POWER QUALITY IMPROVEMENT IN DISTRIBUTION SYSTEM USING DSTATCOM

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CANDIDATE'S DECLARATION

I, Shivam Gupta, Roll No. 2K18/C&I/19 student of M.Tech. (Control & Instrumentation), hereby declare that the Dissertation titled **"Power Quality Improvement in Distribution System using DSTATCOM"** which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

We hereby certify that the Dissertation titled "**Power Quality Improvement in Distribution System using DSTATCOM**" which is submitted by Mr. Shivam Gupta, Roll No. 2K18/C&I/19, Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under our supervision. To the best of our knowledge this work has not been submitted in part or fulls for award any Degree or Diploma to this University or elsewhere.

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ABSTRACT

In the recent times, the electrical distribution network is facing challenges in maintaining power quality (PQ) due to increasing use of sensitive electronic equipment in most of the residential, industrial and commercial applications. These electronic equipments behave as nonlinear loads to the power system network. The custom power devices (CPDs) are being used as remedies to improve the PQ problems faced by the power distribution network, the commonly used CPDs are D-STATCOM (distribution static compensator), UPQCs (unified power quality conditioners), and DVR (dynamic voltage restorers) etc. A DSTATCOM is used for elimination of harmonics in source current, reactive power compensation, power factor correction and for load unbalancing through appropriate control of its voltage source converter (VSC). A DSTATCOM injects current into system to maintain source current sinusoidal and maintain unity power factor between source voltage and current. The present work gives a detailed performance analysis of DSTATCOM using two different types of control algorithms for VSC i.e. synchronous reference frame (SRF) and Adaptive Based control. These control schemes are modeled and simulated in MATLAB SIMULINK to generate reference source current and control signal to D-STATCOM to mitigate power quality problems under different loading condition. The comparison performance analysis of both algorithms on the basis of THD (total harmonic distortion) in source current is presented. The performance of DSTATCOM for reactive power compensation, power factor correction and load balancing is also analyzed using SRF and adaptive based algorithms. The DSTATCOM is connected in shunt configuration to distribution system feeding different type loads.

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POWER QUALITY IMPROVEMENT IN DISTRIBUTION SYSTEM USING DSTATCOM

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<u>LIST OF ABBRIVATIONS</u>

DSTATCOM	Distribution Static Compensator
APF	Active Power Filter
PPF	Passive Power Filter
PQ	Power Quality
FFT	Fast Fourier Transforms
IGBT	Insulated Gate Bipolar Transistor
IRPT	Instantaneous Reactive Power Theory
SRF	Synchronous Reference Frame theory
ADALINE	Adaptive Linear Neuron
LMS	Least Mean Square
IGBT	Insulated Gate Biased Transistor
PID	Proportional Integral Derivative
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
VSC	Voltage Source Converter
UPQC	Unified Power Quality Conditioner
PCC	Point of Common Coupling
DVR	Dynamic Voltage Regulator
CPD	Custom Power Devices
MCCF	Multiple Complex Coefficient Filter
SOGI	Second Order Generalized Integrator
VSI	Voltage Source Inverter
CSI	Current Source Inverter
PCC	Point of common coupling

CHAPTER 1
INTRODUCTION

1.0 INTRODUCTION

Electricity is key element in the growth of economy of a country. In modern world the importance and need of good power supply is growing day by day but maintaining quality and reliability of the power supply is a complicated task. If power quality of supply is not maintained, it will affect the performance of other loads of end user. The power quality (PQ) should be maintained at all level generation, transmission, distribution, and utilization level but majority of the problems in supply are from consumer level or utilization level. In present time every sector of commercial, domestic, agriculture and industrial uses different types of electronic equipment and the uses of this type equipment is increasing day by day. Every equipment has some power electronic converter at front end because of which that equipment act as non-linear load to our conventional supply. Those non-linear loads draw nonsinusoidal current from the power source.

These power quality issues affect all type of end customers in distribution system directly or indirectly in terms financial loss of due to interruption of process, manufacturing loss due to stoppage of the process, damage of equipment, raw material wastage, data loss at data centers and so on. There are many industries in manufacturing and banking sector where small problem interrupt the entire process for hours. These are some power quality issues which affect the end customer because of which the importance of power quality in distribution system is increasing day by day.

1.1 POWER QUALITY ISSUES AND REMEDIES

According to Institute of Electrical and Electronics Engineers (IEEE) standard IEEE 1100 " Power quality is the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." In simple words perfect sinusoidal voltage with constant amplitude and frequency is an indication of perfect power quality which allows any sensitive electronic equipment to work without any loss in performance and life of equipment.

Power quality issues generally divided into three broad categories, Harmonics in the system which is introduced by the rectifier based non-linear load in system which distorts the waveform of voltage and current and increase power usage. The non-linear loads inject harmonics in supply current waveform. Low power factor or poor power factor operation it refers high reactive power in the system because of this load will demand heavy amount of current from source this heavy current damage the insulation of wires and cables. Now-a day's most of loads in industries, agriculture and domestic are inductive in nature like motors, fans, pumps, etc. these inductive loads need reactive power so burden of reactive power increases in the system. When the need of reactive power increases in system, this will cause voltage sag at the distribution side and demand heavy amount of current. When system is lightly loaded or at no load condition voltage swells at distribution side happen. Voltage unbalance because of non uniform distribution of loads, it creates voltage unbalance in all three phases which affects performance and life of the machinery connected to the supply. Excessive neutral current because of unbalanced load is creating power quality issue like heating of wire and cables. Some natural phenomenon like lightning, flashover, equipment failure, and faults also affect the power quality [1]-[2].

Power quality issues are increasing in number because of the use sensitive electronic equipment which is non-linear loads in nature like computer, laptop, Xerox machine, TV sets, printer, scanners, fax machines, battery chargers, medical equipment electric furnaces, fluorescent lamp, and adjustable speed drives etc. Due to increased problem of power quality, different types of technique to improve power quality evolved in the past century. To improve power quality one can use passive components, passive filter, and active filters. There is many categories comes under each of filtering option in which DSTATCOM comes under active filtering which is effective but because of high cost of operation [3].

1.1.1 PASSIVE COMPENSATOR

It is consist of lossless passive component like inductor and capacitor with switches or without switches. They can absorb and supply fixed or variable reactive power according to the PQ issues. They improve power quality of the system by enhancing the efficiency and utilization of the equipment connected in the network. These compensators are used in distribution system to improve voltage profile at PCC, reduce the losses, for power factor improvement, for neutral current compensation, for load balancing. The use of these passive compensator components is simple, cost effective and easy installation they are still used in large power rating system. These are further classified and used as series, shunt and hybrid (arrangement of both series and shunt) passive compensator.

1.1.2 PASSIVE POWER FILTERS (PPF)

In low and medium power rating system we use passive filter because of his low cost of operation and simple operation. It is also used in some high power rating but requirements for design is different from low and medium power rating. In early days passive filter were used to compensate the harmonics present in the system because of their simple operation but in further stages of research different types of arrangement and topologies has been discovered according to the need of the system. Now this PPF is used to provide compensation for harmonics currents and reactive power in system. Passive filters generally classified in three types known as:

(i) Series Passive Filter
(ii) Shunt Passive Filter
(iii) Hybrid Passive Filter

(i) Shunt Passive Filter

It is connected in parallel with non-linear loads which injects harmonics in to the supply system. It provides low impedance path to harmonics from the load because of which harmonics does not enter to the system but stay in L-C passive circuit. If the design of the filter done properly it offers two functions first is filtering of harmonics and second is compensation of reactive power to improve power factor of system. These filter further categorized as Band-pass or Tuned filters and High-pass or Damped filters.

Tuned filters have single tuned, double tuned and multiple tuned in single tuned filter is tuned at one specific frequency, when two single tuned circuit combined it is known as double tuned filters it is used in high voltage application. More than two tuned filter are not used in practice because it has no specific advantage and it is difficult to adjust in one circuit. High pass filter absorbs all the higher order of harmonics and provide damping. Shunt passive filter have some problems like resonance condition with source impedance, it provides fixed compensation to the system and poor power factor at light or low load condition.

(ii) Series Passive Filters

This series passive filter consists of simple parallel L-C element which is connected in series with non-linear loads which injects harmonics in to the supply system. It provides high impedance path to block the harmonics from the load. To block single harmonic current series passive filter is used and to block multiple harmonic currents multiple filters need to be connected in series. But this arrangement consumes reactive power and create voltage drop. That is the reason shunt passive filter is more used. In small power rating system to block third harmonic current single phase series passive filter is quite popular.

(iii) Hybrid Passive Filters

It consists of series and shunt passive filters combination which is used in many industrial applications. If the series and shunt both filters used together they offer good filtering characteristics. If only passive shunt filter is used then sometimes resonance condition with supply occurs but one single tuned series filters is used then it blocks the resonance between supply and shunt filter and also absorbs excess reactive power at light load condition. For many large powers rating applications combination of both filters is used because of its low cost.

There are some limitations of these passive power filters like these filters not work with varying system conditions, tuning frequency and size of filter cannot be changed easily if they installed in system, there are number of elements present in the filter if any element damaged then resonant frequency will change, power loss also there because of the resistive element, parallel resonance between source and filter etc. are some limitation of passive filters.

1.1.3 ACTIVE POWER FILTERS

Due to limitation of passive filters and limited application of the filter encouraged to develop the active filter. These filters generally have two types:

(i) Shunt active power filter (SAPF)

(ii) Series active power filter

(i) Shunt Active Filters

Shunt active filters are used to provide harmonic current compensation, reactive power compensation and neutral current compensation in any distribution system. Shunt APF has DC bus connected VSC, AC interfacing inductors and small passive filters. To generate gating signal for switches in VSC control algorithm and PWM current control is used. VSI based shunt APF is used most commonly.

(ii) Series Active Filters

Series active filters are used to provide compensation present in the voltage and current in the system. Series APF has DC bus connected VSC which is in series with primary side of single phase transformer a small rating RC filter is connected across the secondary side of transformer. The control algorithm and PWM current control is used to generate the signal for switches present in the VSC.

1.2 CLASSIFICATION OF POWER QUALITY ISSUES

In general, variation of voltage or current waveform from the ideal waveform is defined by the term power quality issues or problems. These issues in voltage or current create different types of problem on user side like failure of equipment, loss of data, affecting the manufacturing process etc. To maintain the power quality throughout the network some devices installed at customer side. Here are some classifications of power quality issues depending upon the affect that is present in power system:

1.2.1 SHORT DURATION VARIATION AND LONG DURATION VARIATION

Voltage Sag when reduction in rms voltage level to 10% - 90% of nominal at the power frequency, for the duration of half cycle to one minute. Voltage sag may be effect of fault in distribution or transmission system or the switching on of heavy loads.

Voltages swell when increases in the rms voltage level to 110% - 180% of nominal value at a power frequency for duration of half cycle to one minute. Voltage swell caused by switching off heavy loads, energizing capacitor bank and transfer of loads from one source to another source.

Under voltage when the rms voltage falls below 90% of the nominal voltage for duration more than one minute.

Over voltage occurs when the rms value of voltage rises above 110% of the nominal voltage for duration more than one minute.

1.2.2 POWER INTERRUPTIONS

When electrical supply delivered to the consumer is goes away this is called power interruption. These interruptions further classified according to their duration momentary interruption (time period between 0.5 cycles and 3 seconds), temporary interruption (between 3 seconds and 1 minute) and sustained interruption (more than one minute).

1.2.3 FLICKER, TRANSIENTS AND NOISE

Flicker is response of lighting system when fast changing loads connected to the power system. Such variation observed by the human eye. Devices that shows instant load current variations cause voltage fluctuations and light flicker like electric arc furnaces, arc welders, x-ray machines and electric boilers etc.

Transients occur when spikes are present on a sine wave of voltage and current, amplitude of spikes is between few volts and thousand volts. Transients classified into two types impulsive transient which is a small unidirectional change in current, voltage or both on power line. The main causes are switching of inductive loads, lighting and removal of heavy loads. Oscillatory transient is a small bidirectional change in current, voltage or both on a power line. The main causes of transients are switching of inductive loads and pf correction capacitors.

Noise refers to superimposition of high frequency signals with the sine waveform of the AC voltage or current. Noise usually occurs because of the improper grounding and it is capable of damaging electronic devices such as controllers and computers.

1.2.4 LOW POWER FACTOR, UNBALANCE LOADING AND HARMONICS

Poor power factor or low power factor is caused in the system when load connected is highly inductive load (electric motors, transformers, fan, and pumps) and it means high reactive power needed to the system.

Unbalance condition occurs when unbalance load is connected in the system does not draw equal amount of current from all the three phases this increase the current on neutral wire as the unbalance increases overheating and risk of fire increases. In an unbalanced voltage condition if any motor operate it will create the opposing torque and impact the performance of motor.

Harmonic distortion is the variation from ideal sinusoids. Harmonics are not produced by system itself, but load connected to system. When nonlinear loads (rectifier, inverter) are connected to the system it injects harmonics into supply system. When Harmonics combined with the fundamental voltage or current sinusoids it will create non sinusoidal shape. This non sinusoidal shape is the sum of different sine waves of magnitude and phase angles and different multiple of system fundamental frequency. To measure harmonic distortion of any waveform we can calculate total harmonic distortion (THD) of waveform.THD measures every individual component magnitude and phase angle of entire harmonic spectrum.

Some effect of poor power quality is given below:

- Noise, heating and decresed life span of capacitor, surge suppereser, cables, machines, fuses and customers equipment.
- Due to harmonics there are some extra losses in cables, transmission lines, motors, generators and transformers.
- Due to unexpected disturbances such as current or voltage magnification failure in power system components and consumer loads.
- Mal operation of protective devices such as fuse and relay.
- Tripping of any electronic sensitive devices.
- Data loss in any device.

1.3 OUTLINE OF THE DISSERTAION

Chapter -1 gives the broad introduction on power quality, it also discuss classification of different types issues due to poor power quality and their remedies.

Chapter-2 In this literature review of published work on different types of power quality issues and different types of techniques used to improve power quality have been discussed.

Chapter-3 gives the brief description about DSTACOM and its components, design, principal and control algorithms used for power quality improvement in distribution system.

Chapter-4 is about simulation and performance analysis of DSTACOM for harmonic compensation, reactive power compensation, power factor correction and load unbalancing condition in distribution system.

Chapter -5 presents main conclusion of the present work and future scope of work in the area of power quality improvement.

CHAPTER 2
LITRATURE REVIEW

2.0 INTRODUCTION

The power quality has emerged one of the important areas of research in last 40 years increasing use of the electricity. When the reach and availability of electricity is great then some researcher and user of electricity started noticing some issues on power quality that motivate them to research and provide solution to maintain the power quality. Lot of research and article published on the various power quality issues which are discussed in previous chapter. The brief literature review related to power quality improvement using different devices and different technologies is studied and presented as literature survey:

2.1 CLASSIFICATION OF LITRATURE SURVEY

In this section an extensive review of some published work on power quality issues and techniques used to mitigate those issues is presented.

2.1.1 Classification of Power Quality Issues

Power quality issues like harmonic elimination, reactive power compensation, power factor correction, voltage unbalance, neutral current and voltage regulation at point of the connection are common form of PQ issues.

B. Singh et al. discussed about power quality its standards and issues and also discussed about different types techniques used to solve the power quality issues [4].

B. Singh and J. Solanki discussed about compensation for reactive power and harmonics caused by different types of loads. Three different methods(SRF, IRPT and Adaline) are used for reference currents estimation for DSTACOM and compared 2009 [5].

A.K Akella et al. discussed about harmonic and power factor correction in three phase four wire systems when nonlinear load is connected at the end of distribution system. In this DSTATCOM used SRF control algorithm to mitigate the issues 2014 [6].

B. Singh et al. discussed attenuation of the harmonics such as noise, notches, dc offset and distortion injected in the system because of non linear loads. Least mean square based neural network structure control algorithm is used in DSTATCOM to improve for the power quality of power network. 2017 [7].

Srinivasan et al. discussed issues like load compensation and Power Factor correction using novel predictive control with instantaneous symmetrical component theory on for extraction of reference current in DSTATCOM. 2015 [8].

Y.C.Wang et al. discussed about Adaline based DSTATCOM to compensate power quality problems. The compensating current is produced with the help of unit positive –sequence voltage vector. 2011 [9].

N. Kumar et al. discussed comparison between voltage source inverter and CSI based DSTATCOM in terms of power factor correction and harmonic compensation. A VSI based DSATCOM offers more advantage compare to CSI based DSTACOM. 2015 [10].

Timothy A. Haskew et al. compared performance of VSI based STATCOM conventional d-q vector control technology and a direct-current vector control schemes to provide reactive power and voltage support to the system. 2013 [11].

S.R Arya et al. discussed to improve power quality issues under linear/ nonlinear loads in distribution system using DSTATCOM and the extraction of active and reactive components of reference current from correlation and cross correlation algorithm in time domain. 2012 [12].

A. Ahirwar and A Singh discussed about improvement of power factor, voltage regulation, reducing harmonics in supply current and also provide load balancing in the system using conventional instantaneous reactive power theory (IRPT) and modified IRPT based DSTATCOM 2016 [13].

A.K Panda et al. discussed about harmonic elimination in the source current and unbalance condition due to nonlinear based load and ADALINE based control algorithm is used in DSTATCOM to provide solution to the network. 2016 [14].

B. Singh et al. discussed about balancing of load, neutral current elimination, power factor correction and voltage regulation in system when industrial loads are connected. modified IRPT based DSTATCOM is used 2005 [15].

S.R. Reddy et al. discussed about harmonic elimination, neutral current elimination, improve voltage regulation and reactive power compensation using SRF based DSTATCOM and hysteresis band current controller for better switching 2018 [16].

E Hossain et al. discussed about power quality issue in renewable energy sources connected power network. The different types of devices DSTATCOM, UPQC, DVR UPS, etc are discussed to mitigate the power quality issues 2018 [17].

S.R. Reddy and P.V Kishore discussed about reducing the losses and improving the voltage regulation at the busses. Comparison between push pull and VSI based DSTATCOM is presented 2014 [18].

Nielsen et al. discussed about the protection of sensitive electronic loads in low and medium voltage level system from voltage sag, A DVR is cost effective solution for such protection [19].

B.S.S. Kumar and R.S. Kumar discussed about harmonic elimination and reactive power compensation using different types of control algorithm in DSTATCOM and performance is analyzed [20].

T. Zaveri et al. discussed PQ issues in three phase four wire system connected to the non linear load. The different control algorithms based DSTATCOM operation is compared in harmonic distortion, grid power factor and compensator rating [21].

T. Penthia et al. discussed about harmonic elimination and unbalanced current condition at supply side under single phase fault condition Adaline based DSTACOM is used [22].

M.I.M Montero et al. discussed harmonic cancellation and reactive power compensation when non linear load is connected and to provide solution for these power quality issues using shunt active power filters [23].

2.1.2 Classification Based on Control Techniques Used for PQ Issues

D.P. Kothari et al. discussed about T-connected transformer for neutral current compensation and three legs DSTATCOM to compensate harmonic, reactive power also improve voltage regulation and power factor. SRF and IRPT based control algorithm are used [24].

S. Rana et al. used a three phase DSTATCOM to compensate the power quality issues. For extraction of reference current Double Second Order Generalized Integrator Synchronous Reference Frame (DSOGI-SRF) is applied in DSTACOM. It gives good performance in power factor correction, voltage regulation and load balancing [25].

P. Jayaprakash and E. Varghese discussed about different control algorithms of DSTATCOM for extraction of reference current and compared the performance analyzed. These algorithms are IRPT, SRF, Adaline and Back Propagation [26].

M.A Mahmud et al. discussed about design of Non-linear controller design for a DSTATCOM and compared with conventional PI controller used in DSTATCOM. it improves the voltage stability of distribution network [27].

M.K Mishra and K.Karthikeyan discussed the response of DSTATCOM under varying unbalanced loads. The DC-link voltage has a fast acting dc-link voltage controller. The performance is compared with conventional PI controller [28].

P.Chittora et al. discussed about Hopfield Neural network based control algorithm in DSTATCOM to eliminate different types of harmonics injected by the non-linear loads present in distribution system. It also improves power factor and load unbalancing problem [29].

R. Bansal et al. discussed about modified fuzzy controller based control algorithm for extraction of reference current and control of shunt active power filter (SAPF) to improve Power quality of micro grid. It is implemented on hardware [30].

S.R. Arya and B. Singh discussed about DSTATCOM based on kernel incremental Meta learning algorithm (KIMEL) control algorithm which shows the reactive power compensation, harmonics elimination and load balancing under different kind of balanced and unbalanced linear and non-linear loads [31].

