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Novel Predictive Current Controller for DSTATCOM to Improve Power Quality

M.Balasubramanian [1], Dr.P.Selvam [2], Dr .R.Sagayaraj [3] , Remya K P[4], Rajitha A R[5] , Dr .Jenopaul.P [6]

[1]Assistant Professor, Department of EEE, Government College of Engineering, Tirunelveli, India. Email: srivibalu_svpr@yahoo.co.in
[2] Assistant Professor, Department of EEE, Government College of Engineering, Tirunelveli, India. Email: selvam@gcetly.ac.in
[3]Professor, Department of Electrical and Electronics Engineering, Muthayammal Engineering College, Rasipuram, Tamilnadu, India. Email: rsrajeee@yahoo.co.in
[4]Assistant Professor, Department of EEE, Adi shankara institute of Engineering and technology , kerala., India. Email: remya.eee@adishankara.ac.in
[5]Assistant Professor, Department of EEE, Adi shankara institute of Engineering and technology , kerala., India. Email: rejitha.eee@adishankara.ac.in
[6]Professor, Department of EEE, Adi shankara institute of Engineering and technology , kerala., India. Email: jeno.eee@adishankara.ac.in

ABSTRACT

The Novel predictive current control method for distribution static compensator (DSTATCOM) is proposed in this paper with an improved four-leg topology for load compensation. The source current distorted when a nonlinear load was connected to the grid. When an unbalanced load is connected, the source current becomes unbalanced. Using the proposed technique, converter switching pulses are derived. The desired system behavior is defined by the cost function. By keeping track of reference current, compensation of reactive power, unity power factor is achieved and the supply current turns to balanced and sinusoidal. During the steady and dynamic state scenario, this scheme also removes neutral current. the reactive and harmonic elements of load current derived using synchronous reference frame theory (SRFT). The Novel predictive current control algorithm is effectively employed that monitor reference current and provide sinusoidal source voltage under both steady-state and dynamic scenario at the point of common coupling(PCC).

Keywords: Distribution Static Compensator (DSTATCOM), Synchronous Reference Frame Theory (SRFT), Predictive Current Control, Power Quality(PQ), Voltage Source Inverter (VSI), Total Harmonic Distortion (THD).

1. INTRODUCTION

The electric power system has three major components: power generation, transmission, and distribution. At the generating stations, energy is produced from a variety of sources. Any electric power produced at such a station must be transported over a long distance. Transmission lines and switching stations connect different generating stations. Between generating electricity and distributing it to customers, there are many phases. All components of a power system must work properly for a stable power supply. There are several issues at hand, including power equipment and system maintenance, system operational stability, power supply network service, and faults. The power system's major challenge is power loss. Electric power quality (PQ) [2-3] is a concept used to describe the process of evaluating and maintaining good power quality in AC electrical power generation, transmission, distribution, and consumption. The AC supply networks are contaminated for a variety of causes, including natural ones like lightning, flashover, equipment failure, and faults. Since consumption of non-sinusoidal current, a variety of consumer equipment pollutes the supply network. As a consequence, consumer equipment failure or malfunction occurs and hence PQ is measured in relation to the supply network's frequency, voltage or current. Some power quality issues arise when various loads are connected at PCC [4-5]. Some linear & non-linear loads

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create harmonic currents, unbalanced currents, reactive power demand, low power factor, and an excessive neutral current. different types of power filters like active, passive, and hybrid in series, shunt, or both arrangements are used to minimize power quality issues, depending on the loads. In distribution networks, custom power device like DSTATCOM used to address all forms of PQ issues. A DSTATCOM is a shunt-connected system [6-8] that corrects voltage by injecting current (leading or lagging). DSTATCOM also provides inductive or capacitive reactive power which needs at the load stage. There are many forms of DSTATCOM referred to in literature [9-11]. When the neutral current in a distribution system increases due to a nonlinear load, power quality issues arise. Four leg compensators minimize the neutral current. The compensator can be controlled by the, which sends switching pulses to VSI. Here a discrete-time model of the system is used by proposed controllers to approximate the next times step value for load current [12-19]. After that, the cost function is minimized and the computation time has been cut into half. Switching pulses are produced using a predictive controller and the VSI is powered by pulses. The VSI then injects the current in PCC.

2. CIRCUIT DIAGRAM and DESIGN OF FOUR LEG DSTATCOM

A. Circuit Diagram

Fig 2.1 shows the Schematics diagram of FL-DSTATCOM. Depending on the demands of customers, there are three-phase loads and single-phase loads in a four-wire three-phase power delivery system. This results in extreme strain on the distribution feeder by unbalanced currents along with neutral current. The DSTATCOM protect the distribution bus from supplying unbalanced currents by compensation. Here the DSATCOM has four-leg VSC which uses Novel predictive current control.

