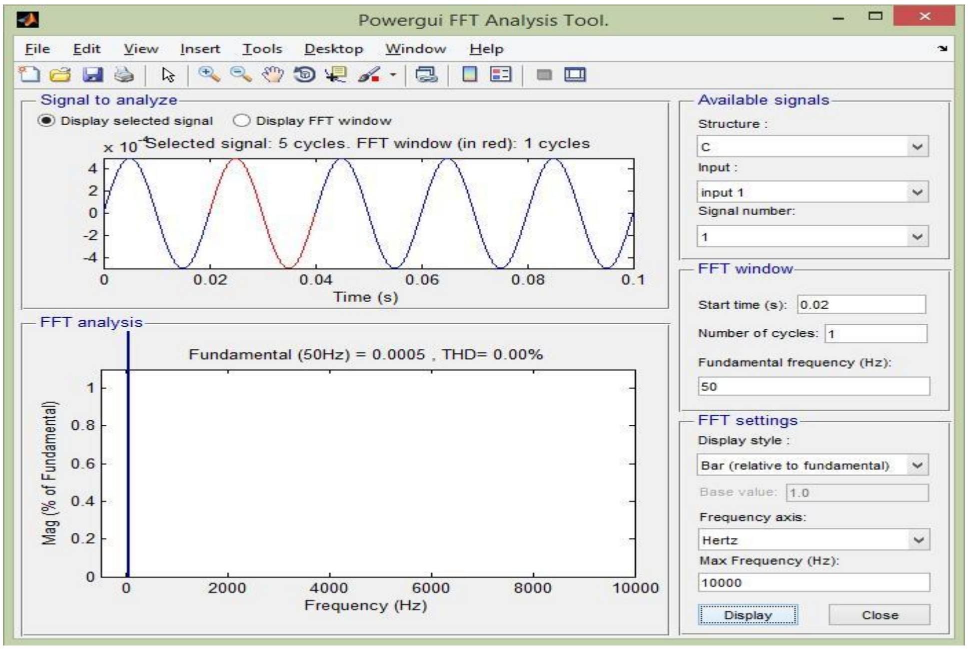

Figure 7: Total harmonic distortion for unbalanced load

c. Balanced and unbalanced load

The system when connected with balanced and unbalanced load shows the load voltage and load current in figure 8. The source current is shown in figure 9 which increases system loss and reduce the efficiency

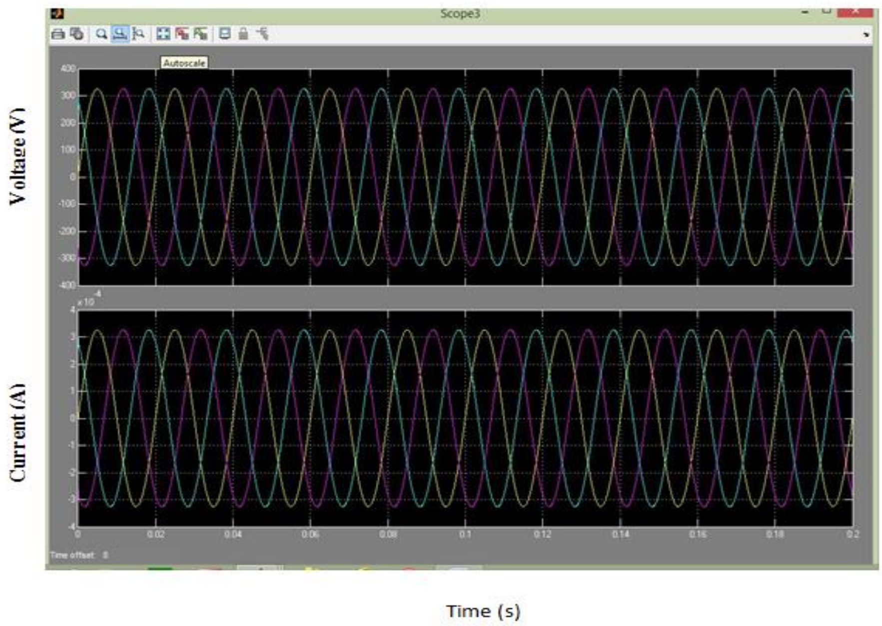

Figure 8: Load voltage and Load current under balanced and unbalanced load in a system.