J. Solanki and B. Singh discussed about the implementation of Adaptive control algorithm for Shunt Active Filter to maintain sinusoidal and unity power factor source current in distribution system.[32]

S.R. Arya and B. Singh discussed about the performance of leaky LMS based control algorithm for DSTATCOM to solve different types of power quality issues like harmonic elimination, reactive power compensation and unbalanced loading condition [33].

S. Osowski discussed about the novel approach to estimate the harmonics in the power system and it uses the optimization neural network theory [34].

P.Chittora et al. discussed about the efficient control of DSTATCOM using multiple complex coefficient filter (MCCF)-second-order generalized integrator (SOGI). MCCF filter extract fundamental component of voltage and SOGI for extraction of fundamental component of load current. This control of DSTATCOM compensate different types PQ issues in distribution system [35].

P.Chittora et al. discussed about performance analysis of different types of filters used in DSTATCOM for extraction of fundamental component of Load current. These filters are multiple complex coefficient filter, moving average and Butterworth filter [36].

M. Tumay et al. discussed about novel technique for reference current extraction in unified power quality conditioner (UPQC) for different type of voltage and current based power quality problem in distribution system.[37]

Y. Yoldas et al. discussed about various configuration and different types of control strategies used in DSTATCOM to compensate different types of power quality problems in distribution system. It gives comprehensive review on DSTATCOM.[38]

K. Kant et al. discussed about the notch filter which is used for fundamental frequency load current component extraction. Which is further used to estimate reference supply current in DSTATCOOM.[39]

P. Dey and S. Mekhilef discussed about d-q control theory and modified phase locked loop (PLL) for shunt hybrid active filter for estimation of reference current. The performance is evaluated based on harmonic compensation and reactive power compensation.[40]

D.C. Pham et al. discussed about the modeling of voltage source inverter and its application to control the induction motors.[41]

M.A Rahman et al. discussed about different types of current controller used for controlling Voltage source converter like hysteresis, PWM and others. [42]

Brij N. Singh and Parviz Rastgoufard discussed about the theory of reactive power to develop the novel control algorithm for the active filter to compensate harmonics created by non –linear load in the distribution system.[43]

P. Chittora et al. discussed about modified recursive based gauss-Newton based control algorithm in shunt active filter to improve power quality problems like load unbalancing, low power factor, harmonic and problem of neutral current in distribution system. [44]

A. Singh presented detailed analysis, modeling, design and control algorithm for three different configuration of DSTATCOM for improving power factor, voltage regulation and also harmonic compensation when system connected to non-linear load and also different types of loading condition.[45]

M. Badoni et al. discussed about the design of adaptive neuro-fuzzy inference system based controller to control DC link voltage and voltage at load bus d-q theory based DSTATCOM. This controller shows satisfactory performance in power factor correction and harmonics compensation under different types of loading conditions.[46]

A. Chandra et al. discussed about a new control technique for active power filter to compensate reactive power and neutral current, eliminate harmonics current.[47]

A. Nabae et al. discussed about combined system of shunt and series active power filter to compensate harmonics in distribution system due to non –linear load.[48]

2.2 RESEARCH GAP

In last two decades the issue of power quality improvement based on novel and conventional algorithms are being discussed extensively in literature. The control algorithms are analytical in nature and have some limits but few authors also reported the use of learning based algorithms. These learning algorithms are less analytical and reduced computational complexity, fast and accurate in nature compared to the conventional algorithms. Different types of non-linear controller and filters are also used with these algorithms to improve overall performance of DSTATCOM and distribution system.

2.3 OBJECTIVE OF THE PRESENT WORK

In the present work effort has been made to study following aspects of power quality issues and their improvement:

(a) Identification of power quality issues like harmonics, reactive power demand, low power factor and load unbalancing in distribution system with linear and non-linear loads.

(b) Improvement of power quality issues in distribution system with non-linear loads using conventional control methods like synchronous reference frame (SRF) theory.

(c) Improvement of power quality in distribution system feeding non-linear loads using learning based algorithm like ADALINE.

2.4 CONCLUSION

In this chapter a review of the published work on power quality issues and techniques used to improve power quality are discussed. The research gap in the area of power quality in distribution system are identified and the defined objective of the present work.

CHAPTER 3

MATHEMATICAL MODELING AND DESIGN OF DSTATCOM FOR DISTRIBUTION SYSTEM

3.0 INTRODUCTION

The power system has mainly three levels to supply electricity to the consumer or end user. These levels are Generation, Transmission and Distribution. The power quality issues arise in all three levels but the distribution system is more vulnerable to the power quality issues because of variety of loads used by the consumers. The loads mainly non-linear loads such as power electronic converter based loads, computer battery charging system, UPS, printer etc. inject harmonics into the system and affect the performance of the systems. The inductive loads (motors, solenoids, relays and compressors) create reactive power demand in the system. Unbalance loading or unequal loading give rise to the neutral current this leads to the heating of wire and cables. To mitigate these types of issues in distribution system conventionally passive compensator (inductor and capacitor) are deployed in the network. The active and passive filtering are discussed in chapter 1. In this chapter scope of active filtering using DSTATCOM is discussed and the performance of DSTATCOM using conventional and learning based algorithm is analyzed.

3.1 POWER QUALITY IMPROVEMENT DEVICES

In modern day power system mainly in distribution side are facing different types of power quality issues due to excessive use of sensitive equipments in residential, industrial, traction and commercial applications. The evolution in power electronic converter has given the concept of custom power devices which are most commonly used the power quality improvement devices. To provide quality power to the commercial and industrial consumers is the major challenges to power utilities due to diverse nature of loads. The power electronics based controllers are also called custom power devices are now used to improve PQ. The uses of these devices are mainly in low and medium distribution system. The Custom power devices mainly consist of a VSI with self supporting dc bus voltage with large DC capacitor. The Custom Power Devices (CPDs), namely, DSTATCOMs (distribution static compensators), UPQCs (unified power quality conditioners) and DVRs (dynamic voltage restorers) are used to remove the power quality problems according to the need. In these CPDs, DSTATCOMs are mainly used for power quality problems like harmonic elimination, poor power factor, unbalanced currents, increased neutral current and poor voltage regulation. According to the power quality issues an appropriate configuration of DSTATCOM is selected in practice.

3.1.1 DISTRIBUTION STATCOM (DSTATCOM)

A distribution static compensator is a shunt compensator used in parallel to the consumer loads it can improve power quality issues like harmonic elimination, low power factor, unbalanced currents, increased neutral current and poor voltage regulation. The power semiconductor switches such as insulated gate tripolar transistor (IGBT) switches are used in converter for fast switching control. The fast switching of IGBTs using proper control algorithm provides effects of load balancing, reactive power balance and harmonic elimination etc. A DSTATCOM is a variable current source capable to provide harmonics current demand of the load. To increase the dynamic rating, a passive filter can be used in shunt position with DSTATCOM. These hybrid filters has been used to cancel out the harmonic currents at the PCC (point of common coupling) voltage normally injected by nonlinear loads. Suitable configuration of DSTATCOM is used in practice according to the problem faced.

Many configurations and control algorithms are developed over the time and a DSTATCOM can be classified based on mainly three types:

Converter-based classification: converter used in DSTATCOM is either VSI or CSI.

Topology-based classification: In this DSTATCOM realized with or without transformer.

Supply system-based classification: According to the number of phases.

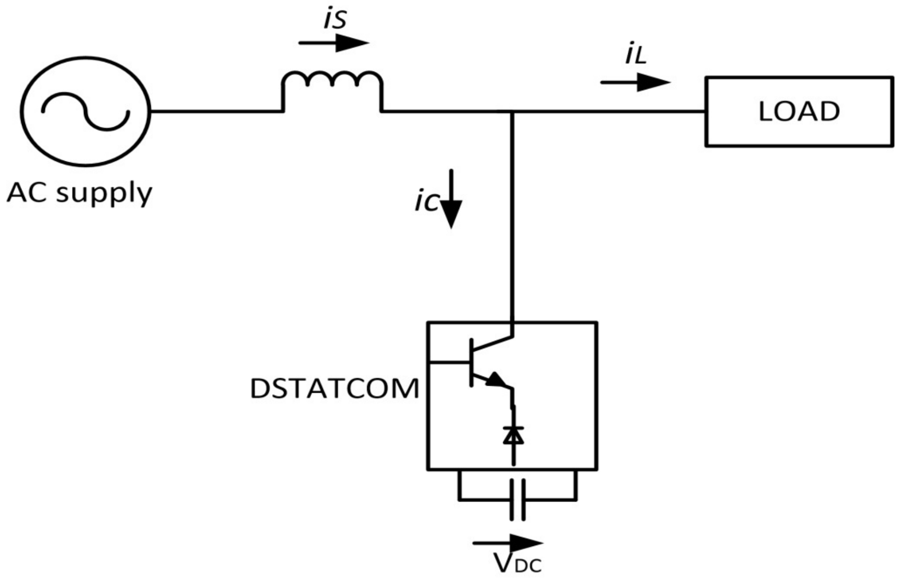


Figure 1: General configuration of DSTATCOM

3.1.1.1 Three –Phase Three-Wire DSTATCOM

In this type of DSTATCOM there are two categories non isolated VSC and isolated VSC through different connection of transformers. But the three legs based three phase three wire DSTATCOM is commonly used in practice.

At the Pcc DSTATCOM improves power quality. A DSTATCOM is power electronic controller which has very fast response time and most significant controller for any distribution side Fig.2 shows a three leg VSI based DSTATCOM. By varying the phase angle and magnitude of the voltage of the VSC with respect to the PCC voltage DSTATCOM can trade active and reactive powers according to the need of the distribution system. A VSC based DSTATCOM is always preferred over CSC based DSTATCOM for power quality improvement, such as harmonic elimination, reactive power compensation, neutral current compensation, and load balancing. The use of IGBT switches is major technology advancement in the DSTATCOM which makes this device response time fast and efficient.

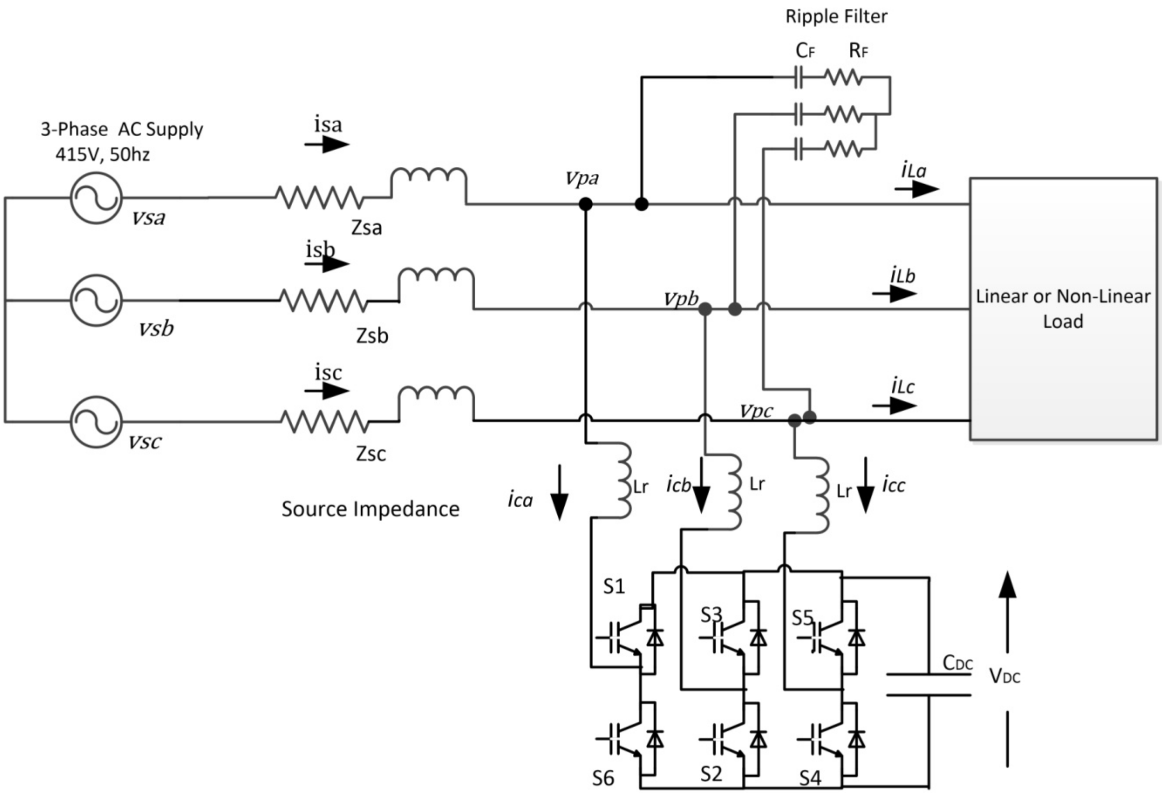


Figure 2: Three-leg VSC based three -phase three- wire DSTATCOM

3.1.1.2 MAIN COMPONENTS OF DSTATCOM

The main components of a DSTATCOM are:

(i) Voltage Source Converter

VSC is a power electronic converter which is made with six IGBT switches with parallel diodes and one dc energy storing element like capacitor. By providing appropriate switching pulses to the switches of VSC adequate compensating currents are generated by VSC. It can generate appropriate amount of magnitude, frequency and phase angles of voltage or current which is required for compensation. The VSC is used to change the complete voltage or current or just inject the lost part of the voltage or current to solve the problem faced by the system while connected to any non-linear load. To supply energy to the converter it has one energy storage device.

(ii) Energy Storage Device

The charging of energy storage device is done by battery source or by converter itself. It stores reactive energy. The main function of this device is to supply the appropriate amount of the energy to VSC through a dc link to generate the injecting current or voltage.

(iii) Transformer

The coupling transformer has two very important roles. First, it provides isolation between the converter and high voltage system. Second, the inductance of transformer makes sure that DC capacitor not short circuited or discharged quickly. The output of VSC is linked with the system through coupling transformer. There are different connections of transformer used in practice according the problem.

(iv) Filters

At the output side of VSC filters are used to prevent the system by high frequency current ripples. The filter element (R C) provides low impedance path to high frequency component and filter out the component from entering into the system. To damp out the high frequency resonance in the system resistor series with capacitor acts as voltage filter. The LC filter is used to match the output impedance of inverter and to eliminate the harmonics.

3.1.1.2 PRINCIPLE OF OPERATON OF DSTATCOM

DSTATCOM solve power quality issue such as reactive power compensation, unbalanced currents and neutral current problem due to unequal loading, harmonics and also provide sinusoidal balanced current to the supply. An IGBT based current controlled VSC with DC bus capacitor is fundamental DSTACOM. Using proper control algorithm, reference currents of DSTATCOM is estimated the gating pulses are generated by employing hysteresis current control by comparing reference current and sensed supply current to provide indirect current control of VSC which injects appropriate currents in the system. By modifying control algorithm one can also achieve the zero voltage regulation condition at PCC (Point of Connection).

3.1.2 DYNAMIC VOLTAGE REGULATOR/RESTORER (DVR)

The DVR is always joined in series configuration. Fig.3 shows a general configuration of DVR. To maintain and regulate the voltage at the load side it injects voltage in to the system. It is connected between the supply and load at PCC. When voltage sags/dips are seen by the sensitive loads the DVR boost up the load side voltage. There are various types of control algorithms and circuit connection that can be implemented in DVR. A DVR is always in standby mode, if there no voltage sag detected then there are no injection of voltage but when sags detected DVR injects appropriate amount of voltage to protect from any failure happening at load-side. The configuration of the DVR consists of an injection/booster transformer which has two purpose firstly injection of voltage through it and secondly isolation. In addition to this a DVR has a energy storage unit, voltage source converter, harmonic filter, and control system. A DVR works in three modes protection mode, standby mode and injection mode.

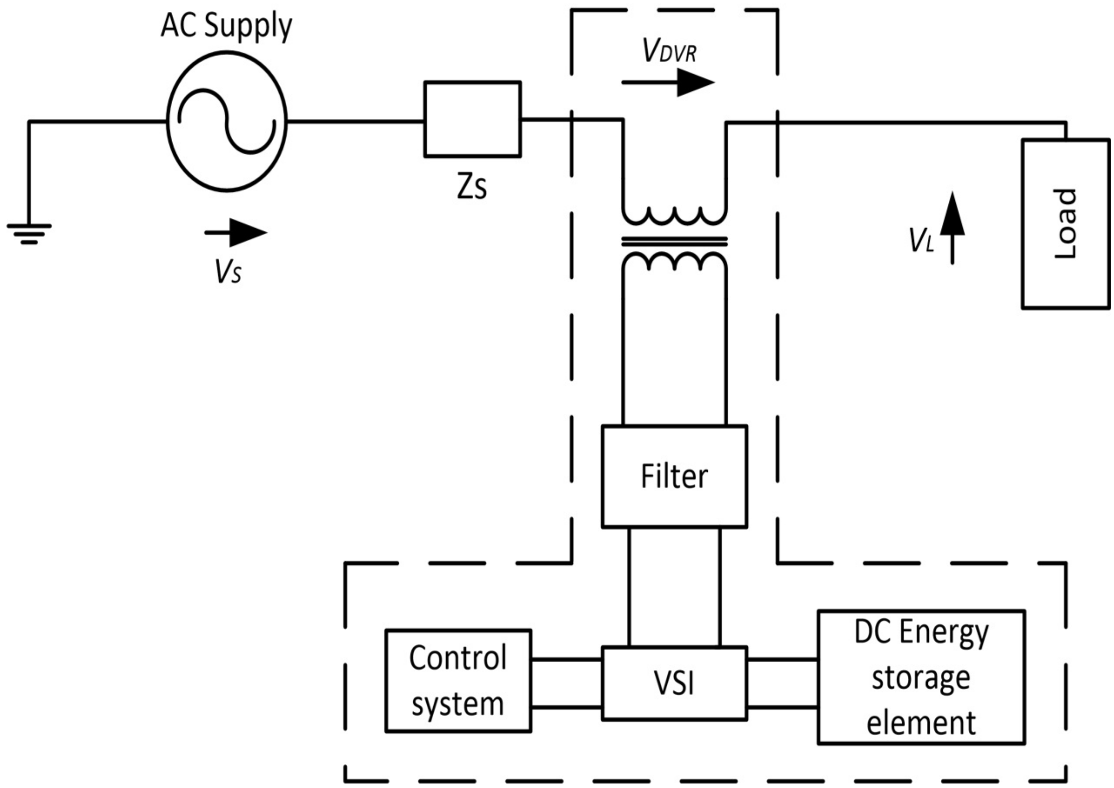


Figure 3: General Configuration of DVR

3.1.3 UNIFIED POWER QUALITY CONDITIONER (UPQC)

Fig.4 shows a basic configuration of UPQC. A UPQC is an integration of series and shunt active filters which is used to compensate reactive power, harmonics and negative –sequence current injected by loads. It has ability to improve power quality at the PCC on distribution system. With ideal compensation the Pcc voltage is the fundamental sinusoidal voltage, source currents are also sinusoidal and in phase of the source fundamental voltage. A UPQC is the combination of both series and shunt both so their functions are also different. Series filter isolate and suppresses voltage based problems and shunt filter cancels current based problems like harmonics by non linear load. There are lot of control algorithm used to know the reference value of voltage and current. The dual function of UPQC solves the problems of consumer and the utility.