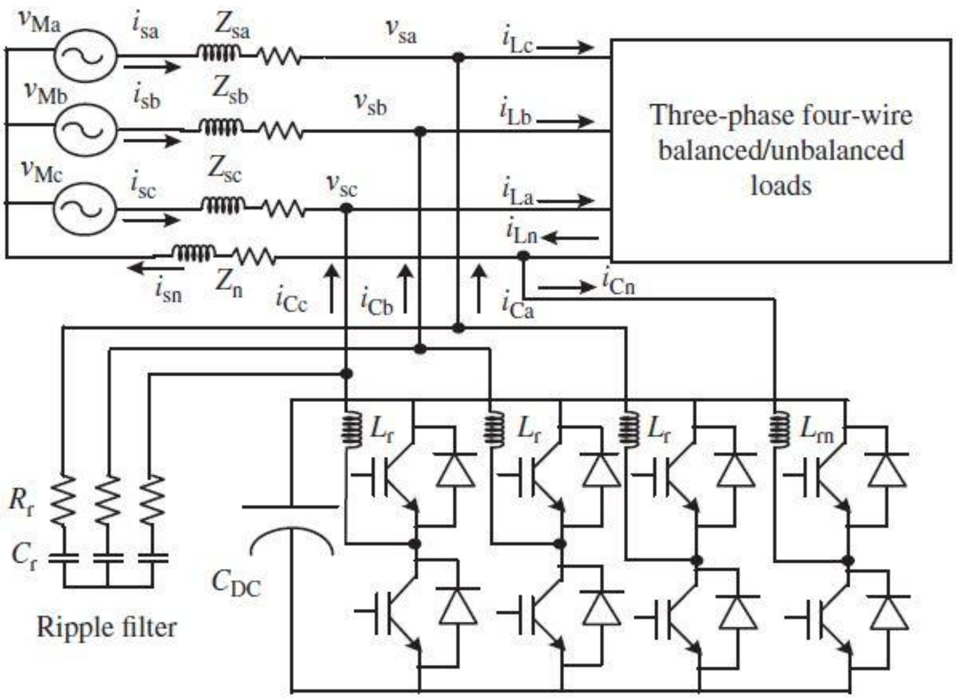

Fig 2.1 Schematic diagram of FL-DSTATCOM

B. Design of DSTATCOM

Estimating an AC inductor, DC capacitor bus voltage, DC capacitor, and a ripple filter range are all part of this design. The DSTATCOM's rating is determined by the reactive power and unbalanced current compensation required by the loads.

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As a result, DSTATCOM's current rating is affected by the load power while the voltage rating is determined by bus voltage. The inductor and ripple filter was configured to limit the effect of switching ripples based on the switching frequency. The energy storage capacity available during transient conditions defines the DC bus capacitor configuration.

a. DC bus voltage

The DC bus capacitor voltage V_{dc} is determined by the minimum voltage level needed to obtain the DSTATCOM VSC's desired AC output during PWM operation.

$$V_{dc} = V_{ll} * 2\sqrt{2}/m\sqrt{3} \tag{1}$$

where m -modulation index, V_{ll} -line to line PCC voltage.

b. DC Bus Capacitor

The V_{dc} of the DSTATCOM decreased when a load was added and increased when the load was withdrawn. Second harmonics occur when there are unbalanced load currents or unbalanced DC bus voltages. The capacitance is calculated by taking the second harmonic ripple voltage across the capacitor and dividing it by two.

$$C_{dc} = {}^{I_O}\big/_{(2\omega V_{dc,pp})} \tag{2}$$

where I_O denotes the capacitor current, ω denotes the angular frequency, and $V_{dc,pp}$ denotes the capacitor voltage ripple.

c. AC Inductor

The DC bus voltage (V_{dc}), switching frequency f_s, and current ripple I_{cr} are the variables that decide the AC inductance L_r of a VSC.

$$L_r = \sqrt{3}mV_{dc}/(12af_sI_{cr}) \tag{3}$$

The ripple filter inductance for the neutral leg is,

$$L_{rn} = mV_{dc}/(3\sqrt{3}af_sI_{cr}) \tag{4}$$

Where I_{cr} is the ripple current.

3. CONTROL STRATEGY

A. NOVEL PREDICTIVE CURRENT CONTROL

The proposed predictive control approach assumes that a VSI can only generate a certain number of switching states and each switching state is forecasted using system models [1]. To ensure that the required switching state is enforced, a selection criterion (i.e) cost function must be set which is to be determined for the estimated control variables. The potential value of control variables is determined for every possible switching state and the state that minimize the cost function is chosen. The measures that make up this control technique are as follows:

- Build a cost function.
- Create a converter model that includes all switching states.
- Construct a load model for forecasting.

The three-phase inverter is a power circuit that converts DC to AC power according to the scheme shown below. The controller must consider the following functions when implemented:

- For all switching states, forecast the behavior of controlled variables.
- For each forecast, a cost function is calculated.

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Choose a switching state with the lowest cost feature. Implementation of the predictive control approach poses unique challenges depending on the platform. The number of measurements may be important depending on the complexity of the regulated process [1].