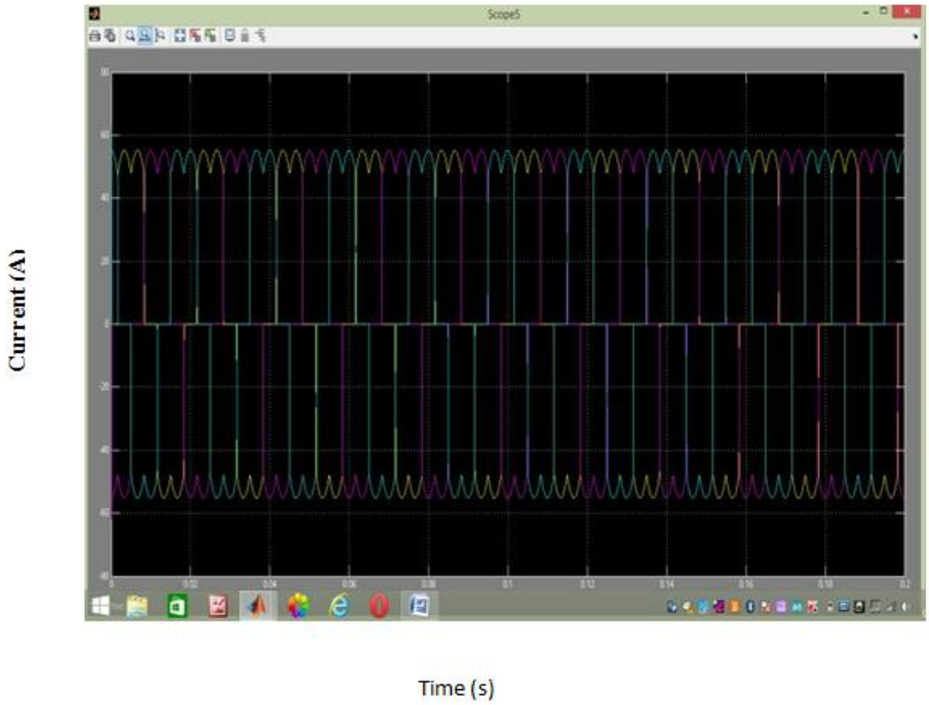

Figure 9: Source current under balanced and unbalanced load

The total harmonic distortion is measured as 30.27% and reduce the performance and affects the power quality of the system and is shown in figure9. Hence it must be suppressed by injecting the compensating current to the system at Point of Common Coupling (PCC) end.

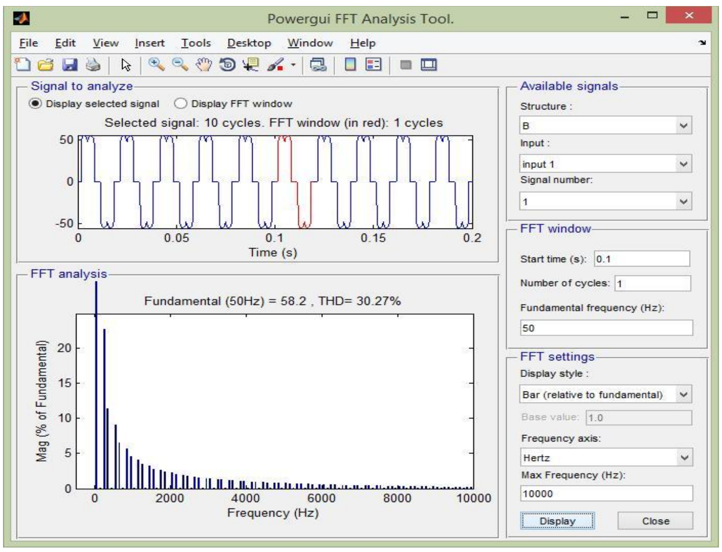

Figure 10: Total harmonic distortion for balanced and unbalanced load

d. With SVC and Filter

The lack of reactive power affects lifetime and efficiency of the system. To suppress the harmonics and to inject compensating current Shunt active filter and SVC is connected at load end.