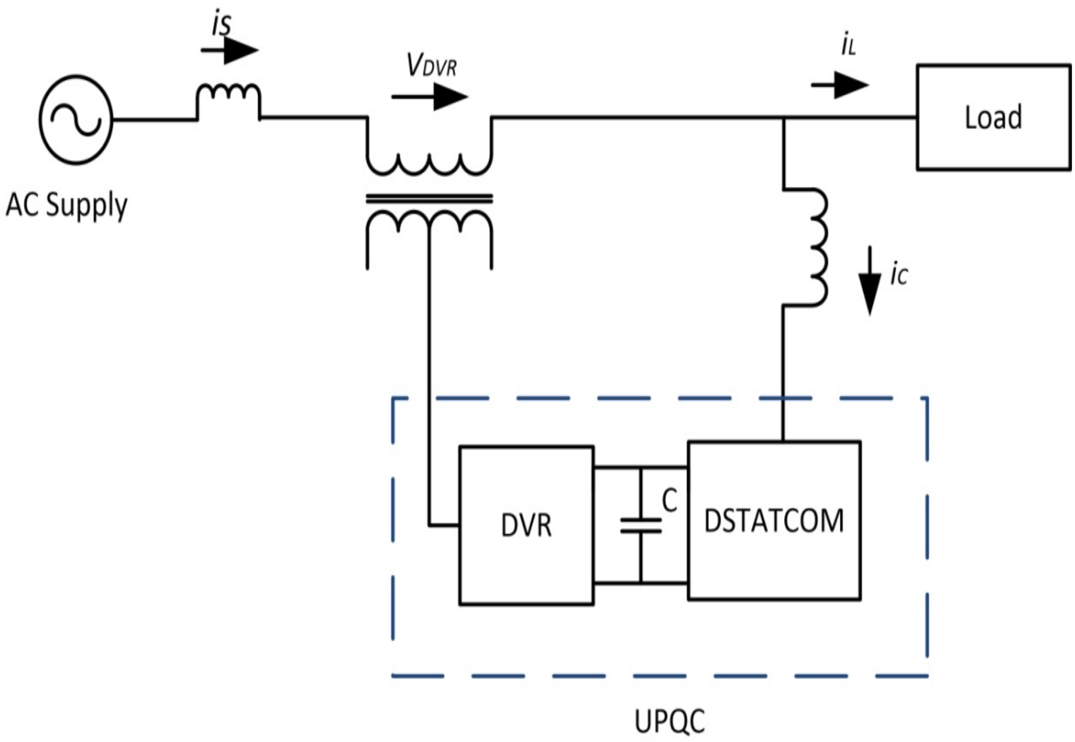


Figure 4: Basic Configuration of UPQC

3.2 MATHEMATICAL MODELING OF DSTATCOM BASED DISTRIBUTION SYSTEM

3.2.1 Modeling of VSC

The DSTATCOM model equation for three leg can be written using KVL in DSTATCOM circuit shown in Fig. 2:

$$v_{pa} = i_{ca}R_r + L_r\frac{d}{dt}i_{ca} + v_{ca} \qquad (3.1)$$

$$v_{pb} = i_{cb}R_r + L_r\frac{d}{dt}i_{cb} + v_{cb} \qquad (3.2)$$

$$v_{pc} = i_{cc}R_r + L_r\frac{d}{dt}i_{cc} + v_{cc} \qquad (3.3)$$

Wherev_{pa}, v_{pb} and v_{pc} are 3-phase instantaneous voltages at the PCC . v_{ca} , v_{cb} and v_{cc} three phase voltages at the AC side of DSTATCOM. R_r and L_r are the resistance and inductance of DSTATCOM. i_{ca}, i_{cb} and i_{cc} are the DSTATCOM currents. These equations can also be written first order differential equation for current

$$\frac{d}{dt}i_{ca} = \frac{(v_{pa}-v_{ca}-R_r i_{ca})}{L_r} \quad (3.4)$$

$$\frac{d}{dt}i_{cb} = \frac{(v_{pb}-v_{cb}-R_r i_{cb})}{L_r} \quad (3.5)$$

$$\frac{d}{dt}i_{cc} = \frac{(v_{pc}-v_{cc}-R_r i_{cc})}{L_r} \quad (3.6)$$

For DC link voltage first order differential equation can be written as:

$$\frac{d}{dt}v_{DC} = \frac{(i_{ca}SWA+i_{cb}SWB+i_{cc}SWC)}{C_{DC}} \quad (3.7)$$

Where v_{DC} is the dc link Voltage of DSTATCOM and SWA, SWB, SWC are the switching function for the control of DSTATCOM and decided by ON or OFF position of IGBT switches. SWA is taken '1' when upper switch of phase a leg in ON and '0' when OFF. The three-phase ac side voltages of DSTATCOM (v_{ca}, v_{cb}, v_{cc}) are calculated as:

$$v_{ca} = \frac{(+2SWA-SWB-SWC)v_{DC}}{3} \quad (3.8)$$

$$v_{cb} = \frac{(-SWA+2SWB-SWC)v_{DC}}{3} \quad (3.9)$$

$$v_{cc} = \frac{(-SWA-SWB+2SWC)v_{DC}}{3} \quad (3.10)$$

3.2.2 Modeling of Three Phase AC Source

The modeling of three phase AC source can be written using KVL in Fig.2:

$$v_{sa} = i_{sa}R_{sa} + L_{sa}\frac{d}{dt}i_{sa} + v_{ta} \quad (3.11)$$

$$v_{sb} = i_{sb}R_{sb} + L_{sb}\frac{d}{dt}i_{sb} + v_{tb} \quad (3.12)$$

$$v_{sc} = i_{sc}R_{sc} + L_{sc}\frac{d}{dt}i_{sc} + v_{tc} \quad (3.13)$$

Where v_{sa} , v_{sb} and v_{sc} are the three phase supply voltages and i_{sa}, i_{sb} and i_{sc} are the supply currents. R_s Supply resistance and L_s supply inductance. These equations can also be write as first order differential equation

$$\frac{d}{dt}i_{sa} = (v_{sa}-v_{ta}-i_{sa}R_{sa})/L_{sa} \qquad (3.14)$$

$$\frac{d}{dt}i_{sb} = (v_{sb}-v_{tb}-i_{sb}R_{sb})/L_{sb} \qquad (3.15)$$

$$\frac{d}{dt}i_{sc} = (v_{sc}-v_{tc}-i_{sc}R_{sc})/L_{sc} \qquad (3.16)$$

3.2.3 Modeling of Nonlinear Load

A three phase diode bridge rectifier with resistive-inductive loading (R, L) is taken as balanced nonlinear load and modeled here. This diode rectifier has two modes, i.e. conducting or non-conducting. When conducting, line to line voltage source is connected to the load and load equation of dc side can be written as:

$$v_s = 2R_s i_d + 2L_s \frac{d}{dt}i_d + v_l \qquad (3.17)$$

Can be expressed as:

$$\frac{d}{dt}i_d = \frac{(v_s-v_l-2R_s i_d)}{(2L_s)} \qquad (3.18)$$

where v_s is the instantaneous line voltage depending upon diode pair conducting it changes its value. The ac load currents (i_{la},i_{lb}, i_{lc}) is achieved by using diode current (i_d).

3.3 DESIGN OF DSTATCOM

Designing of DSTATCOM involves the calculation of different type of component used in VSC like dc bus voltage, dc capacitor value, interfacing inductor and filter.

3.3.1 DC Bus Voltage (V_{DC})

The VSC needs minimum DC bus voltage which is calculated as

$$V_{DC} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \qquad (3.19)$$

Where modulation index (m) is taken 1 and line output voltage is V_{LL}.

In the present analysis a distribution network of 415V, 50Hz is taken for purpose of PQ studies using DSTATCOM. Therefore,

$V_{LL} = 415V$

$$V_{DC} = \frac{2\sqrt{2}*415}{\sqrt{3}*1}$$

After calculation V_{DC} value is 677.69 V for a simulation purpose it is selected as 800V.

3.3.2 DC Bus Capacitor (C_{DC})

The energy present in the DSTATCOM during transients decides the value of Capacitor. The principal of energy conservation is used to determine value of C_{DC}.

$$\frac{1}{2}C_{DC}\left(V_{DC}^2 - V_{DC1}^2\right) = 3.V.I.t \qquad (3.20)$$

Where V_{DC} -reference DC voltage, V_{DC1} -minimum voltage of DC bus, V and I are phase voltage and phase current, t- time by which DC voltage is to be recovered Taking V_{DC1}= 677.69 V, V_{DC}=800V, V= 240 V, I=16.68A, t=55ms, and after calculation using equation (3.20) C_{DC}= 2114.85 μF for simulation purpose it is taken as 2300 μF

3.3.3 Interfacing Inductor (L_r)

Selection of AC inductor is depends on the switching frequency (f_s), current ripple ($I_{cr.pp}$) and DC bus voltage (V_{DC}). The compensating current produced by DSTATCOM contains ripple in order to compensate we use this. It is estimated with equation by

$$L_r = \frac{\sqrt{3}mV_{DC}}{12.a.f_s.I_{cr.pp}} \qquad (3.21)$$

Taking f_s=200 KHz, $I_{cr.pp}$=15%, m=1 and a=1.2 the value of L_r comes 3.2mH for simulation purpose round off value 3mH taken.

3.3.4 Ripple Filter

To filter PCC voltage noise, filter is tuned at the half of the switching frequency (f_s). It is always first order high pass filter. Time constant ($T_f = R_f\ C_f$) of filter should small compared to fundamental time period (*T*).$R_f C_f \leq T$, considering $R_f C_f = T_s/10$ Where R_f is ripple filter resistance and C_f filter capacitance and T_s is switching time. For a simulation purpose selected values R_f =10 Ω andC_f = 5.5μF.

3.4 CONTROL OF DSTATCOM

The control algorithm is used for reference current extraction through sensed feedback signals. With the help of these reference currents and sensed supply currents, the PWM based current controllers generate pulses for switching device (IGBT) of VSC used in DSTATCOM. DSTATCOM control algorithms have been used to generate reference currents for the control of DSTATCOMs. The following control algorithms for DSTATCOM are combined for the purpose of performance analysis:

3.4.1 SYNCHRONOUS REFERENCE FRAME THEORY (SRF)

It is called as d-q theory. Fig.5 shows block diagram of the SRF algorithm. The PCC voltages (v_{pa},v_{pb},v_{pc}) the load currents (i_{La},i_{Lb}, i_{Lc}) and DC bus voltage (V_{DC}) are taken from the system in the DSTACOM. Further using Park's transformation load currents converted in to dq0 frame by as shown below:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2} \\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{3.23}$$

These signals further synchronized with PCC voltage using 3-phase phase locked loop (PLL). After the transformation of the load currents and synchronization with the PCC voltage through PLL, to get DC component of load currents i_{Ld} and i_{Lq} passed through a low pass filter (LPF). The d-q load current component made up of fundamental and harmonic components as:

$$i_{Ld}=i_{dDC}+i_{dAC}$$
$$i_{Lq}=i_{qDC}+i_{qAC} \tag{3.24}$$

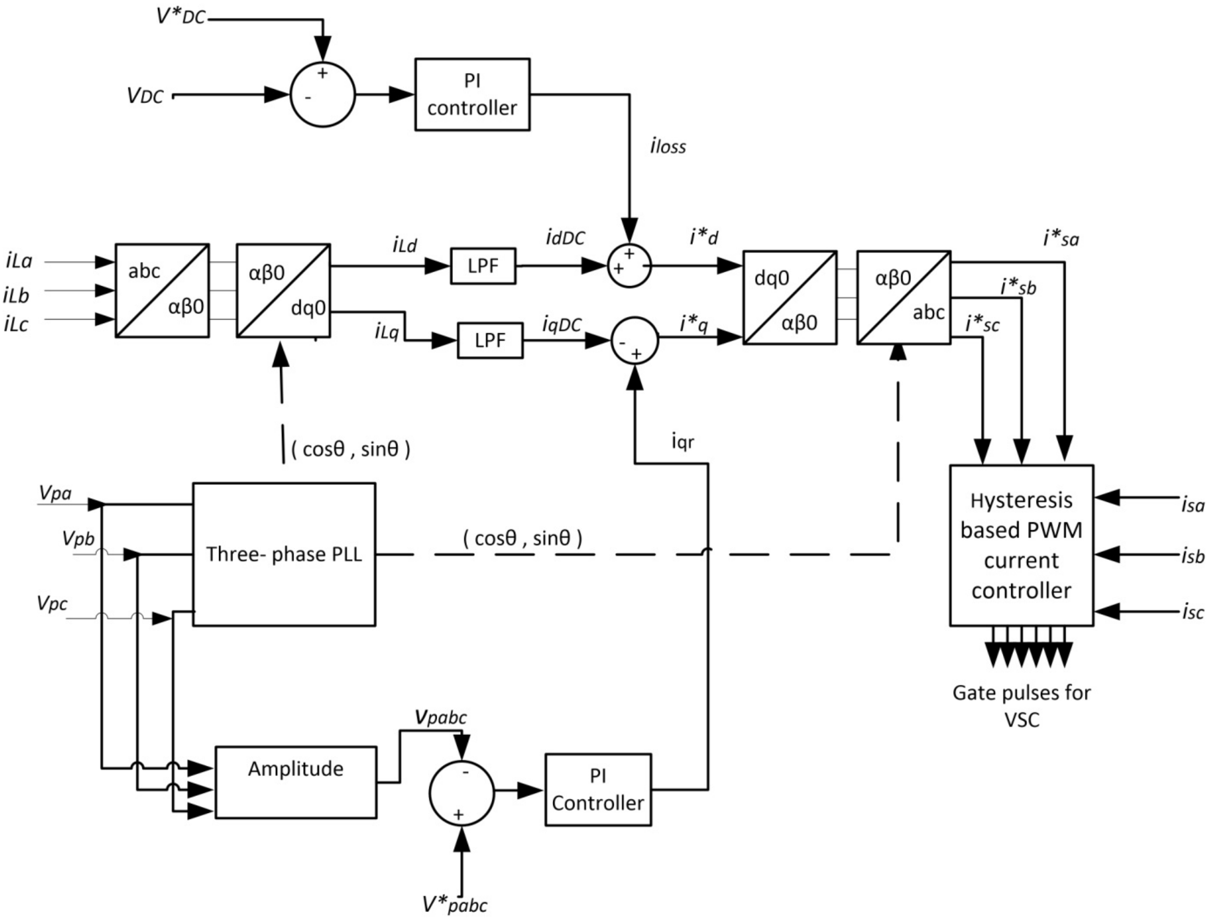


Figure 5: Block Diagram of SRF Control Algorithm

A SRF controller uses LPF to remove the DC quantities of the reference signal and to separate the non-DC quantities. This controller can operate in mainly two modes UPF (unity power factor) and ZVR (zero voltage regulation) mode

In the UPF mode for reactive power compensation consider that to maintain the DC bus voltage and meeting the loss (i_{losses}) in the DSTATCOM the supply side to deliver only DC part of d-axis component of load current (i_{dDC}) along with active power component. The current (i_{losses}) for meeting its losses is the output of the PI controller at the DC bus voltage of the DSTATCOM which is given by:

$$i_{loss}(n) = i_{loss}(n-1) + K_{pd}\{v_{de}(n)-v_{de}(n-1)\} + K_{id}v_{de}(n) \qquad (3.25)$$

$$v_{de}(n) = v^{*}_{DC}(n)-v_{DC}(n) \qquad (3.26)$$

Where $v_{de}(n)$ is error between the reference DC voltage (v^{*}_{DC}) and the sensed DC voltage (v_{DC}).Proportional gain constant K_{pd} and integral gain constant K_{id} of PI controller.

The reference direct axis supply current (i_d^*) is

$$i_d^* = i_{dDC} + i_{loss} \qquad (3.27)$$

this reference direct axis supply current (i_d^*) should be in phase with the voltage at PCC. To get the reference supply currents we apply reverse Park's transformation shown in equation (3.28) with i_d^* shown in Equation 3.8, $i_q^* = 0$ and $i_0^* = 0$.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \\ i_0^* \end{bmatrix} \qquad (3.28)$$

In ZVR mode to achieve zero voltage regulation at PCC, supply delivers the direct axis component (i_d^*) in equation (3.27) and the difference of quadrature axis component (i_{qDC}) of the load and the output of the PI controller (i_{qr}). With the help of PI controller voltage at PCC (V_{sp}) and the reference voltage (V_{sp}^*) is controlled. The output of PI controller is reactive power component of current (i_{qr}) for zero voltage regulation of the PCC voltage. The amplitude of the voltage at PCC (V_{pabc}) is calculated with voltage (v_{pa}, v_{pb}, v_{pc}) as:

$$V_{pabc} = (2/3)^{1/2}(v_{pa}^2+v_{pb}^2+v_{pc}^2)^{1/2} \qquad (3.29)$$

To regulate PCC voltage to a reference value a PI controller is used:

$$i_{qr}(n) = i_{qr}(n-1) + K_{pq}\{v_{te}(n)-v_{te}(n-1)\} + K_{iq}v_{te}(n) \qquad (3.30)$$

Where

$$v_{te}(n) = v_{pabc}^*(n) - v_{pabc}(n) \qquad (3.31)$$

Is error between reference voltage (v_{pabc}^*) and actual terminal voltage amplitude (v_{pabc}). K_{pq} Proportional gain constants and K_{iq} integral gain constants of the PI controller. The reference quadrature-axis supply current (i_q^*) is

$$i_q^* = i_{qr} - i_{qDC} \qquad (3.32)$$

To get the reference supply currents reverse Park's transformation is applied as shown in equation (3.28) with i_d^* shown in equation (3.27) and i_q^* shown in equation (3.32) and i_0^* as zero. These reference supply currents $(i_{sa}^*, i_{sb}^*, i_{sc}^*)$ with sensed supply currents (i_{sa}, i_{sb}, i_{sc}) are compared in hysteresis current controller to generate signals for IGBT.

3.4.2 ADALINE-BASED CONTROL ALGORITHM

ADALINE stands for Adaptive Linear Neuron or Adaptive Linear Element. It is first developed by Bernard Widrow and Tedd Hoff in 1960. It is one layer neural network with many nodes and each node accepts multiple inputs and generates single output as shown in Fig.6. This control algorithm is based on LMS algorithm and its training through Adaline, which always tracks the unit vector template to maintain the minimized error.

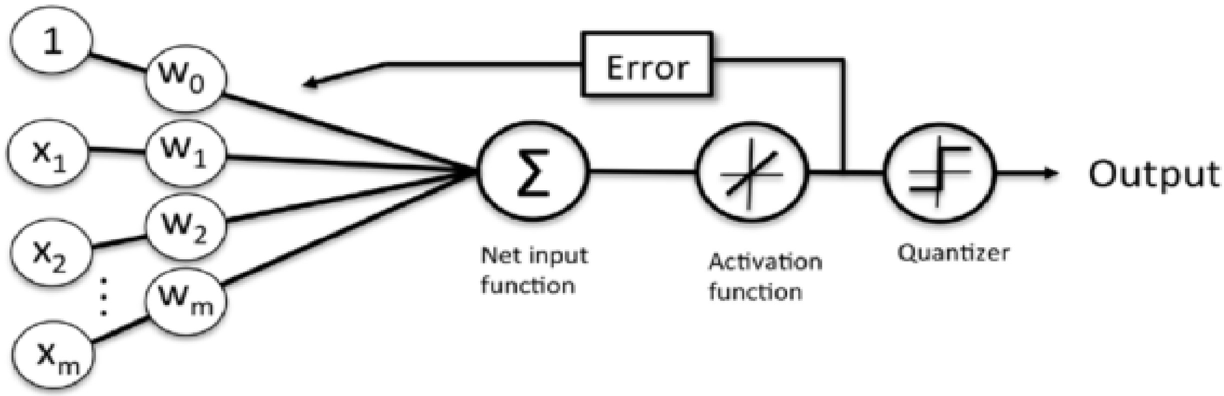


Figure 6 Adaptive linear Neuron

It is easily understand by taking the single- phase system, supply voltage is given as

$v_s = V_1 \sin \omega t$ (3.33)

And sensed load current (i_L) is expressed as

$i_L = i_p^+ + i_q^+ + i^-$ (3.34)

The above equation (3.34) of load current is represented as active and reactive component of positive and negative sequence current. In this control algorithm the extracted current component is always in phase with the unit voltage template. For calculation of unit voltage template sensed voltages are divided by amplitude of PCC voltage.

Estimation of active part of current for single phase is:

$i_p^+ = W_p \times u$ (3.35)

With the help of Adaline technique weight (W_p) is estimated. This weight depends upon the nature of load current and phase voltage magnitude. The method to estimate weights are corresponding to the fundamental frequency real current component based on LMS algorithm tuned Adaline; it always tracks the unit voltage templates to maintain error minimum.

For the comparison with supply currents we estimate reference supply currents with the help of Adaptive linear neural network-based control algorithm. The block diagram of control algorithm is shown in Fig.6.