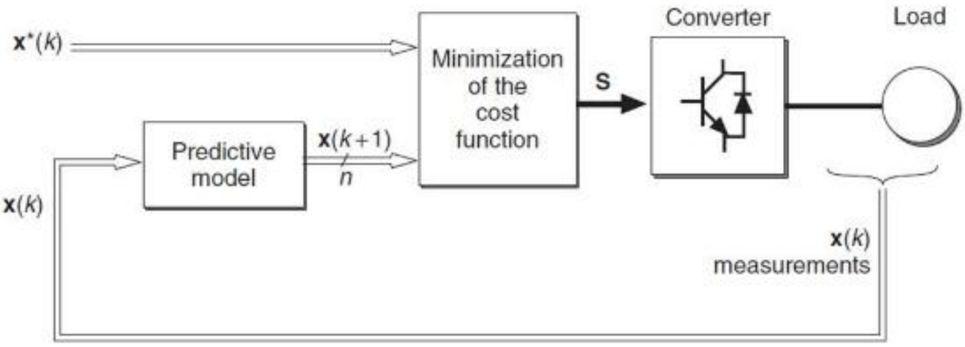

Figure 3.1 Novel Predictive Current Controller Model

To minimize a cost function, all state of switching is determined, then best state is saved for later use. As switching state number increased number of signal to be processed also increase. For 3 phase 2 Level inverter a total of eight switching state prediction is required. As the number of levels increased in multilevel inverter optimization is considered two minimize this calculation. The proposed control method is executed in MATLAB function, with the measured and reference current represented in $\alpha\beta$ coordinate as inputs. The gating signals for inverter is the block output. The benefit of proposed method is the ability to consider the system's nonlinearity in the predictive model, allowing the variable's behavior to be calculated for various conduction states. Specification requirements must be specified to enforce the required switching state. A quality function is used to describe this criterion also evaluated for the governed and expected values. For each potential switching state, the next value of these variables is calculated using an approximation. It is decided to use the switching state with the lowest quality function The predictive control technique for a DSTATCOM's current control is depicted in this block diagram. Current monitoring is carried out using the steps mentioned below. The load current is determined using the reference current value (from the outer control loop).

- The system model approximates the load current value to the next sampling interval for each voltage vectors.
- In this case, the quality function calculates the difference between expected and reference currents and the current error is reduced.

Different quality functions can express different control criteria. For computational simplicity, the absolute error is used in this analysis.

B. SYNCHRONOUS REFERENCE FRAME THEORY (SRFT)

SRFT is a harmonic extractor. It calculates how many harmonics the filter can compensate for. It describes all the current or voltage frequency components. This paper explains how to extract the 3-phase reference currents $(i_{ca}^*, i_{cb}^*, i_{cc}^*)$ used by the active power filters using the most popular approach for harmonic extraction SRFT. The park transformation transforms 3-phase currents or voltages to d-q synchronously rotating reference(SRF) frame [1].

$$\begin{bmatrix} i_q \\ i_d \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ \sin\theta & \sin(\theta-120) & \sin(\theta+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{5}$$

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Since the fundamental component becomes a constant in a synchronous reference frame, to remove high-frequency noise it is sent through a low pass filter (LPF). Initially, the load current converted from 3-phase to d-q SRF in this process. This dq currents composed of AC and DC parts. Initially, the 3-phase load current transformed to a dq SRF which contains both AC and DC components. Here the DC and AC component corresponds to the actual and harmonic component of load current. Then it is passed through 2nd-order LPF with 50Hz cutoff frequency which removes high-frequency harmonic terms. Hence the LPF output is the fundamental frequency terms. To get the high-frequency components, deduct this from the original d component. The harmonic component's portion is expressed by the q component.

As a consequence, it is used explicitly. In three steps, inverse park transformation is used to obtain harmonic signals [1].

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120) & \sin(\theta-120) & 1 \\ \cos(\theta+120) & \sin(\theta+120) & 1 \end{bmatrix} \begin{bmatrix} i_q \\ i_d \\ i_0 \end{bmatrix} \quad (6)$$

This is the reference current for generating switching system gate signals.

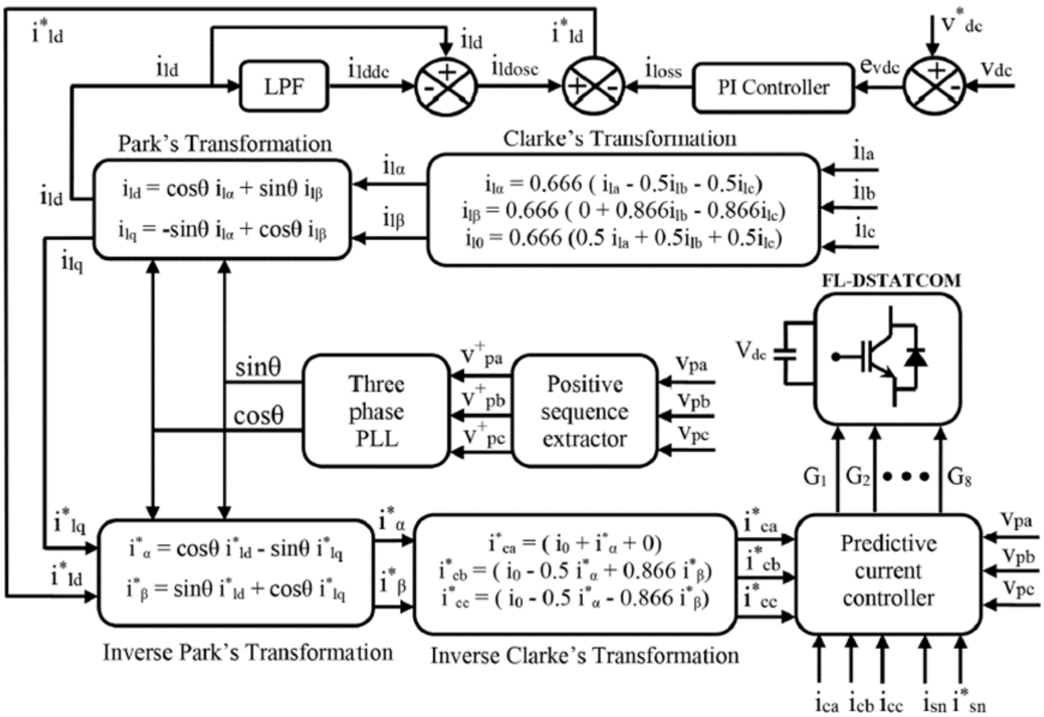

Figure 3.2 Predictive Current Control System

4. SIMULATION MODELS

Figure 4.1 shows the simulation model, which includes a source, load and DSTATCOM. The harmonics are shown and the source current is skewed after connecting a non-linear load.