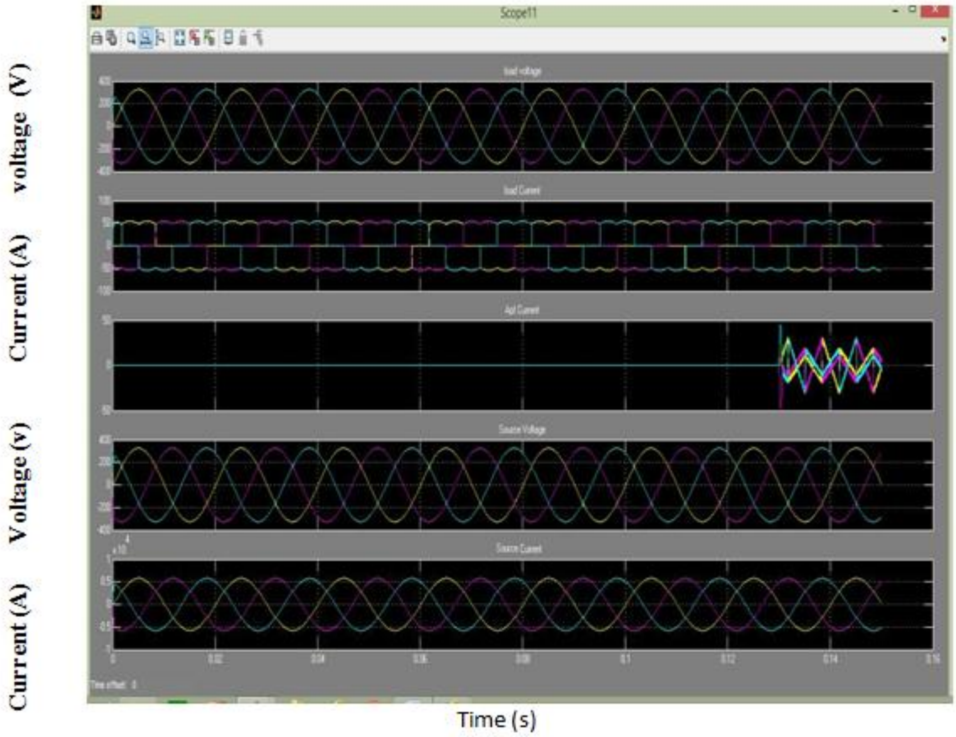

Figure 11: Waveform of a system connected with SAF and SVC under balanced and unbalanced load

Figure 10 shows a system connected with SAF and SVC under balanced and unbalanced load. Figure 11 shows the compensating current injected to the system which improves the power quality with the total harmonic distortion measured as 1.02% as in figure 12. This is very low when compared with the system connected without SAF and SVC. Table 1 provides the THD analysis for the system under different load conditions