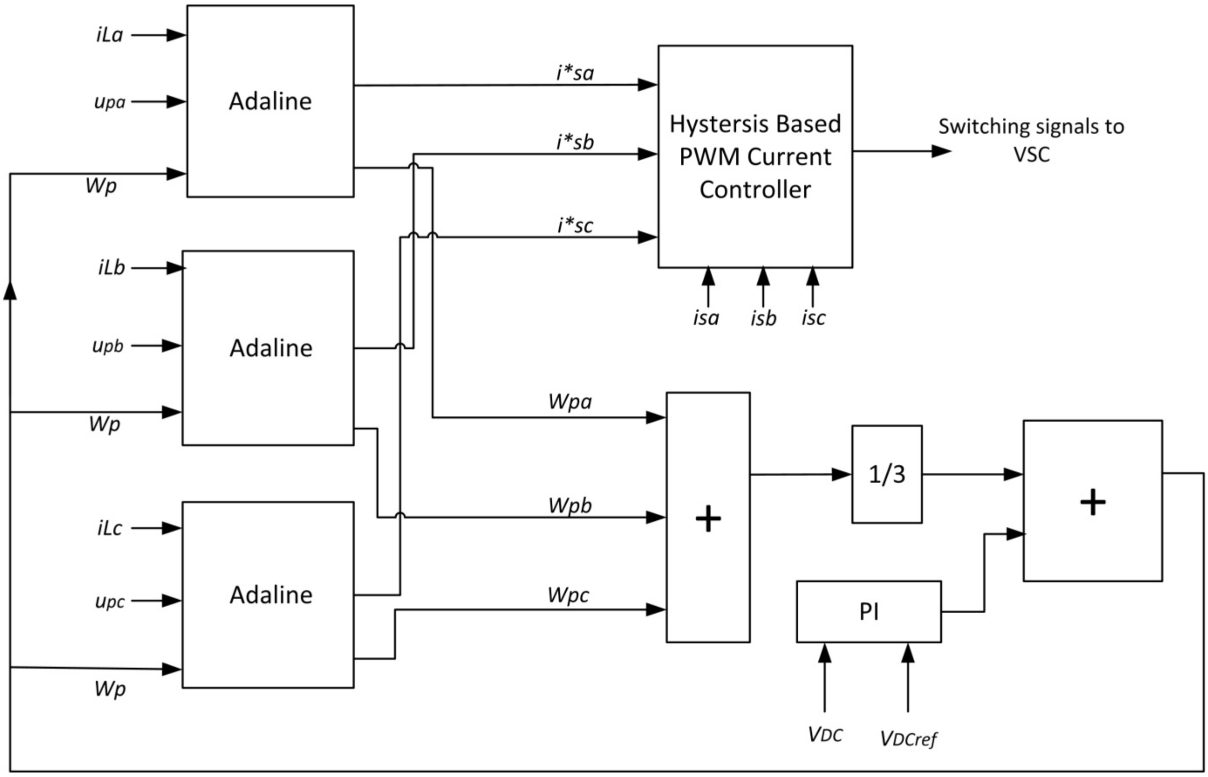


Figure 7: Block Diagram of ADALINE Based – Control Algorithm

The PCC voltages (v_{pa}, v_{pb}, v_{pc}) are sensed and amplitude of voltage at PCC (V_{pabc}) is estimated as:

$$V_{pabc} = (2/3)^{1/2}(v_{pa}^2+v_{pb}^2+v_{pc}^2)^{1/2} \quad (3.36)$$

The in-phase unit vector of (v_{pa}, v_{pb}, v_{pc}) are computed as:

$$u_{pa} = \frac{v_{pa}}{V_{pabc}}, u_{pb} = \frac{v_{pb}}{V_{pabc}}, u_{pc} = \frac{v_{pc}}{V_{pabc}} \quad (3.37)$$

Difference between reference DC bus voltage ($V_{DCref}(k)$) and sensed DC bus voltage of the VSC ($V_{DC}(k)$) of the DSTATCOM at the k^{th} sampling instant is known as the error in the DC bus voltage of the VSC ($V_{DCe}(k)$) given as:

$$V_{DCe}(k) = V_{DCref}(k) - V_{DC}(k) \quad (3.38)$$

Further this error in DC voltage of the VSC is produced by PI controller to maintaining the DC voltage of the DSTATCOM at the k^{th} sampling instant:

$$I_L(k) = I_L(k-1) + K_{pd}\{V_{DCe}(k) - V_{DCe}(k-1)\} + K_{id}V_{DCe}(k) \quad (3.39)$$

Where $I_L(k)$ is part of the d-axis component of supply currents and K_{pd} is proportional gain constant and K_{id} is integral gain constants of PI controller for DC bus voltage. The average weight calculation is given by:

$$W_p = I_L(k) + \frac{\{W_{pa}(k)+W_{pb}(k)+W_{pc}(k)\}}{3} \quad (3.40)$$

Least mean square (LMS) algorithm is used for the extraction of weights.[49]

And after that Adaline NN control algorithm is applied for the training of these weights. The LMS adoption algorithm is shown in Fig.7.

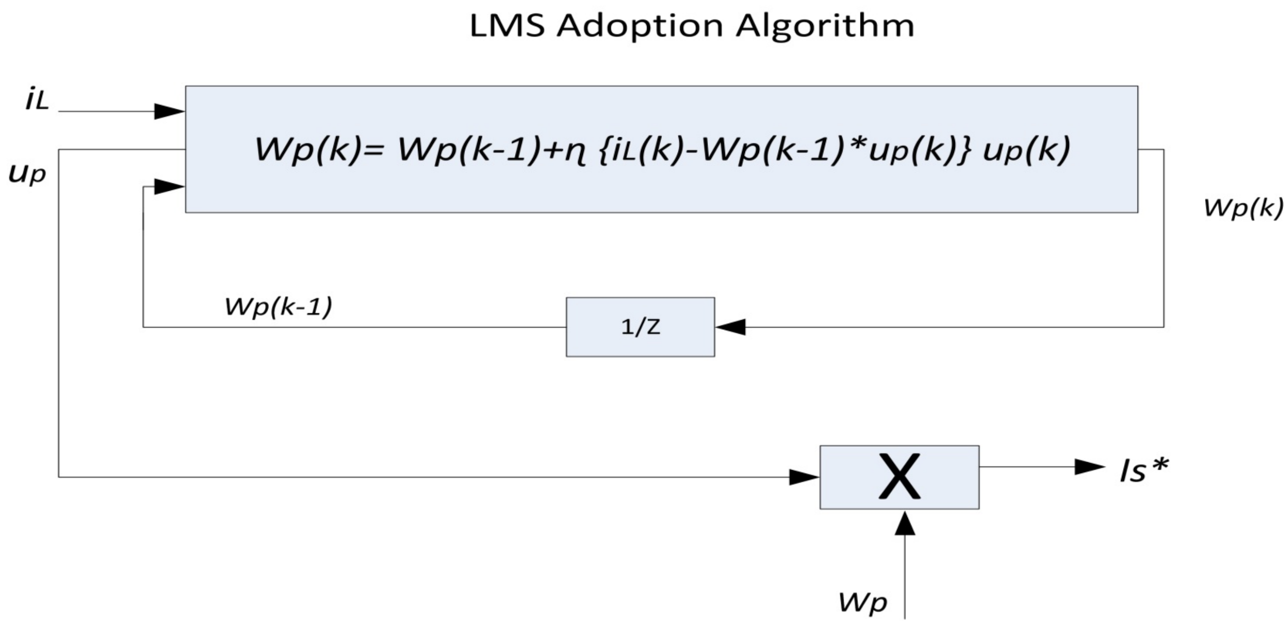


Figure 8: Block Diagram LMS Adoption Algorithm

The estimation of weights for the three phase load current as:

$$W_{pa}(k) = W_{pa}(k-1) + \eta\{i_{La}(k)-W_{pa}(k-1)U_{pa}(k)\}u_{pa}(k), \quad (3.41)$$

$$W_{pb}(k) = W_{pb}(k-1) + \eta\{i_{Lb}(k)-W_{pb}(k-1)U_{pb}(k)\}u_{pb}(k), \quad (3.42)$$

$$W_{pc}(k) = W_{pc}(k-1) + \eta\{i_{Lc}(k)-W_{pc}(k-1)U_{pc}(k)\}u_{pc}(k) \quad (3.43)$$

Where η is the convergence factor or the learning rate which controls the accuracy of estimation and convergence rate. When convergence factor η is high then rate of convergence is fast and estimation accuracy is low but when the value of η low then estimation accuracy is high and rate of convergence low. The value of η is observed experimentally is between 0.01 and 1. Here the value of η is selected as 0.04 to get best results. The fundamental active components of reference supply currents ($i^*_{sap}, i^*_{sbp}, i^*_{scp}$) calculated as:

$$i^*_{sap} = W_p u_{pa}, \qquad i^*_{sbp} = W_p u_{pb}, \qquad i^*_{scp} = W_p u_{pc} \qquad (3.44)$$

With the calculation of quadrature unit vectors of (v_{pa}, v_{pb}, v_{pc}) similarly the reactive components of reference supply current ($i^*_{saq}, i^*_{sbq}, i^*_{scq}$) can be calculated. The total reference supply currents are addition of reactive and active power components which is given by:

$$i^*_{sa} = i^*_{saq} + i^*_{sap}, \qquad i^*_{sb} = i^*_{sbq} + i^*_{sbp}, \qquad i^*_{sc} = i^*_{scq} + i^*_{scp} \qquad (3.45)$$

With sensed supply currents these estimated ref supply currents are compared to generate the gating signal for IGBTs of the VSC used as a DSTATCOM.

3.4.3 HYSTERESIS CURRENT CONTROLLER

It is known as conventional method of hysteresis control or two level hysteresis current control technique. It requires two limits upper band limit and lower band limit. With the help of these current controller we generate gate PWM pulses which further given to switches of the VSC. This method needs comparison between the reference currents i^*_{sabc} estimated by control algorithm and actual sensed source currents i_{sabc} within a small hysteresis band defined by its lower band and upper band limits. We normally select narrow or small hysteresis band that result in fast tracking of currents but switching frequency may become high. When error between currents crosses the upper limit the switches turns off, and when it crosses lower limit switches turns on.

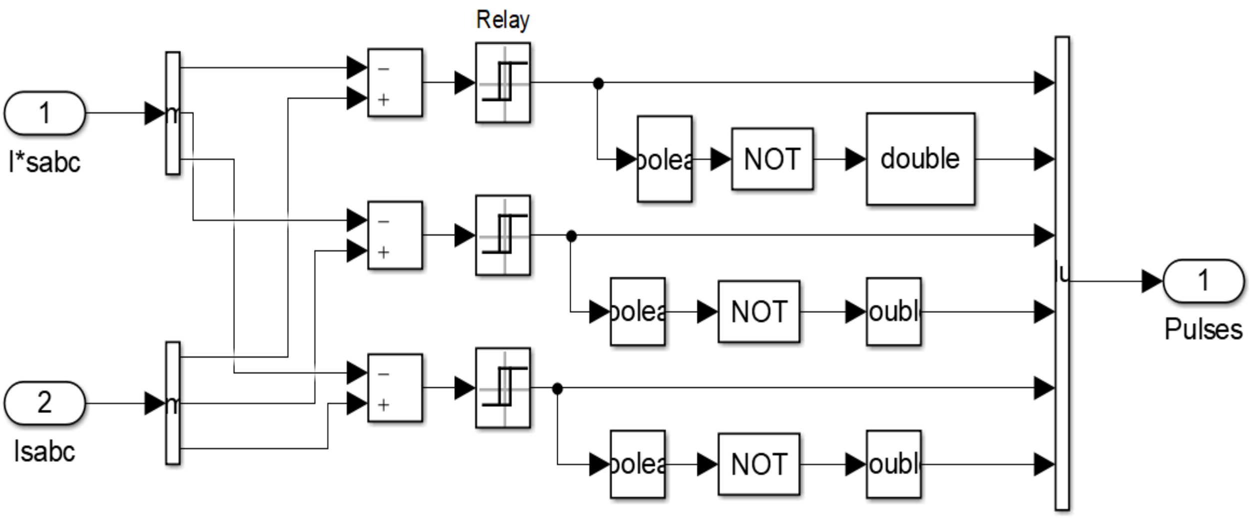


Figure 9: Simulation Model of Hysteresis Current Controller

In this controller, the value of the hysteresis band 'h_b' and the error signal between the reference currents and sensed currents added. When the value $(i^*_{sabc}-i_{sabc}) >$ hb lower switch is on and upper switch is off and when $(i^*_{sabc}-i_{sabc}) < -$ hb upper switch is on and lower switch is off. The simulated model of hysteresis based PWM current controller shown in Fig.8. in model there is actual sensed current (i_{sabc}) compared with reference current (i^*_{sabc}) which produced error signal this error signal further goes to the relay which provides band for controlling of current

3.5 CONCLUSION

This chapter discussed about complete mathematical modeling of VSC based DSTATCOM, supply and nonlinear load. It also deals with the design of DSTATCOM for 415V, 50Hz supply system. This design parameter is used for study the performance of DSTATCOM for different types of power quality issues in power network.

CHAPTER 4
MATLAB SIMULATION AND PERFORMANCE ANALYSIS OF DSTATCOM

4.0 INTRODUCTION

In this chapter a MATLAB model of DSTATCOM is developed, simulated and dynamic analysis of DSTATCOM under different load condition. The dynamic analysis of system gives the information about transient behavior of the components which gives the idea about the safety and protection of component in different condition.

4.1 MATLAB MODELING AND SIMULATION

The three-leg VSC based DSTATCOM connected to a three-phase three-wire AC system is modeled and simulated using MATLAB/SIMULINK. The system description and data is given in the appendix. The block diagram of three phase three wire DSTATCOM with linear and nonlinear load is shown in Fig.10, Fig.11 shows MATLAB based model of DSTATCOM with complete system including control schemes.

The control algorithm for the DSTATCOM is also modeled and simulated in MATLAB. A MATLAB model of DSTATCOM with Synchronous reference frame (SRF) control algorithm is shown in Fig.12, Fig.13 shows model of ADALINE based control algorithm for DSTATCOM.