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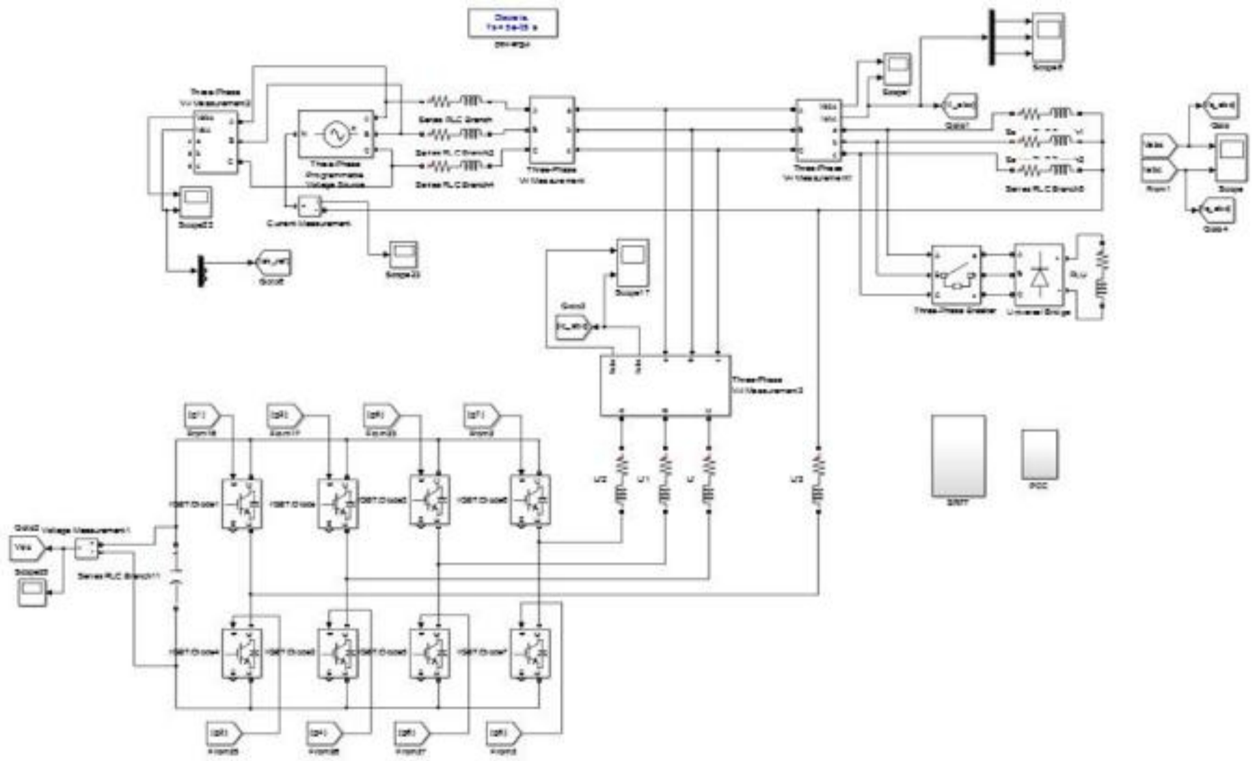

Figure 4.1. Novel Predictive Current Control of Four Leg DSTATCOM

The generation of reference current is clearly shown in the SRF-block. The voltage from the source is used as an input. Clarke's and Park's transformations transform *abc* values to *dq0* values. After that inverse park transformation was applied to convert the *dq0* values to *abc* reference values.

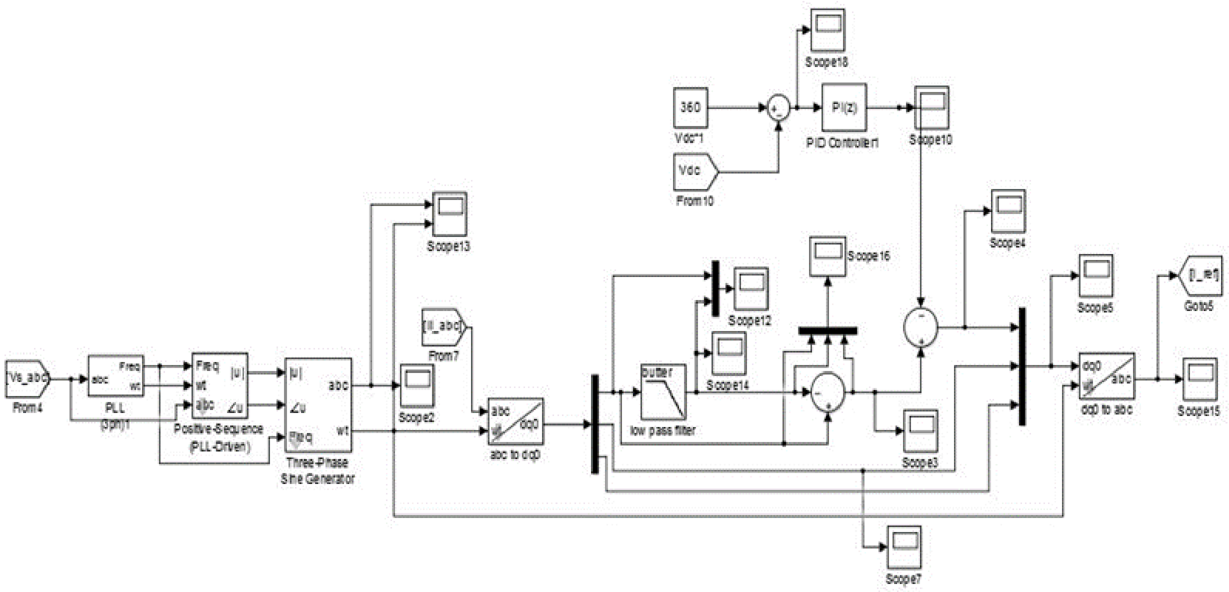

Figure 4.2 Synchronous Reference Frame(SRF) Block

The predictive current controller block provides the gate signals for DSTATCOM. The reference and load currents are compared in this block using the novel predictive current control

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system. It generates a cost function that decides switching signals and predicts the next time step load current value. In addition, the neutral current is compared with its reference and applied through the converter's fourth leg.