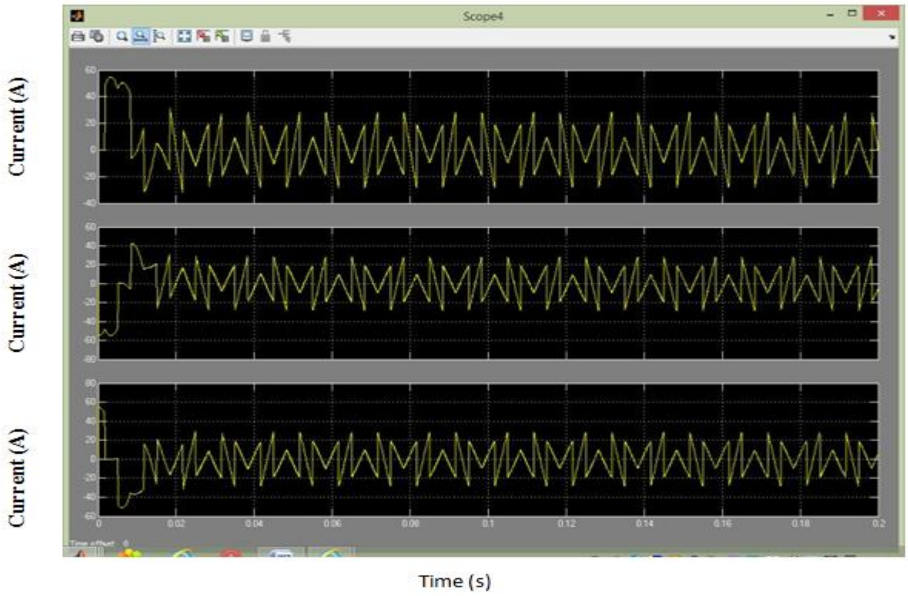

Figure 12: Compensating current injected to the system

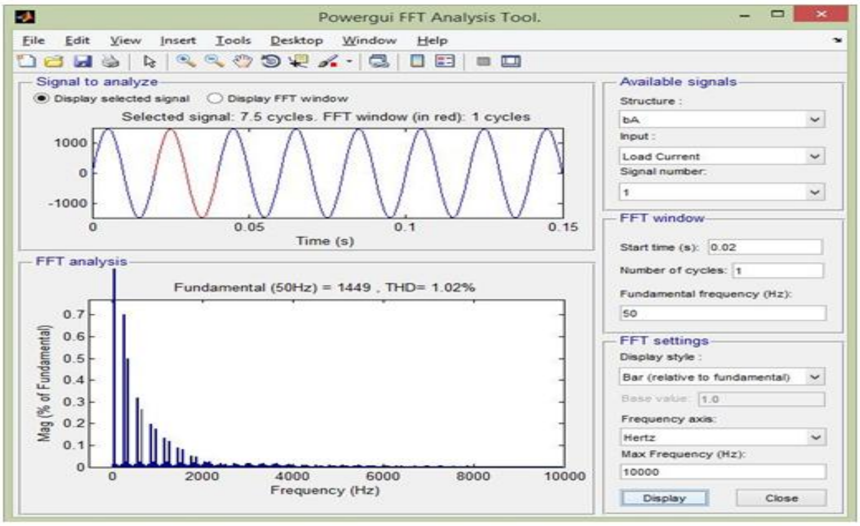

Figure 13: Total harmonic distortion of a system connected with SAF and SVC under balanced and unbalanced load

Table 1: Analysis of THD under different load condition

Determination	Load	THD (%)
Without SAF and SVC	Balanced	0
	Unbalanced	0
	Balanced and unbalanced	30.27
With SAF and SVC	Balanced and unbalanced	**1.02**

Conclusion

Power quality is the major concern for all electrical system under load conditions. The system under unbalanced load with current harmonics and reactive power increases line loss and voltage drop which may lead to system damage. Hence a proper device to be connected at load end to improve the power quality by suppressing current harmonic and injecting reactive power at PCC for the maximum utilization of real power. The harmonic reduction and reactive power compensation is done using shunt active filter and SVC with Model Predictive Control (MPC) in a three phase system. The total harmonic distortion (THD) for the system under balanced and unbalanced load with and without SAF, SVC FACTS device connected at the load end is discussed. THD for the system under balanced and unbalanced load is zero, where the system connected with both the load is 30.27% without SAF and SVC. The proposed method performs better with SAF and SVC connected to the system with the THD value as 1.02%.

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