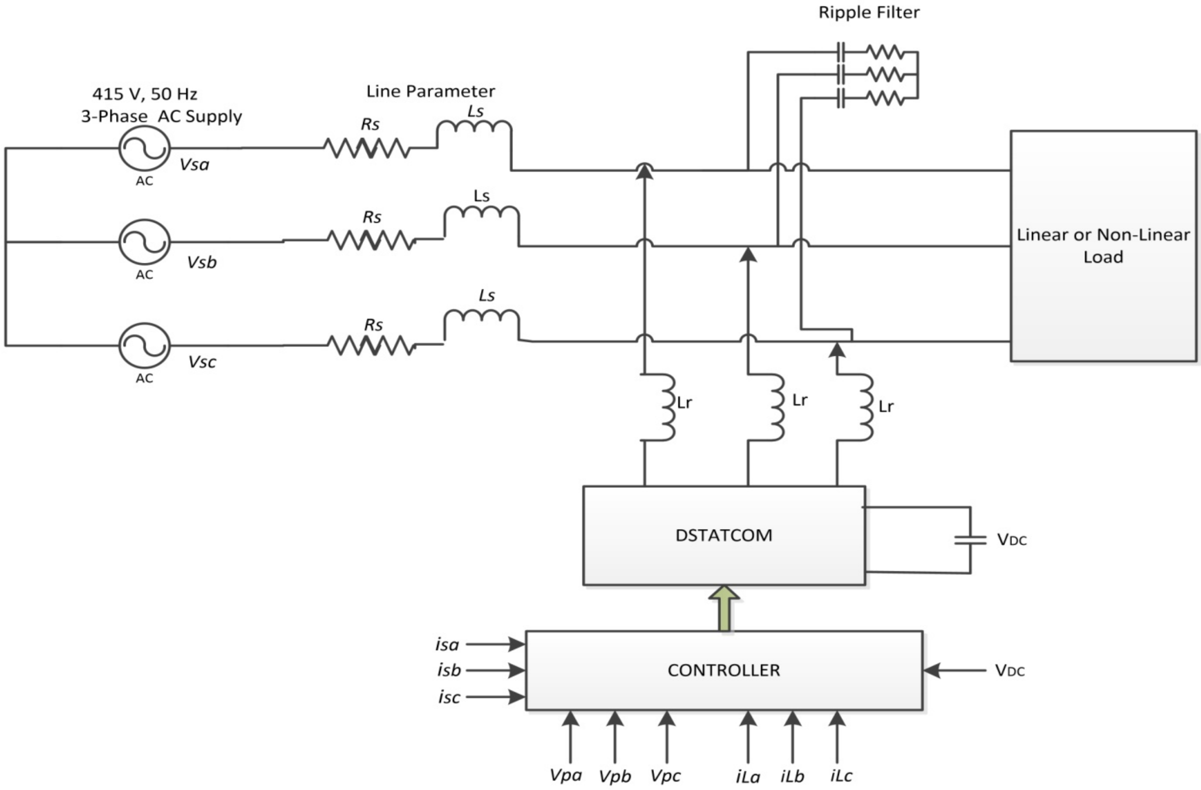


Figure 10: Block diagram of DSTATCOM with linear/nonlinear load

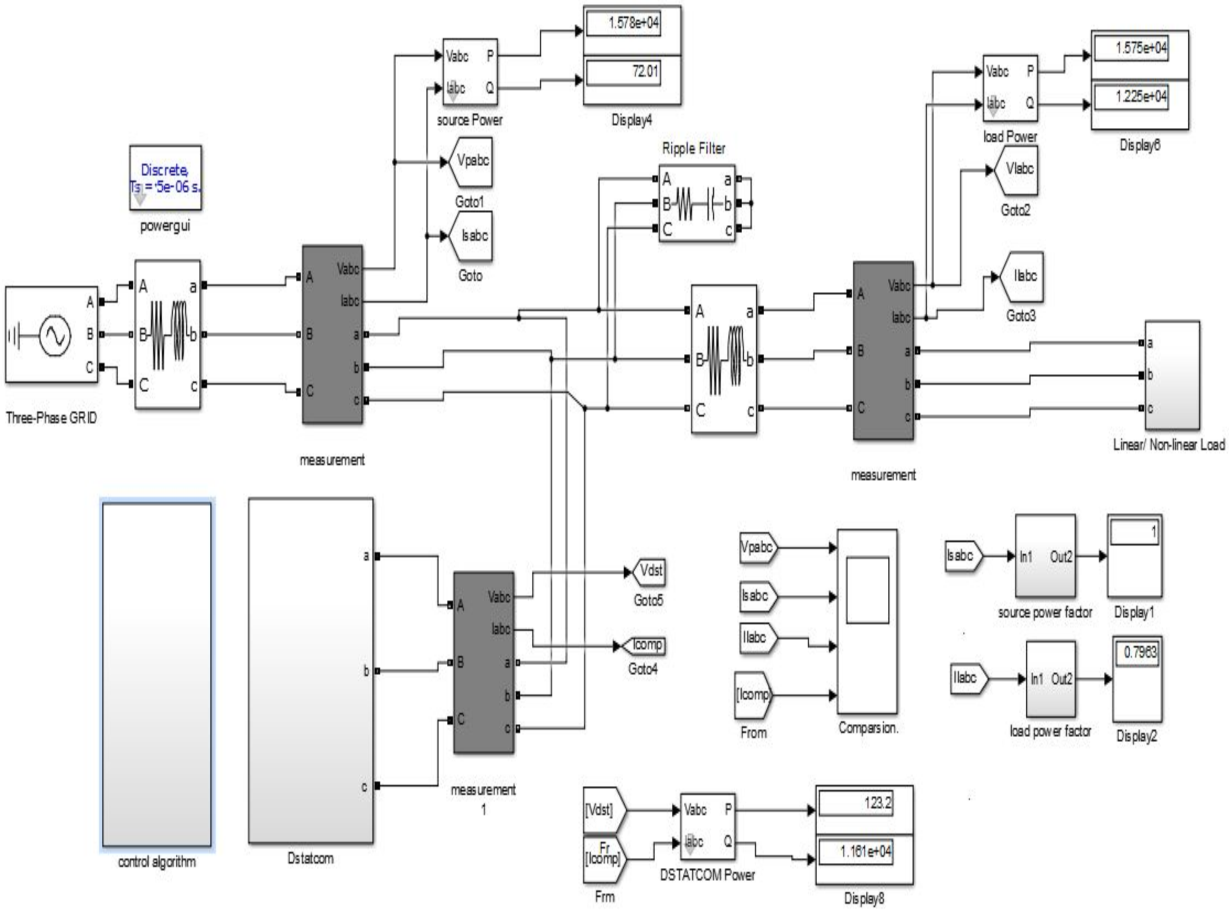


Figure 11: MATLAB Model of DSTATCOM with linear/nonlinear loads

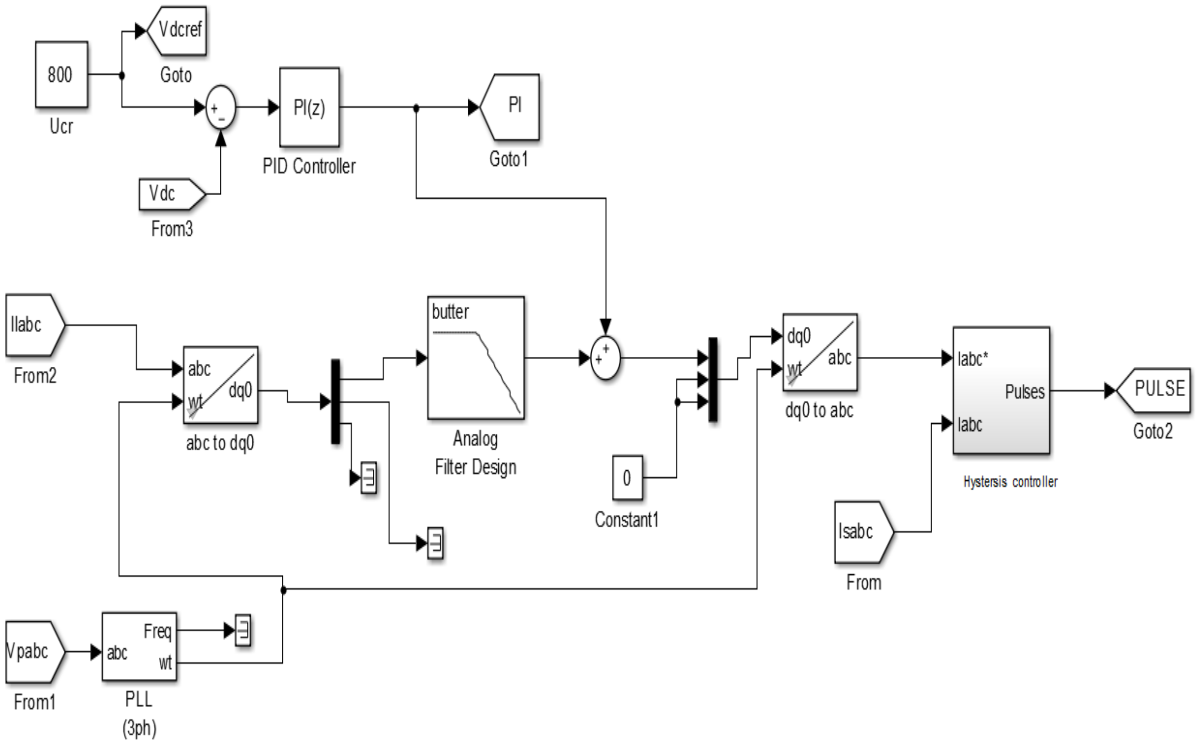


Figure 12: MATLAB Model of SRF Control Algorithm

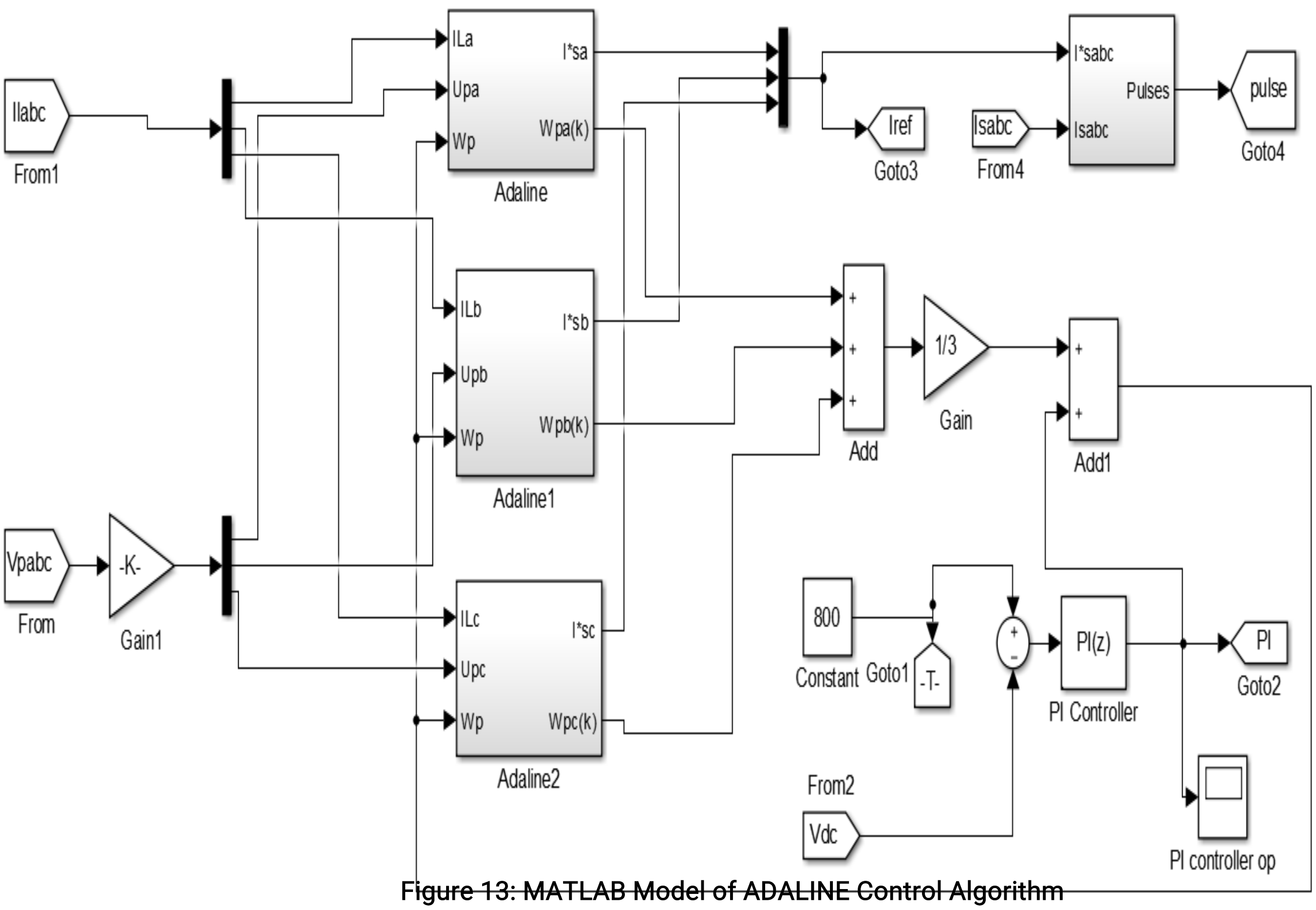


Figure 13: MATLAB Model of ADALINE Control Algorithm

4.2 RESULTS AND DISSCUSION

The performance of three leg-VSC based three phase three wire DSTATCOM is analyzed for harmonic compensation, power factor correction, reactive power compensation and load balancing. The simulation results are presented under different loading conditions and analyzed:

4.2.1 Dynamic Performance of DSTATCOM for Harmonic Compensation

The performance of DSTATCOM with SRF and ADALINE based control algorithms are determined under non-linear load balanced conditions. The THD analysis of source current with and without DSTATCOM with non-liner load and SRF control algorithm is demonstrated in Fig.15 and Fig.17

(I) SRF Control Algorithm

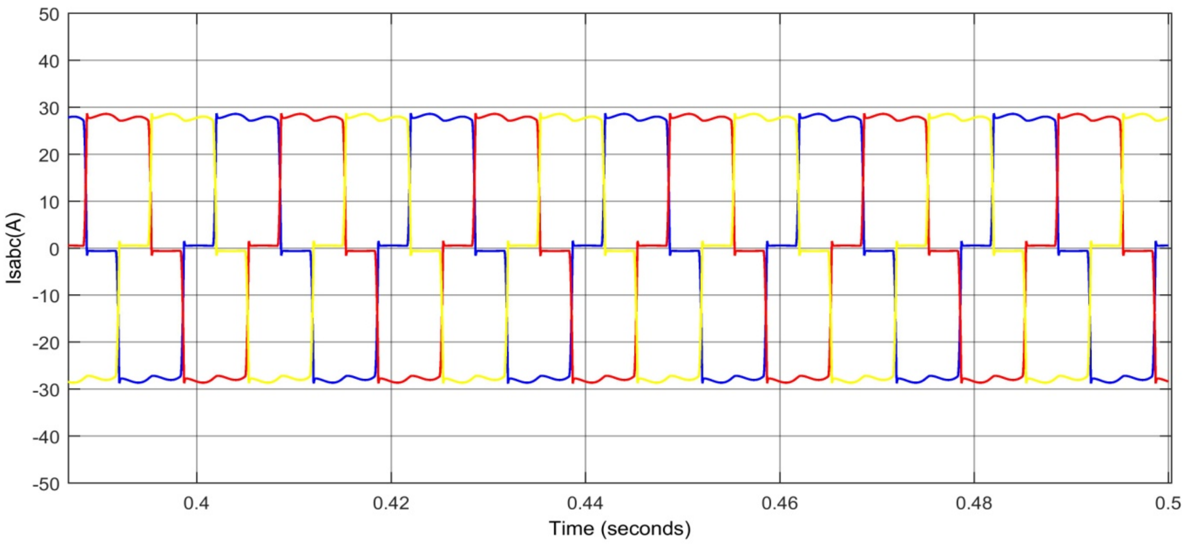


Figure 14: Source Current without DSTATCOM (SRF)

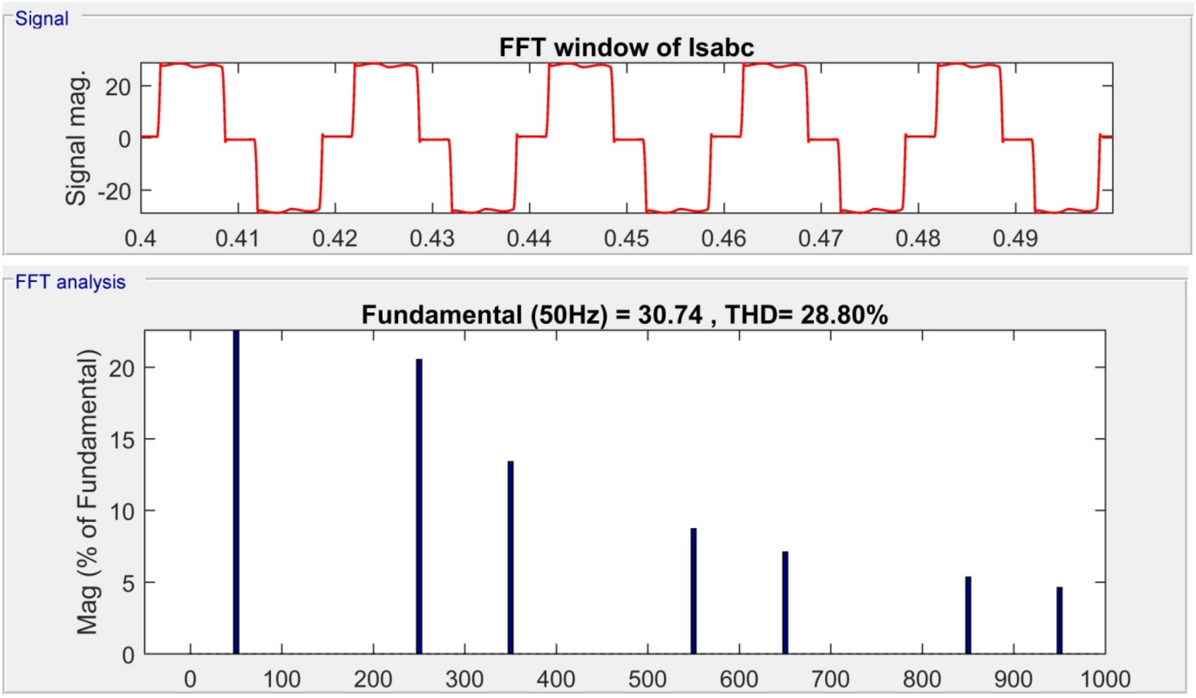


Figure 15: FFT analysis of Source Current Waveform without DSTATCOM (SRF)

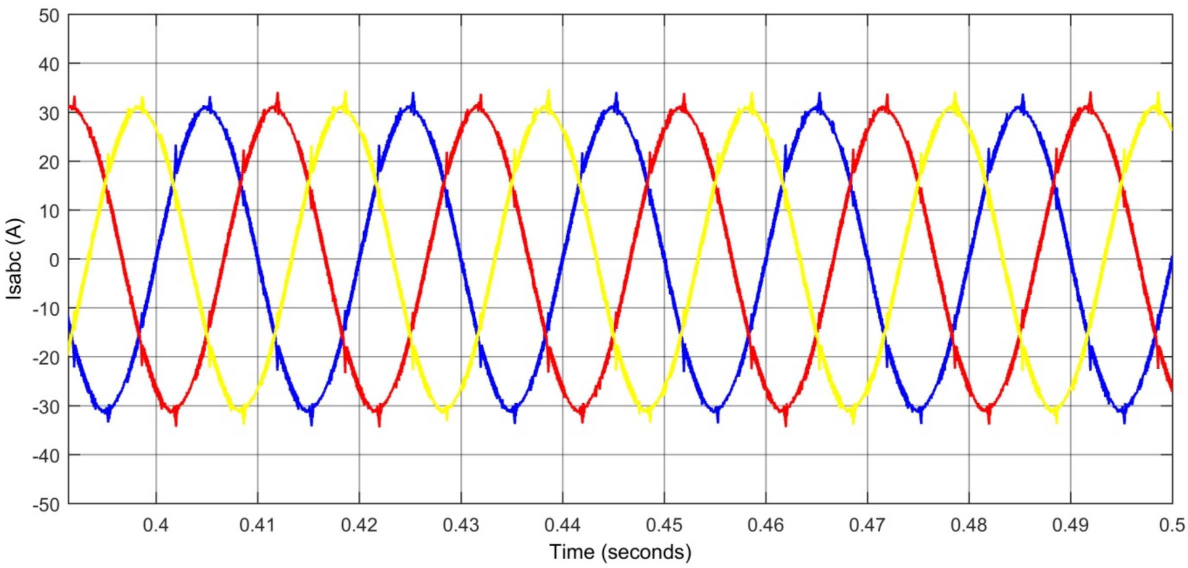


Figure 16: Source Current with DSTATCOM

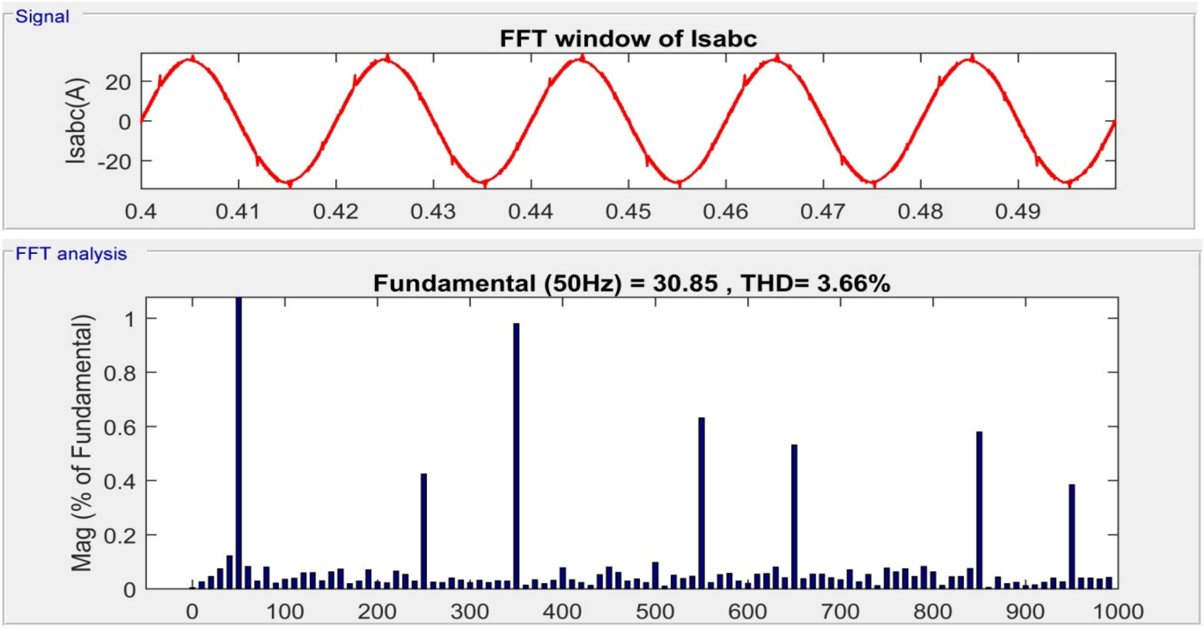


Figure 17: FFT analysis of Source Current Waveform with DSTATCOM (SRF)

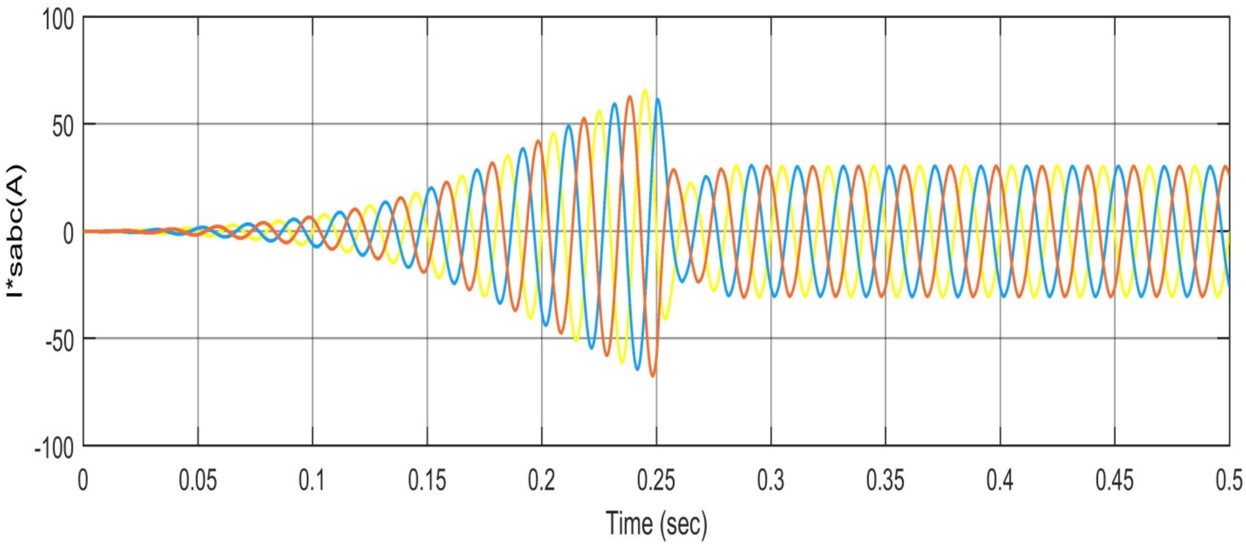


Figure 18: Reference current (SRF)

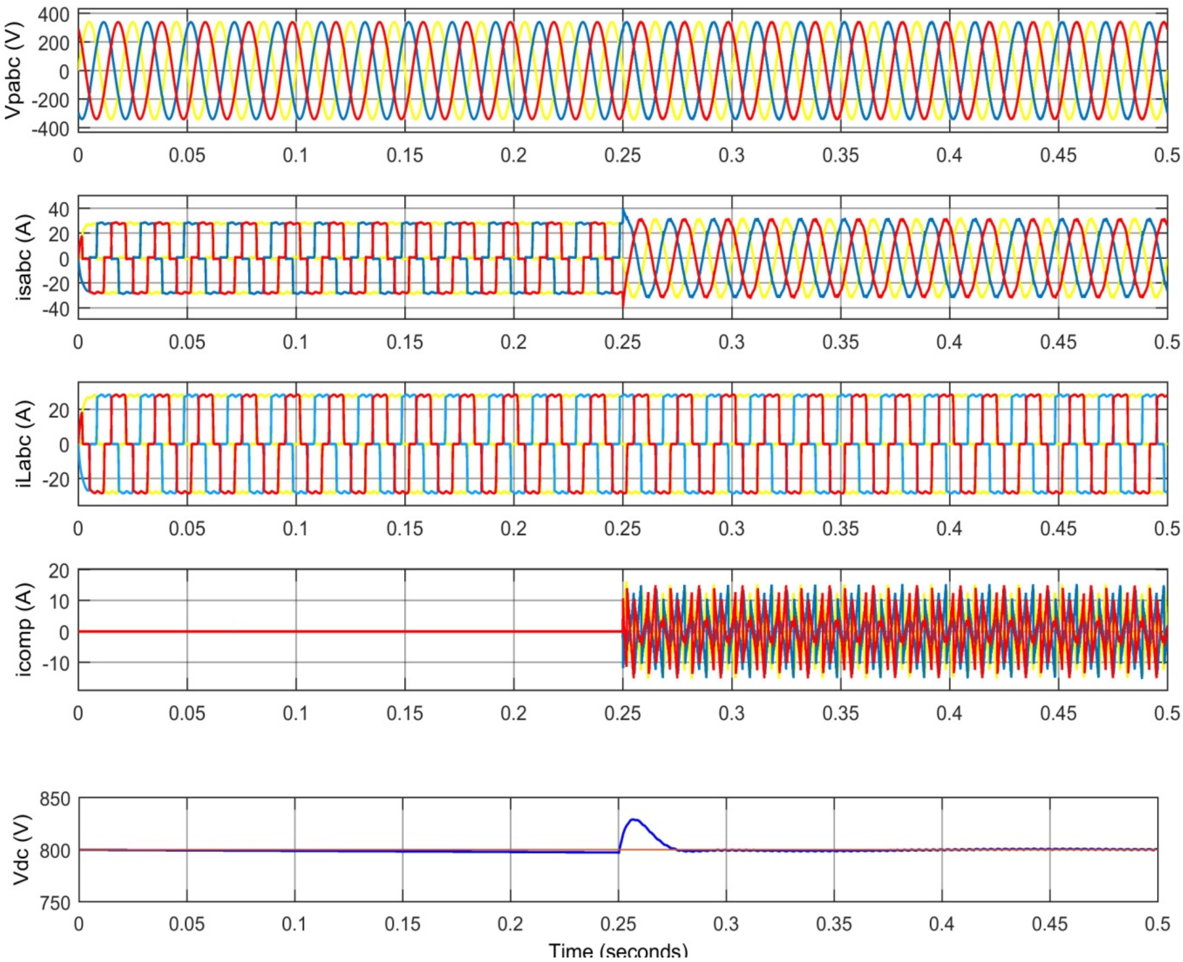


Figure 19: Performance of SRF based DSTATCOM under nonlinear load

It is observed in Fig.15 that in absence of DSTATCOM, the source current THD is very high i.e. 28.80%. Fig.16 shows the source current with SRF based DSTATCOM. In Fig.19 shows the performance of SRF based DSTATCOM at t=0.25 sec DSTATCOM is connected and source current become sinusoidal and balanced with non-linear load. The source current THD is reduced from 28.80% to 3.66% which is up to standard of the IEEE. The DC link voltage is maintained at 800V due to PI controller on DC link.