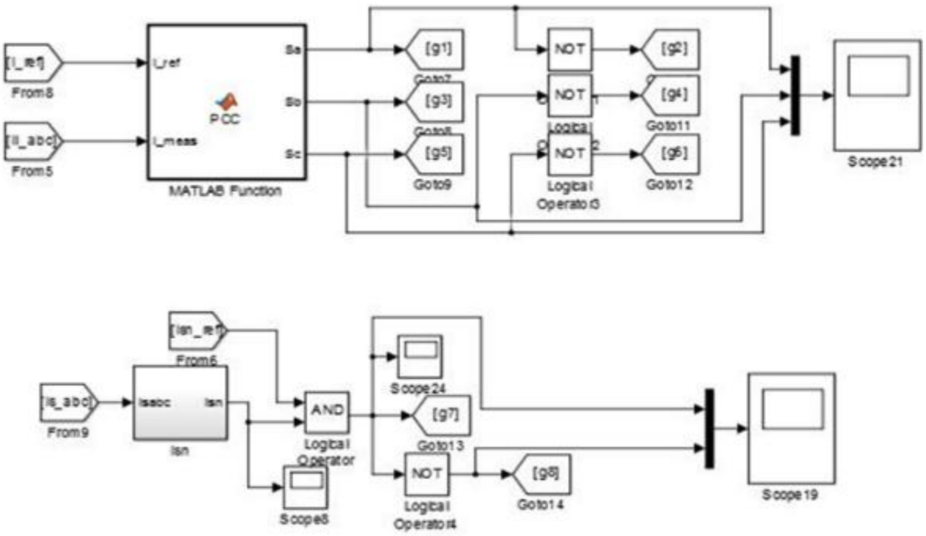

Figure 4.3 Predictive Current Controller Block

5. RESULTS AND DISCUSSION

In the simulation, the 400V(L-L) supply acts as a grid voltage. The unbalanced load was attached at the time of start-up. The non-linear load is attached after 0.2 seconds. The load current is polluted after the load is connected. Other balanced linear loads are also affected as a result.

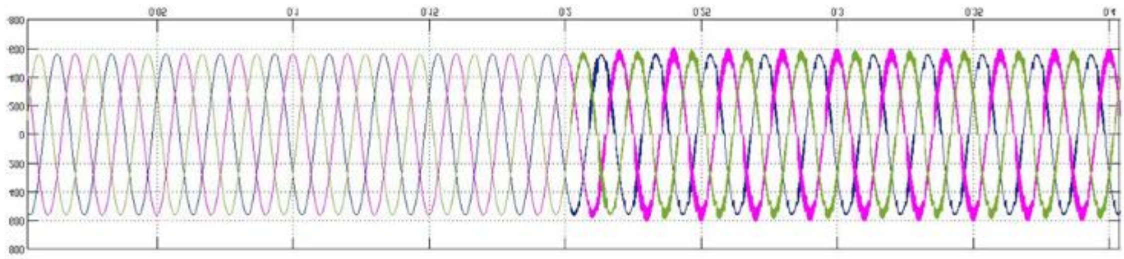

Figure 5.1 Source Voltage Before Compensation

The phase source voltages are depicted in figure 5.1. The voltage level reaches approximately 400V before compensation. The different types of loads are related to the distribution system. The grid voltages are not affected by any loads at first. The source current is distorted and the PCC voltages oscillate when nonlinear loads are connected.

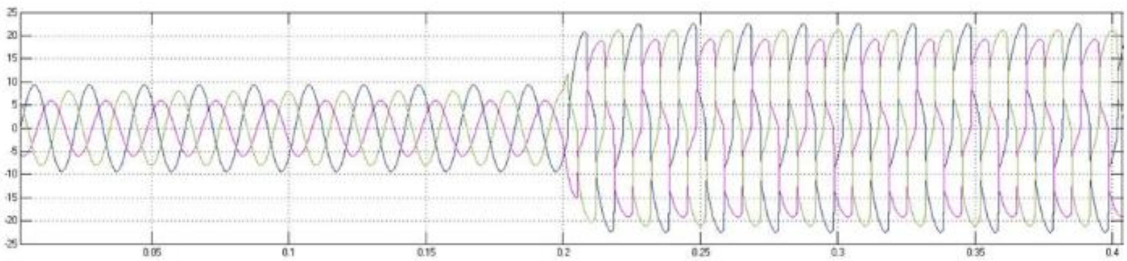

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Figure 5.2 Source Current Before Compensation

After connecting nonlinear and unbalanced loads, the source current becomes distorted as seen in figure 5.2. When a source is connected to an unbalanced load, the source current becomes unbalanced. The nonlinear load attached after 0.2 seconds. Because of impedance changes, a nonlinear load does not take a sinusoidal current. As a result, the source current is distorted.