(II) ADALINE Control Algorithm

In Fig.18 and Fig.20 shows the waveform of source current without and with ADALINE based DSTATCOM. The THD analysis of source current with and without DSTATCOM under non-liner load with ADALINE control algorithm is shown in Fig.19 and Fig.21 respectively.

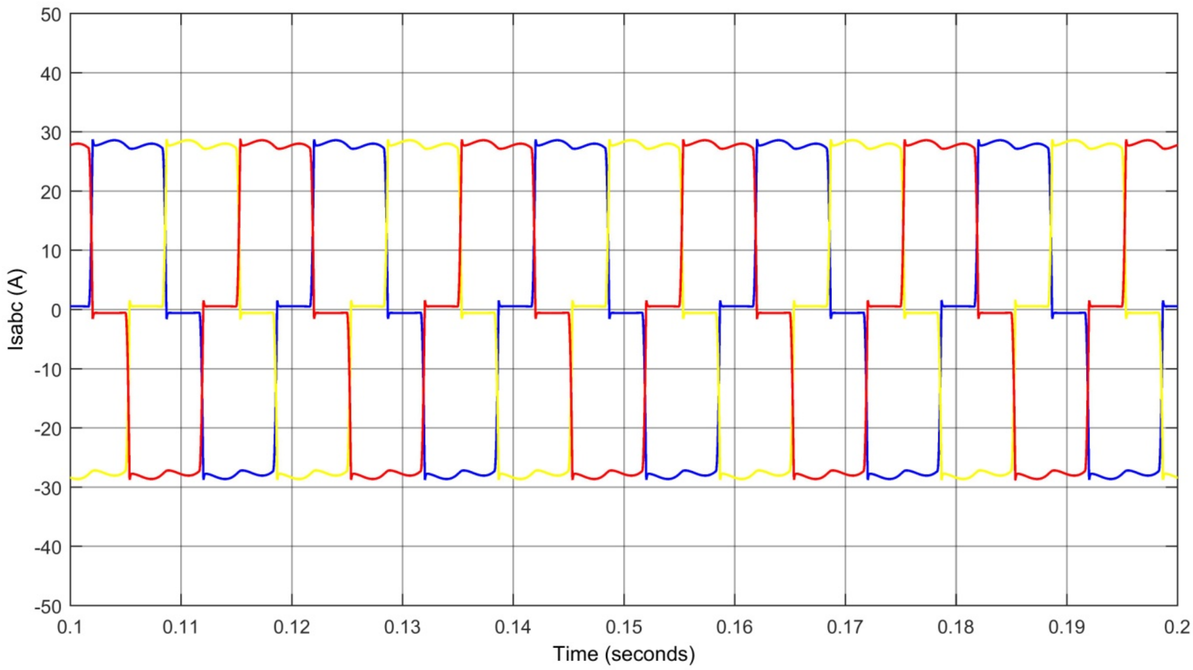


Figure 20: Source Current without DSTATCOM (Adaline)

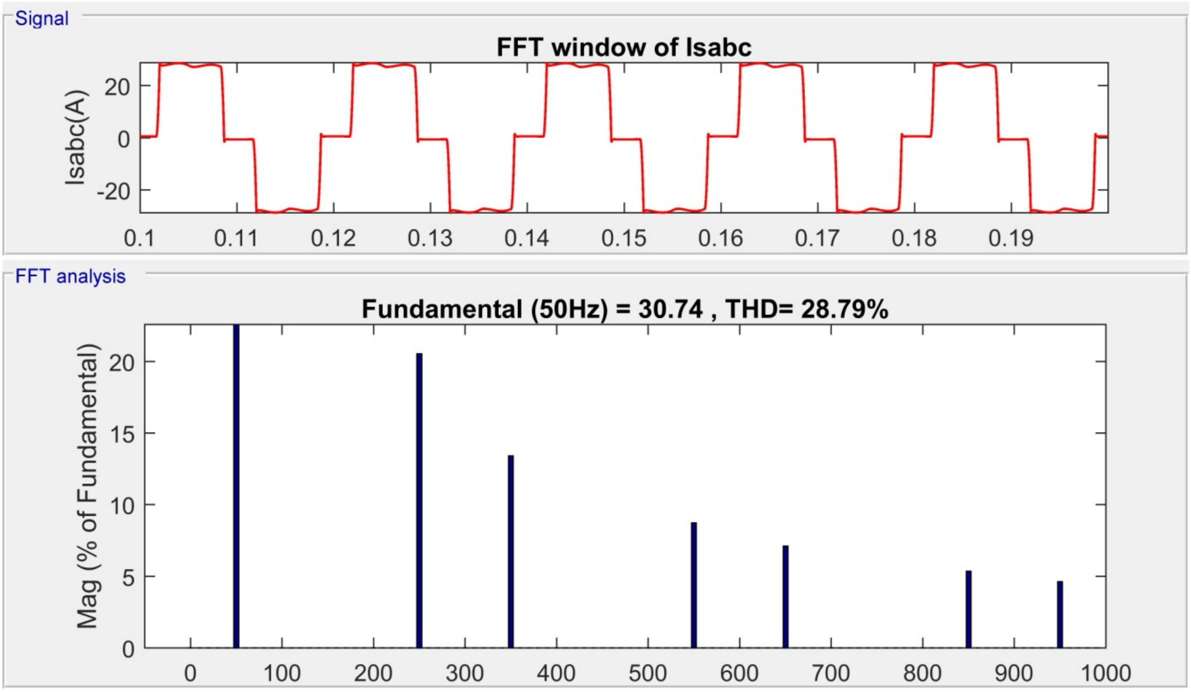


Figure 21: FFT analysis of Source Current without DSTATCOM (Adaline)

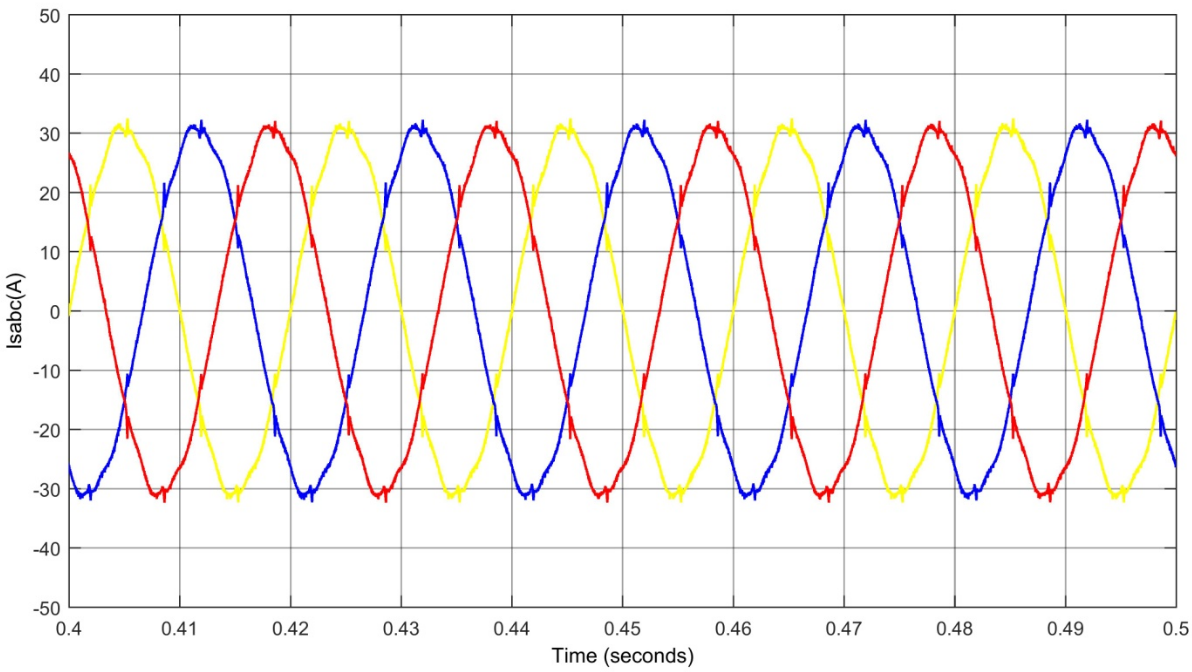


Figure 22: Source Current with DSTATCOM (Adaline)

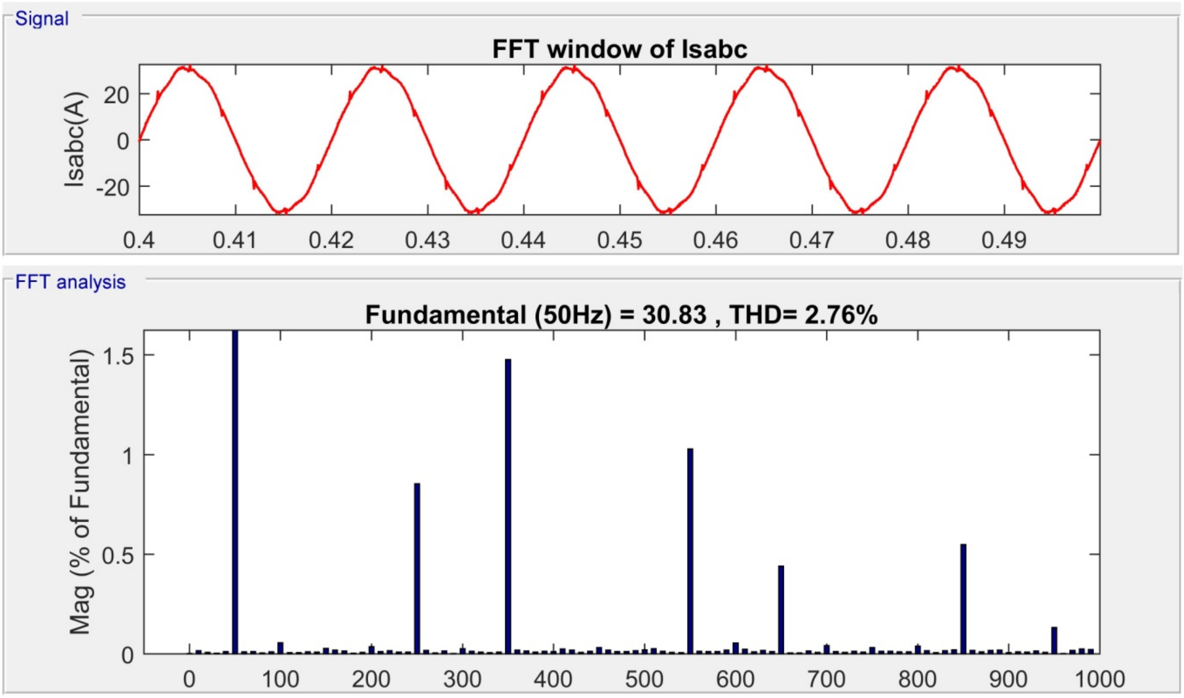


Figure 23: FFT analysis of Source Current with DSTATCOM (Adaline)

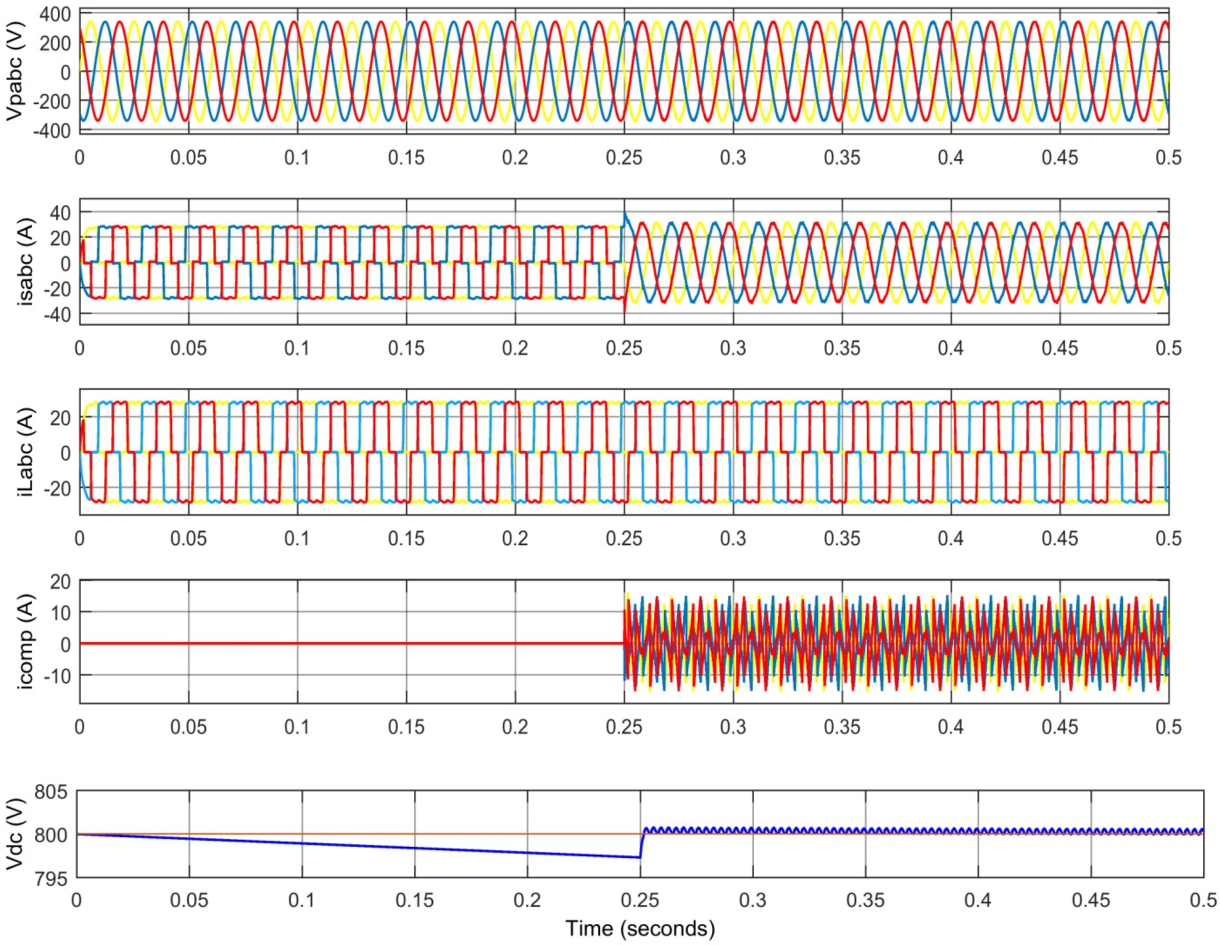


Figure 24: Performance of Adaline based DSTATCOM under nonlinear load

In Fig.24 shows the performance of ADALINE based DSTATCOM with non-linear load. From t=0 to t=0.25sec DSTATCOM is not connected source current is non-sinusoidal and the THD is 28.79%. When at t=0.25 sec DSTATCOM is connected, source current become balanced, sinusoidal under non-linear load. Source current THD is reduced from 28.79% to 2.76% which is up to standard of IEEE.

Parameter	%THD with SRF Theory			%THD with ADALINE Theory		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
PCC Voltage (Vpcc)	2.58	2.56	2.60	1.36	1.39	1.38
Source Current (Is)	3.66	3.65	3.64	2.76	2.76	2.76
Load current (IL)	29.09	29.08	29.08	29.18	29.17	29.16

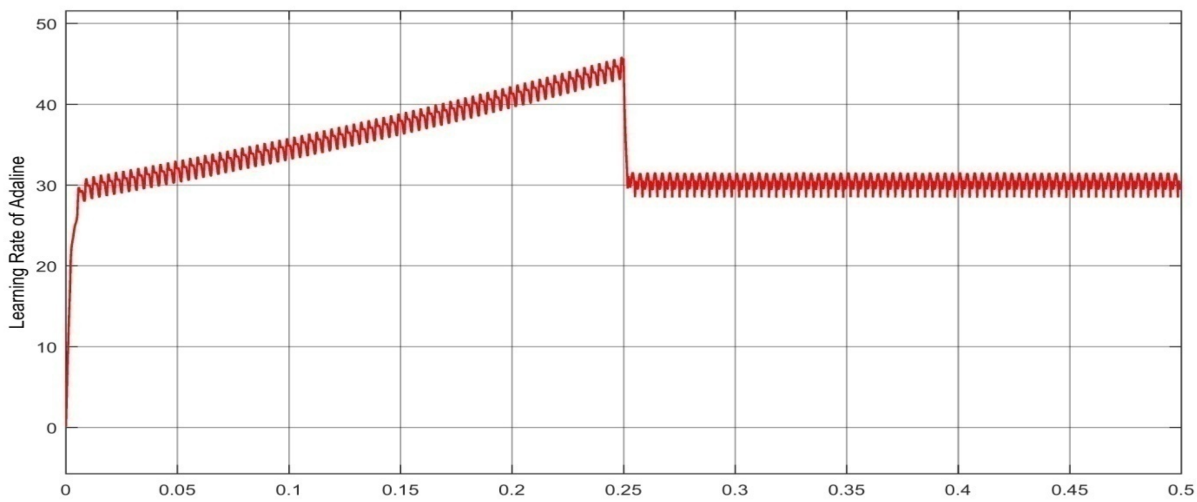


Figure 25: Learning Rate of Adaline

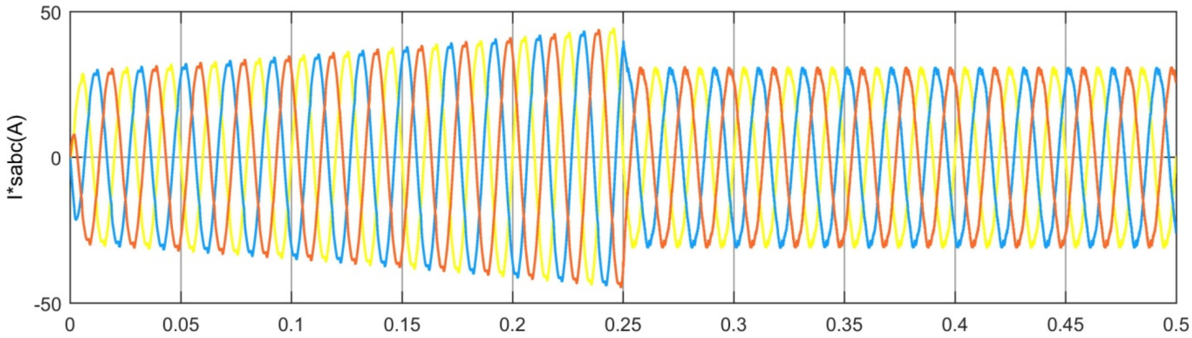


Figure 26: Reference Current (Adaline)

Fig.25 shows the learning rate of Adaptive algorithm when at t= 0.25 sec DSTATCOM is connected and Fig.26 shows the reference current extraction after t= 0.25 sec using Adaline control algorithm.

4.2.2 Performance of DSTATCOM for Reactive Power Compensation and UPF operation

(i) SRF Algorithm

The reactive power compensation of DSTATCOM in demonstrated under linear load of 20KVA and 0.8 lagging pf as shown in Fig.27 and Fig.28 shows the reactive and active power distribution in the system when DSTATCOM is connected.

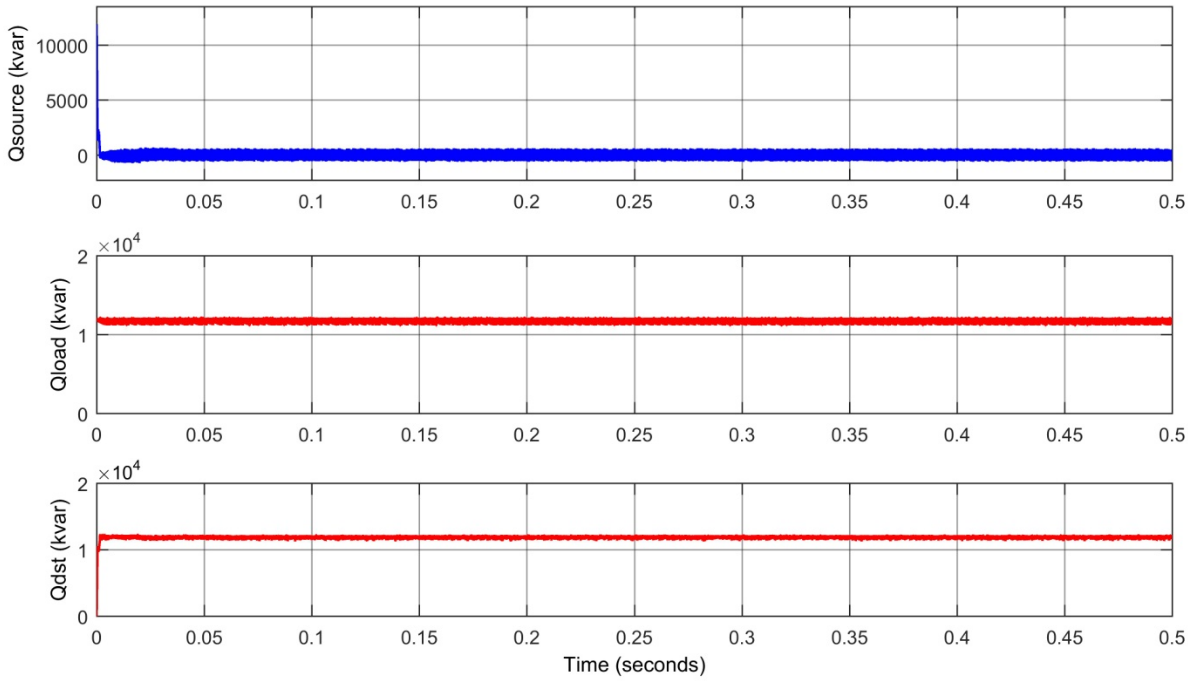


Figure 27: Reactive Power Distribution in the System (SRF)

From Fig.27 it is seen that all reactive power demanded by load is supplied by the DSTATCOM.

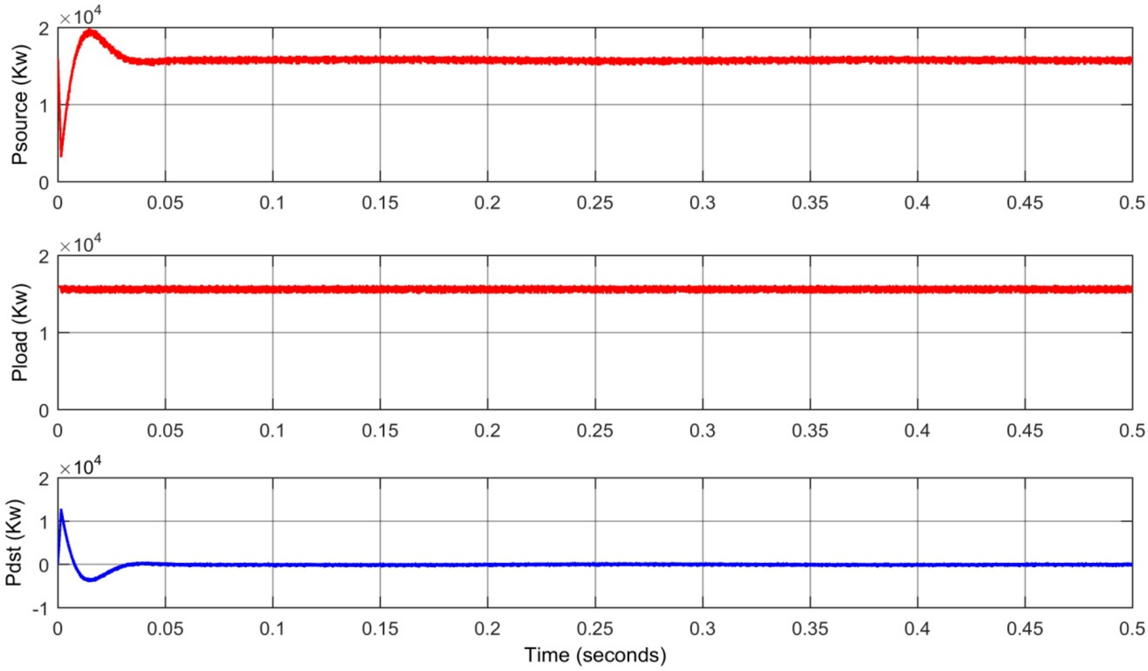


Figure 28 : Active Power Distribution in the System (SRF)

Fig. 28 shows that all the active power is supplied by the grid to the load. The reactive power demanded by load is supplied by DSTATCOM and active power is supplied by the grid. This reactive power compensation improves the power factor of grid or source side.

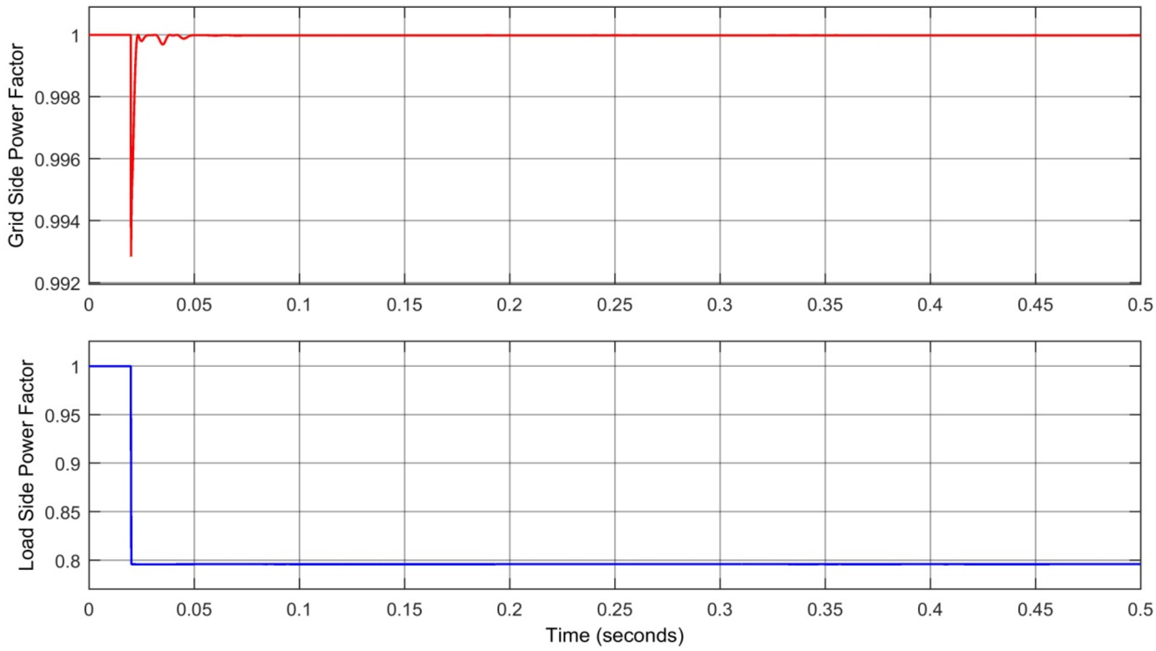


Figure 29 : Unity Power Factor (SRF)

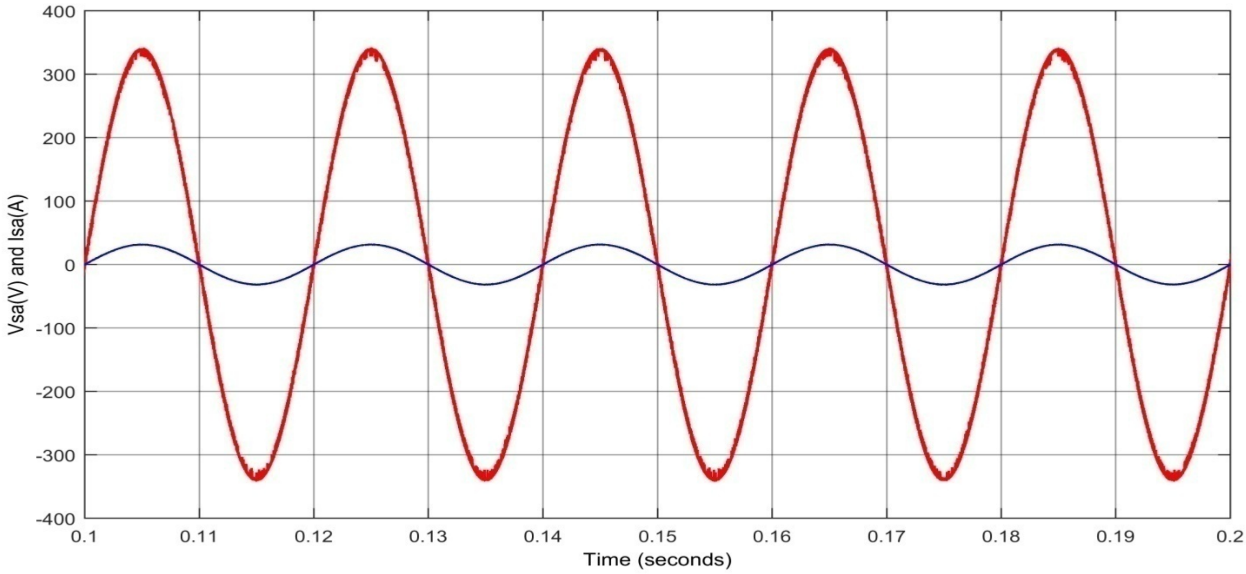


Figure 30: UPF operation at grid side

Fig.30 shows the waveform of the voltage phase 'a' waveform of voltage and current of phase 'a' on grid side are in phase with each other it means source side power factor is unity with lagging linear load.

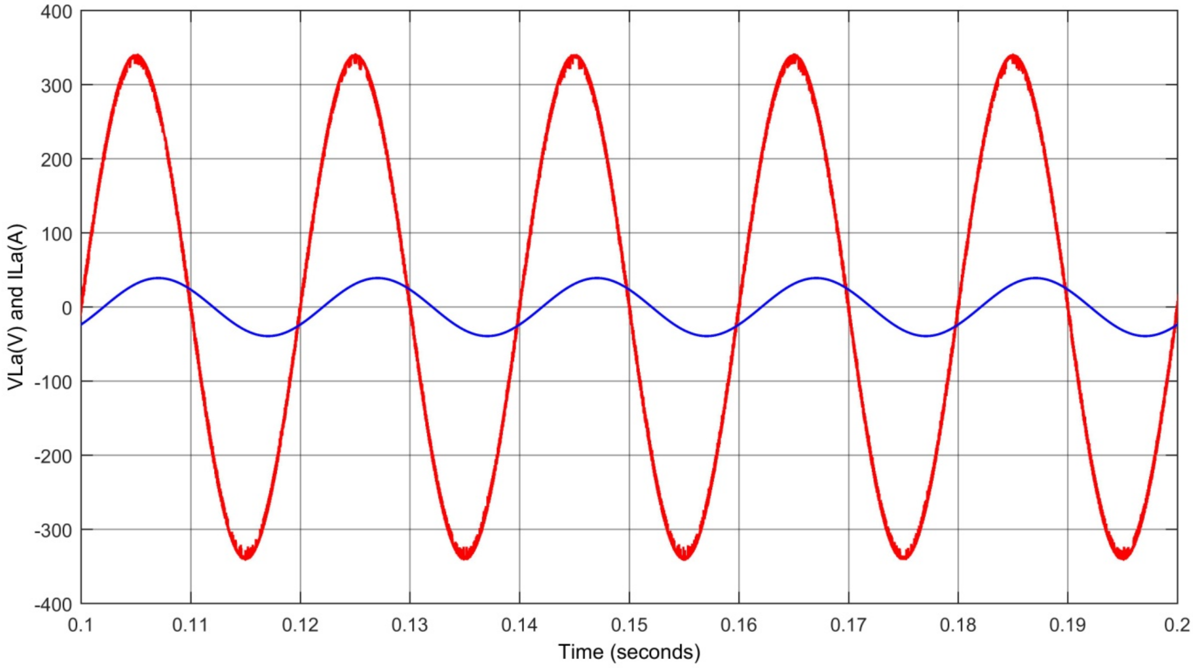
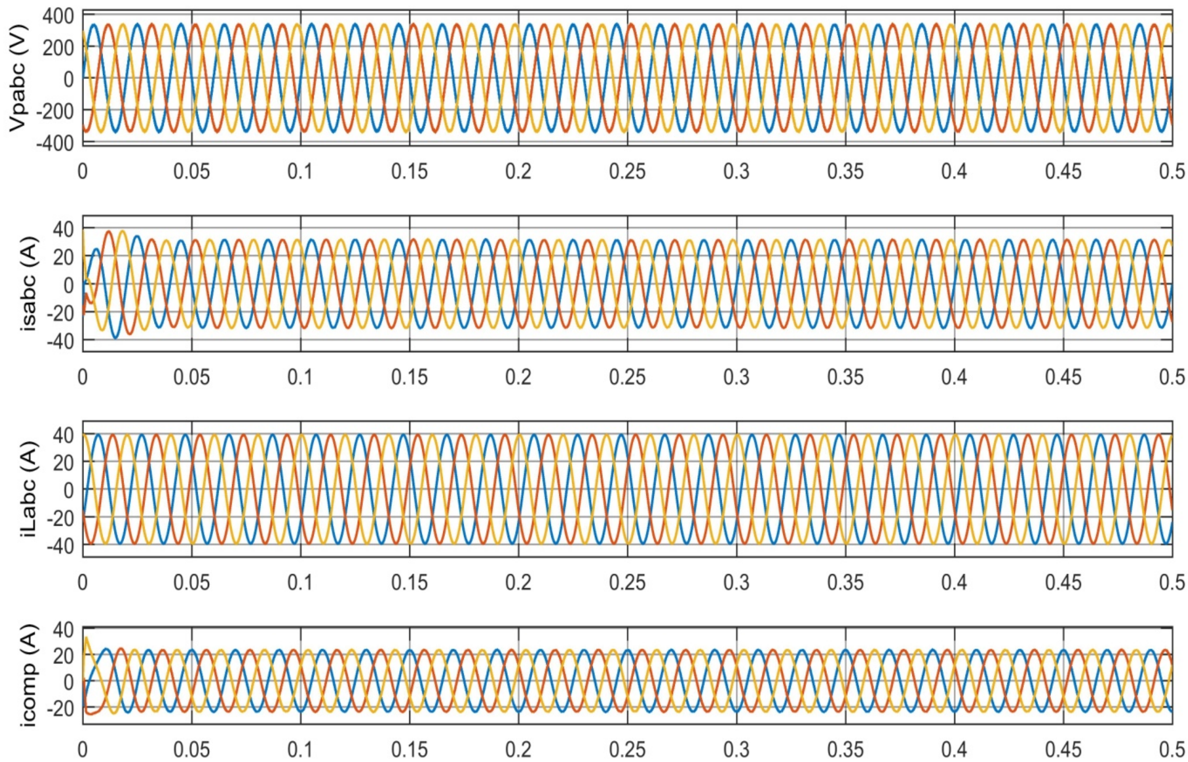


Figure 31: Lagging pf operation at Load side

Fig.31 shows the waveform of the phase 'a' load voltage and current. The load current lagging is behind the load voltage.



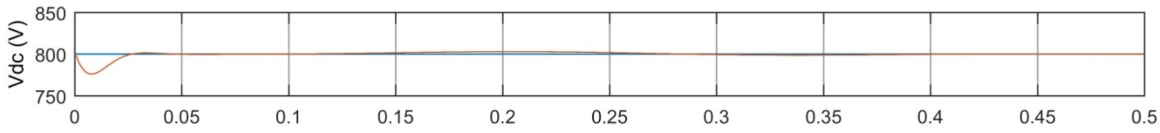


Figure 32: Performance of SRF based DSTATCOM with linear load

(ii) ADALINE algorithm

The reactive power compensation using Adaline based DSTATCOM with 20 KVA, 0.8 pf lagging is shown in Fig. 33. The active power supplied by the source to the load is shown in Fig. 34.