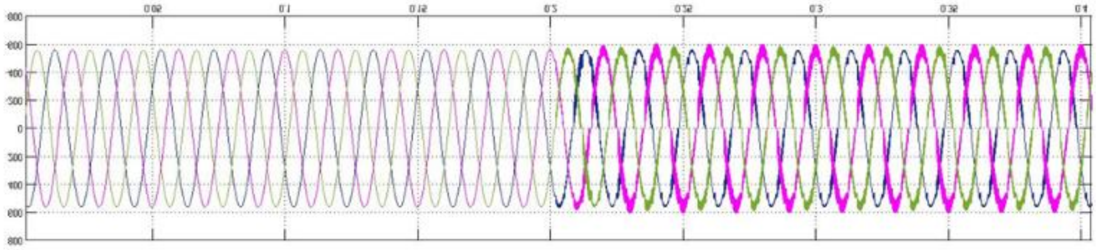

Figure 5.3 Load Voltage

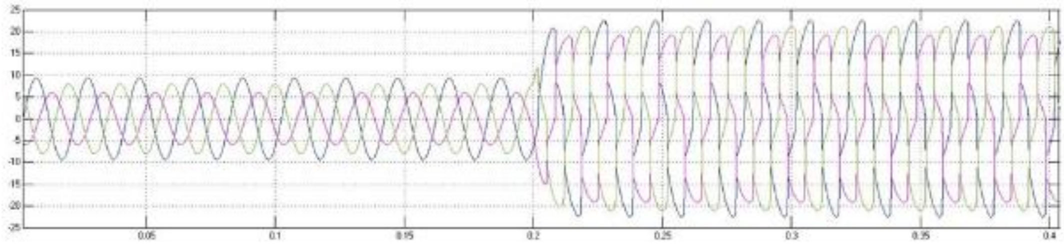

Figure 5.4 Load Current

The voltage and current of the load are represented in figure 5.3 and 5.4. Owing to unbalanced and nonlinear conditions, this is also distorted. Because of the nonlinear load, these values do not have sinusoidal values. Source values and point of common coupling values were also affected by these distorted values.

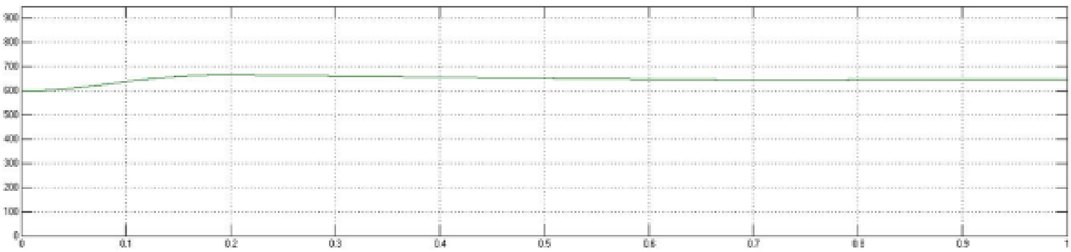

Figure 5.5 DC-Link Voltage

The switches are in on/off conditions after the switching signals are produced. The voltage induced by the DC connection. The DC link voltage is depicted in figure 5.5. It's almost 650 volts. FL-DSTATCOM then provides compensation current to correct the distorted source present.

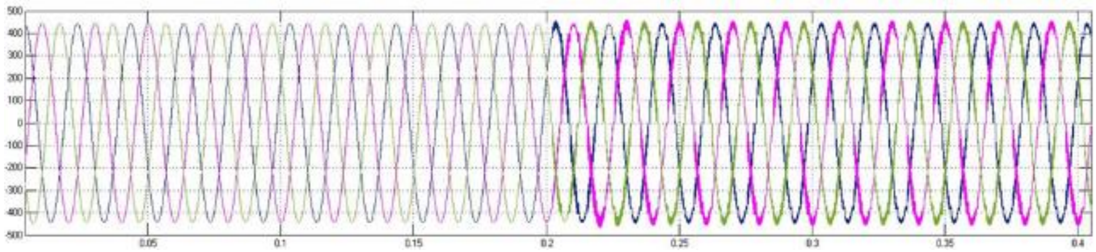

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Figure 5.6 Source Voltage After Compensation

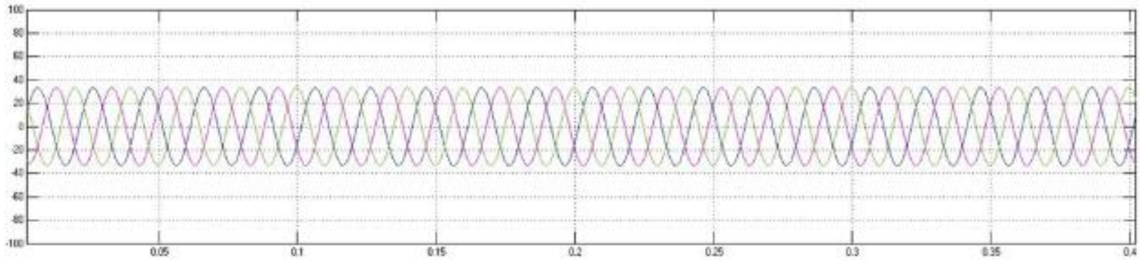

Figure 5.7 Source Current After Compensation

Figure 5.6 and 5.7 shows the voltage and current of the source after compensation. There is no distortion in the source current after compensation. Unbalance and nonlinearity in source current are compensated. The above figures depict a balanced and linear supply current and voltage.