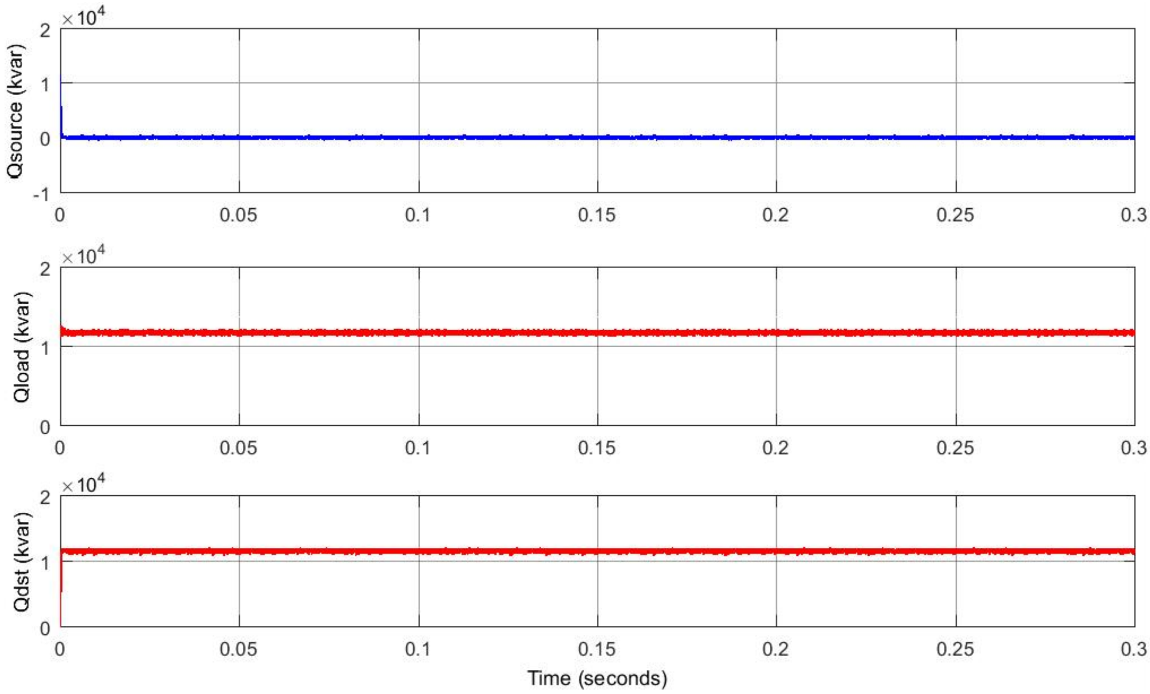


Figure 33: Reactive Power Distribution in the System (Adaline)

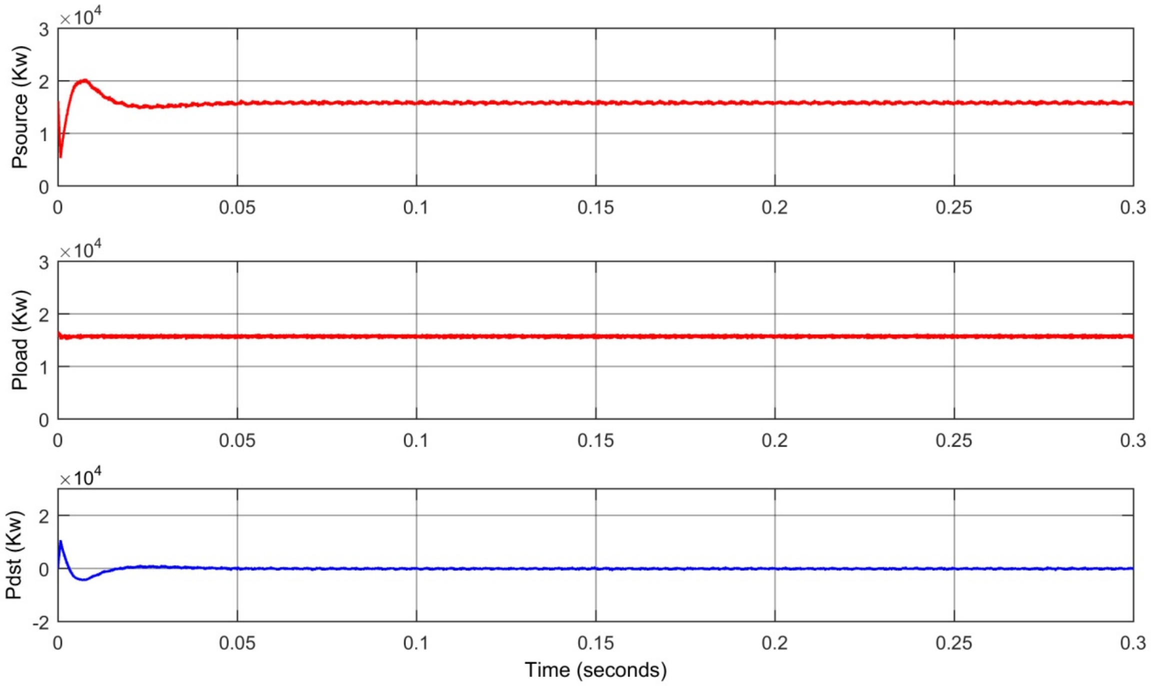


Figure 34: Active Power Distribution in the System (Adaline)

Fig.35 shows that grid or source is operating at unity power factor because all the reactive power demanded by the load is supplied by the DSTATCOM. Fig.36 shows the overall performance of the system with DSTATCOM. The dc link voltage is maintained at 800V.

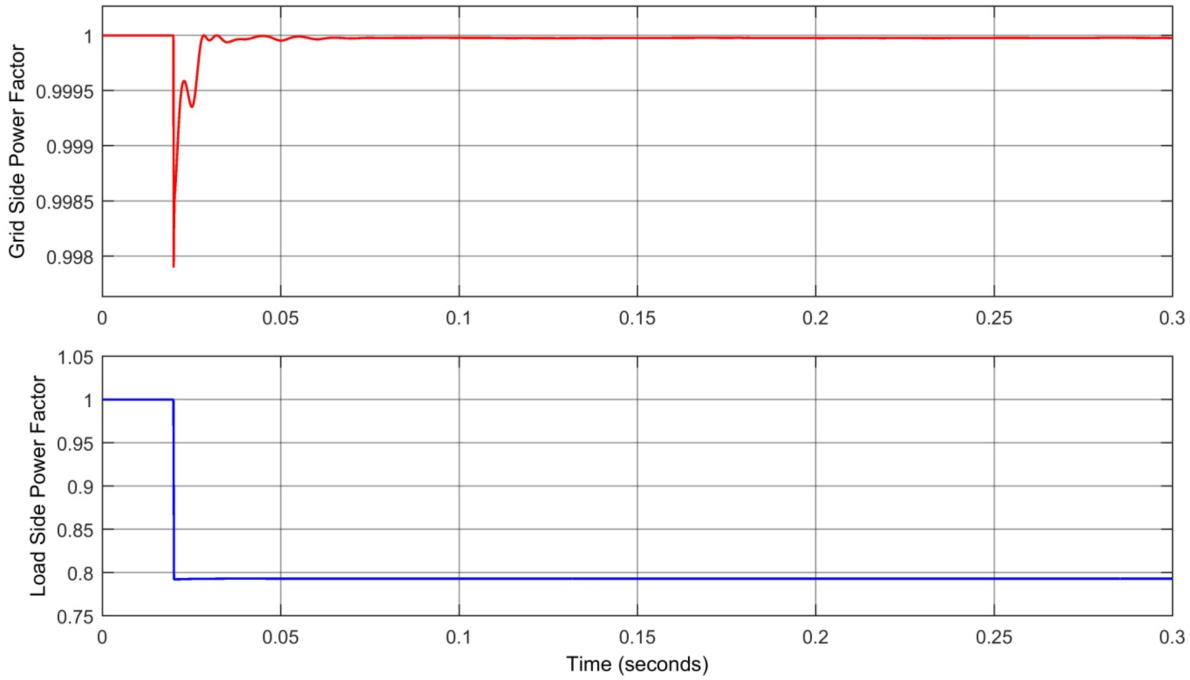


Figure 35: Unity Power Factor Operation (Adaline)

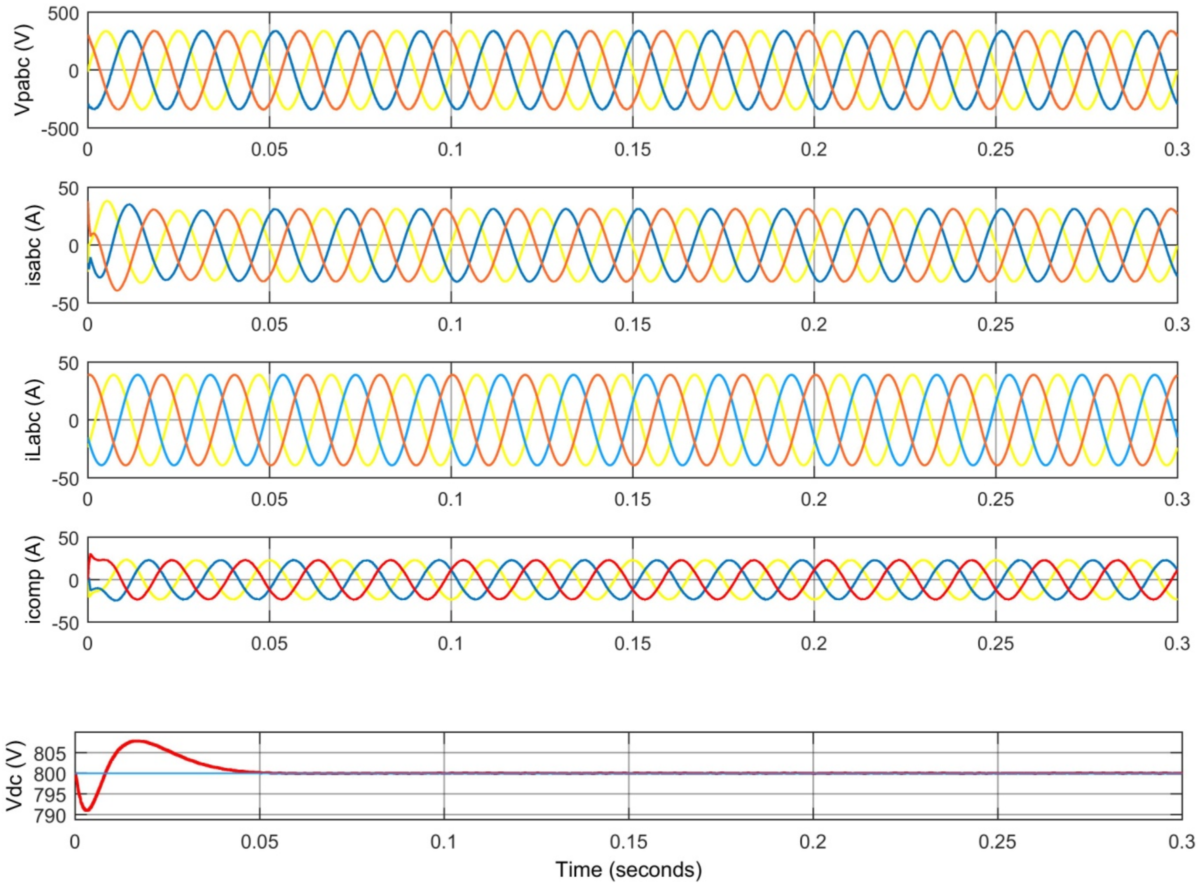


Figure 36: Performance of Adaline based DSTATCOM with linear load

Both the SRF and Adaline based DSTATCOM shows the satisfactory performance with linear load for reactive power compensation and for power factor correction.

4.2.2 Performance of DSTATCOM for Load Balancing

(i) SRF algorithm

The performance of DSTATCOM for load balancing for lagging linear load (20 KVA, 0.8pf) under unbalanced condition is shown in Fig.37.

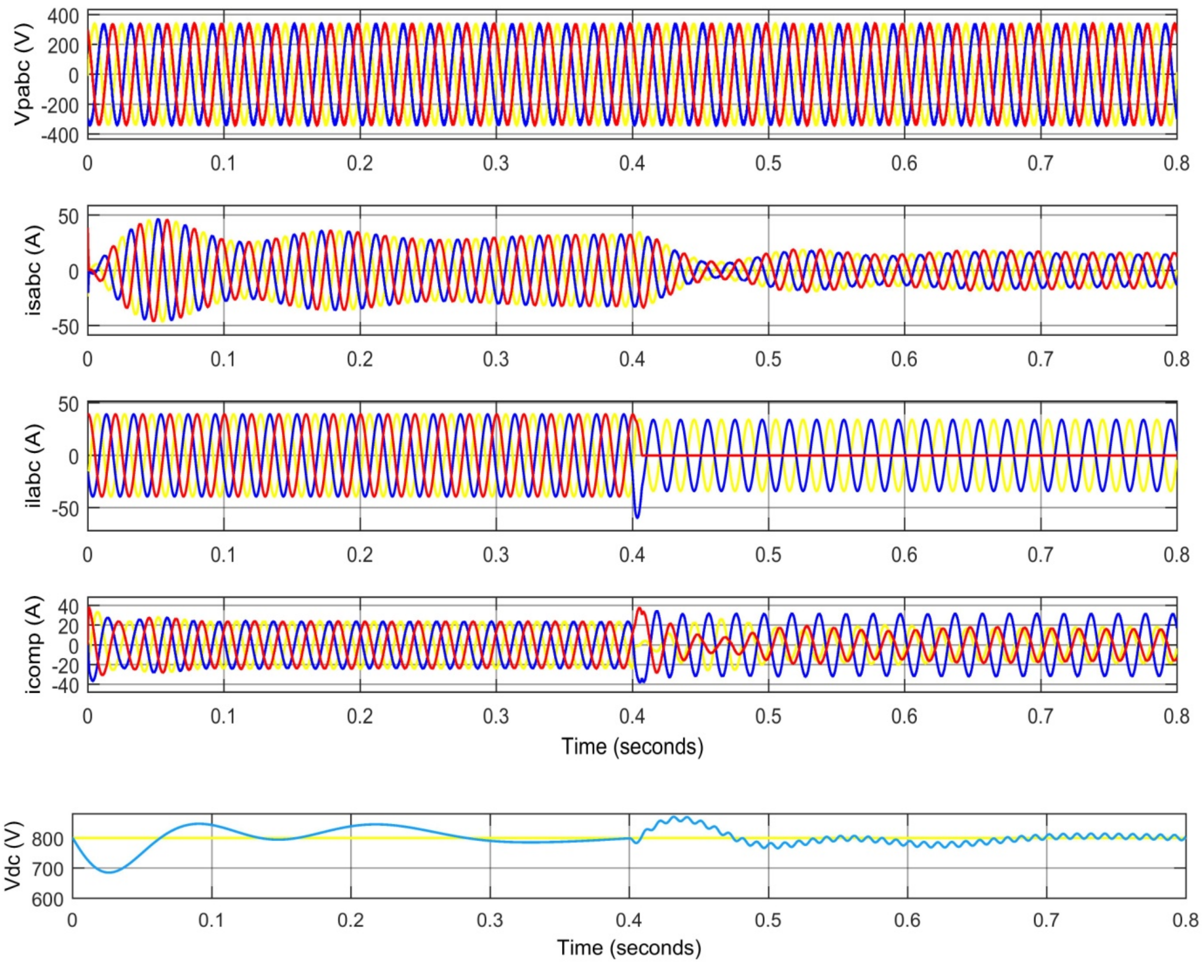


Figure 37: Performance of DSTATCOM under Load Unbalancing (SRF)

From t=0 to t=0.4sec all three phases of load is connected at t=0.4 sec load is changed to two phase load to create load unbalancing, the source current here can observed sinusoidal and balanced as seen in Fig.37 because the unbalance current is provided by the DSTATCOM.

(ii) ADALINE algorithm

The performance of DSTATCOM for load balancing for lagging linear load (20 KVA, 0.8pf) under unbalanced condition is shown in Fig.38.

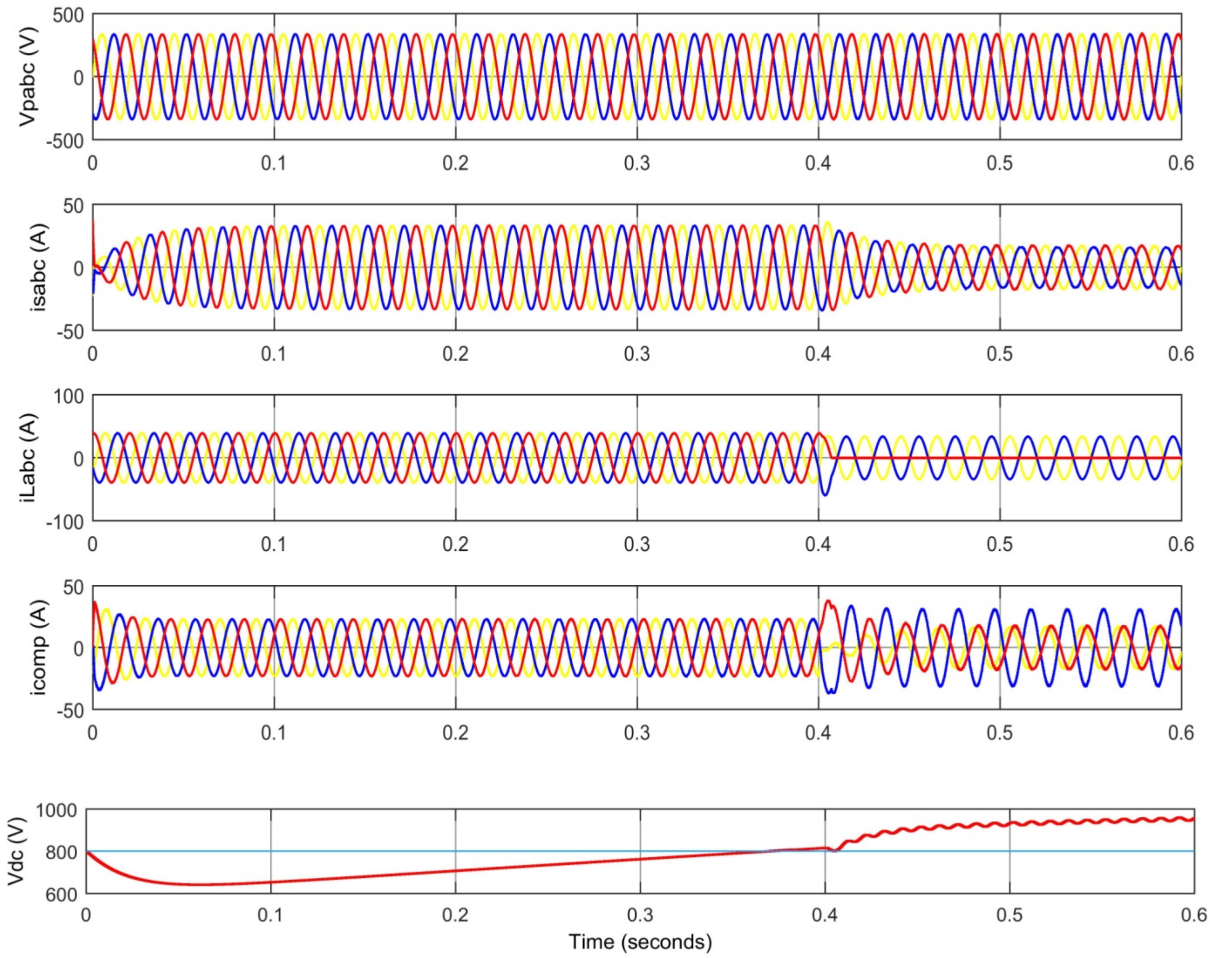


Figure 38: Performance of DSTATCOM under Load Unbalancing (Adaline)

From t=0 to t=0.4sec all three phases of load is connected at t=0.4 sec load is changed to two phase load to create load unbalancing, the source current here can observed sinusoidal and balanced as seen in Fig.38 because the unbalance current is provided by the DSTATCOM.

4.3 CONCLUSION

In this chapter the simulation results with and without DSTATCOM are discussed and the performance of DSTATCOM for harmonic reduction, reactive power compensation, power factor compensation and load balancing with both the algorithm is compared and shown.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE OF WORK

5.0 MAIN CONCLUSIONS

In this dissertation the performance of DSTATCOM under different loading condition using different control algorithms are demonstrated through simulation study.

In chapter-1 the common power quality issues in the distribution system and to mitigate those issues discussed. Some compensation techniques like passive components, passive power filter and active power filter are described.

In chapter-2 the techniques and devices used for mitigating different types of power quality problems in distribution system are shown.

In chapter -3 the mathematical modeling and the design of DSTATCOM is given. The reference current extraction of VSC based DSTATCOM using SRF control scheme and Adaline control scheme is described. For extraction of reference current SRF and ADALINE control algorithm studied and simulated under MATLAB software to study the performance of DSTATCOM connected to 3-phase 415V, 50Hz under different loading condition.

The simulation results with and without DSTATCOM are discussed and the performance of DSTATCOM for reduction of harmonic, compensation of reactive power, power factor compensation and load balancing with both the algorithm one given in chapter-4. The THD of source current is reduced from 28.80% to 3.77% using SRF control algorithm and 28.80% to 2.77% using ADALINE control algorithm. Performance of both the algorithm is satisfactory but ADALINE based control algorithm shows the improved performance because it uses LMS algorithm to calculate its weights. So it can be said that neural network based control algorithm is better than computational based conventional method like SRF because it is simple and fast. These algorithms also show the reactive power compensation when reactive power needed by the load is supplied by DSTATCOM and it also improve the power factor of source side and also shows the satisfactory performance under load unbalance condition.

5.1 FUTURE SCOPE OF WORK

In this work, it is shown that a DSTATCOM effectively compensates load harmonics, reactive power compensation and load unbalancing condition. The work can be extended in following areas:

1. Improve power quality of distribution system using novel control algorithms such as:
    (a) Hopfield neural network based control algorithm.
    (b)Using MCCF-SOGI based controller in control algorithm.
    (c) Using cross-correlation function approach based control algorithm.
2. To improve the voltage profile at PCC by adding AC voltage PI controller in control algorithm to work in ZVR (zero voltage regulation) mode.
3. Exploring computational based control schemes for DSTATCOM such as advanced controller like fuzzy and adaptive fuzzy also employed to DSTATCOM to increase the effectiveness of distribution network.

APPENDIX

SYSTEM RATINGS AND PARAMETERS

Serial No.	System name	Parameter
1.	Three phase voltage source	System voltage – 415 V Frequency – 50Hz
2.	Line parameter	R=0.01Ω, L=0.1mH
3.	Voltage source converter	Three leg, 6 IGBT switches, Capacitor C_{DC} = 2300μF V_{DC} ref =800V Interfacing inductor (L_r)= 3mH
4.	Loads	1.Non Linear Load R=20Ω, L= 30mH 2.Linear Load 20 KVA, 0.8 lagging pf

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