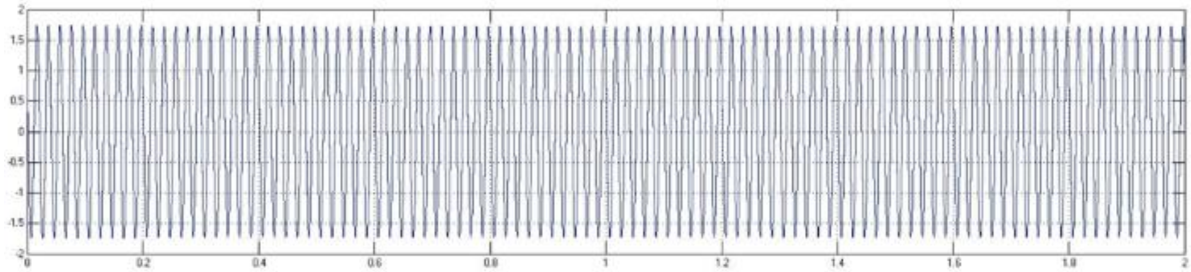

Figure 5.8 Neutral Current Before Compensation

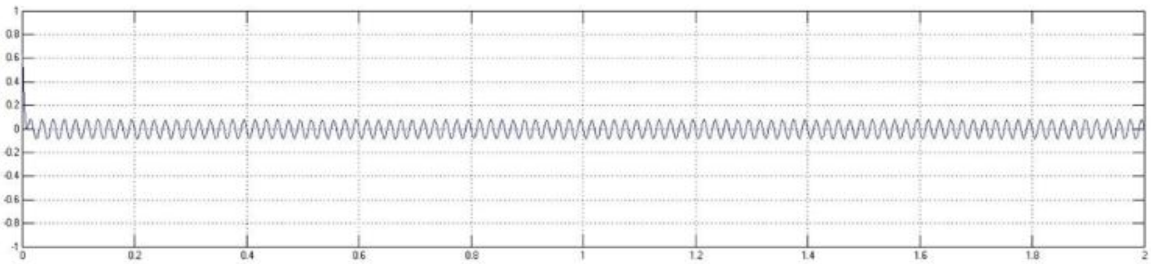

Figure 5.9 Neutral Current After Compensation

Figure 5.8 and 5.9 depicts neutral current with and without compensation. It has a certain amount of neutral current before compensation. After the compensation, neutral current is virtually zero. The THD for source current before compensation is shown in figure 5.10. Since the THD value is about 10%, it indicates the presence of harmonics in the source current. To reduce the harmonics, compensation is required.

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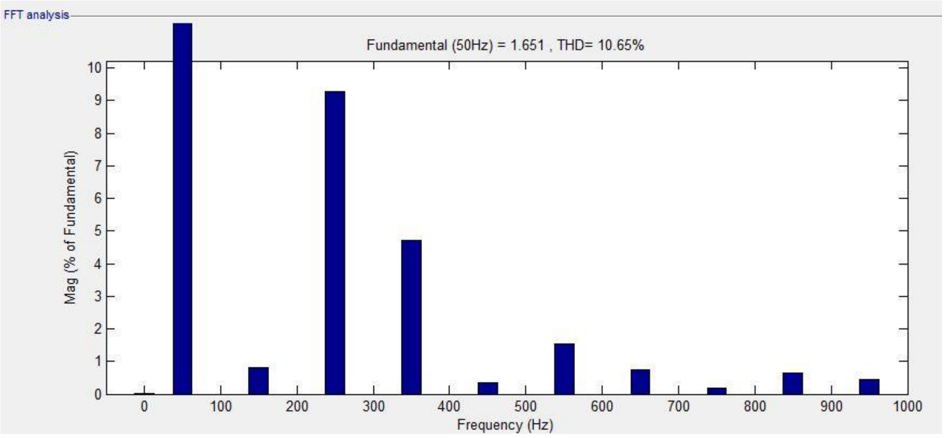

Fig 5.10 THD for source current before compensation

Figure 5.11 represents THD analysis of the source current for different phases in the system. Here, the THD values are reduced to below 5% in the system because of compensation.

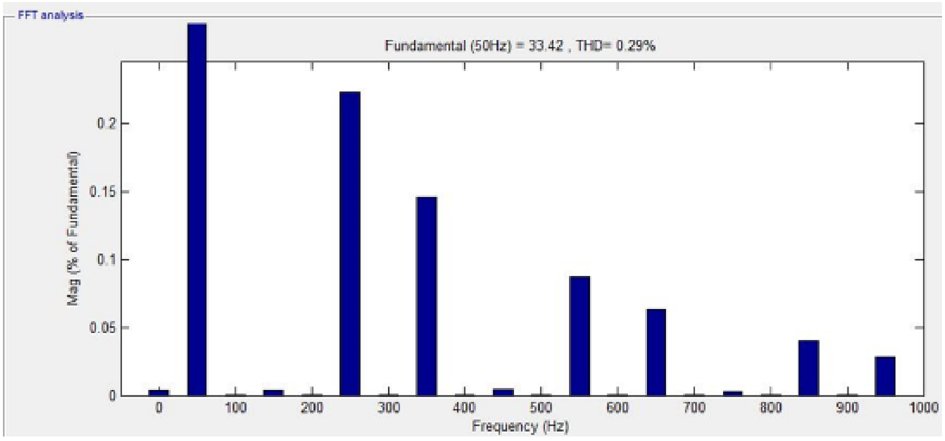

Figure 5.11 THD for Source Current with Compensation

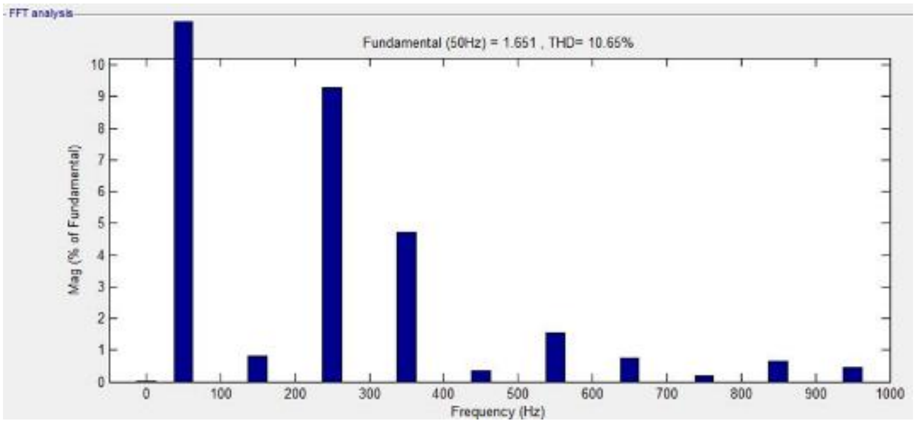

Figure 5.12 THD Value for Load Current

The THD value of load current is shown in figure 5.12. The current in a nonlinear load has several harmonics. THD is nearly 10% at the moment. As a consequence, it is used to express the harmonic current.

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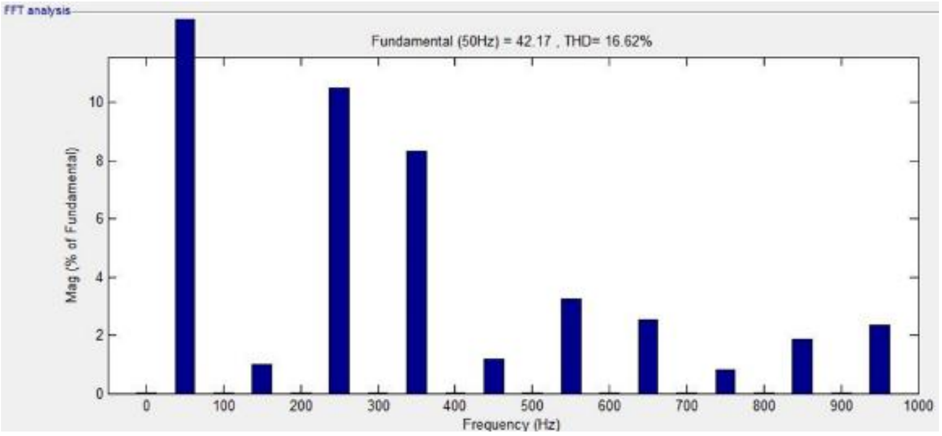

Figure 5.13 THD for Source Voltage Before Compensation

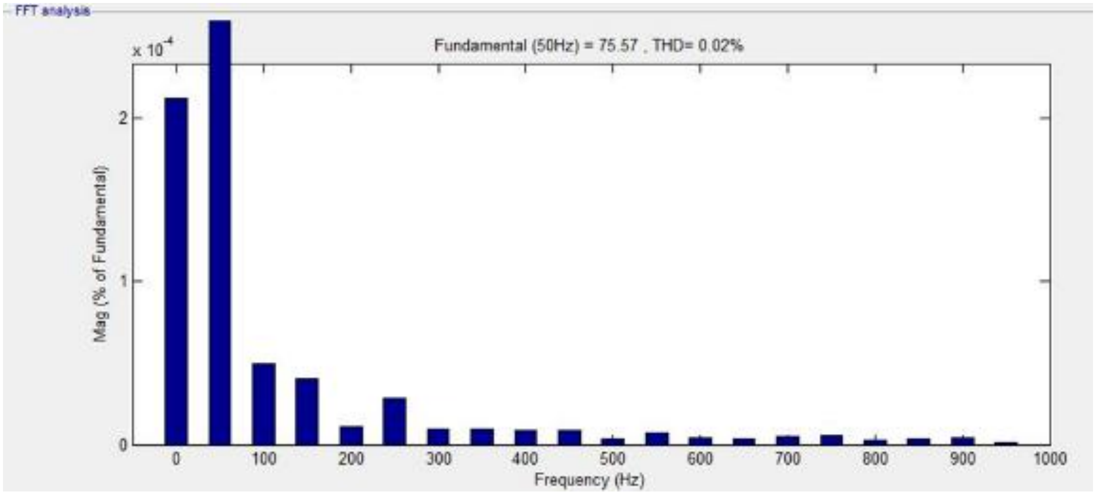

Figure 5.14 THD for Source Voltage with Compensation

The THD study of source with and without compensation is depicted in figure 5.13 and 5.14. The supply voltage's THD value is about 5% after compensation. When a nonlinear load is attached to a sinusoidal source voltage, the current is not sinusoidal. However, the source voltage is unaffected. It demonstrates the reduction of harmonics.

6. CONCLUSION

The performance of novel predictive current control for DSTATCOM is evaluated for harmonic reduction, reactive power compensation, and load balancing. To predict the next time step values of the reference current, a comprehensive discrete-time model of the system is created. This method is adequate for current monitoring and complex results. Without using any modulation techniques, the proposed controller achieves efficient current tracking and transient response. The THD valu for both supply current and voltage is reduced below 5% according to IEEE-519 satndard. Furthermore, under dynamic conditions, the proposed method offers faster and better compensation than a HCC. The output of the simulation indicate that the proposed controller even works well under steady state conditions.

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