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CERTIFICATE

I, **Shweta Agrawal**, Roll No. 2K13/C&I/17, a student of M. Tech. (Control & Instrumentation), hereby declare that the dissertation titled “” is a bonafide record of the work carried out by me under the supervision of **Prof. Madhusudan Singh** of Electrical Engineering Department, Delhi Technological University in partial fulfilment of the requirement for the award of the degree of Master of Technology and has not been submitted elsewhere for the award of any other Degree or diploma.

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ABSTRACT

This dissertation deals with MATLAB simulation analysis of Some Advance Control Algorithms in DSTATCOM. Power quality of distribution systems is influenced by different events in the real time operation of the utilities supply network. It is important to identify these factors and develop remedies for their reduction or removal. In this dissertation, main contribution is to implement some of intelligent control algorithms for DSTATCOM (Distribution Static Compensator) to enhance its operational flexibility, robustness, tracking capability, accuracy, dynamic response etc. according to the requirements. In the present work three control algorithms are implemented for control of a DSTATCOM for elimination of harmonics in supply current, improvement of power factor & reactive power compensation. These are IRP (Instantaneous Reactive Power) theory, SRF (Synchronous reference frame) theory, Unit Template control algorithm. These control algorithms are based on mathematical calculations and on some improved features of previous conventional algorithms. The operation of a DSTATCOM is demonstrated for mitigation of harmonics in source current due to non-linear loads of various types on supply system. The operation of DSTATCOM is also demonstrated in mitigation of harmonics in supply current due to distortion in source voltage. Because supply current is affected due to both distortion in source voltage and nonlinear load These algorithms use two closed loop PI controllers mainly for regulating supply side AC voltage magnitude and DC link capacitor voltage. The control algorithm generates reference supply current for providing PWM signals through PWM controller. Pulse width modulation or hysteresis current controller is used for generation of PWM gating pulses of IGBT's in the VSI. The proposed algorithms are simulated in MATLAB/SIMULINK in different operating conditions. Results simulation are presented and discussed for harmonic elimination and power factor correction at the AC supply terminals.

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List of Symbols and Abbreviations

PQ	Power Quality
DSTATCOM	Distribution STAtic COMpensator
SVC	Static volt-ampere Compensator
PFC	Power Factor Correction
CEMF	Counter Electromotive Force
PWM	Pulse Width Modulation
HCC	Hysteresis Current Controller
SRF	Synchronous Reference Frame
AH	Anti-Hebbian
CTF	Character of Triangle Function
ILST	Improved Linear Sinusoidal Tracer
PCC	Point of Common Coupling
K_{P1}	Proportional Controller gain
K_{I1}	Integral Controller gain
K_{P2}	Proportional Controller gain
K_{I2}	Integral Controller gain to maintain PCC voltage
R_s	Source Resistance
X_s	Source Inductance
R_f	Resistance of interfacing inductor

CHAPTER 1

INTRODUCTION

1.1 General

The power system today are complicated networks with hundreds of generating stations and load centres being interconnected through power transmission lines. The power system is nonlinear system that operates in a constantly changing environment, load, generator outputs, topology, and key operating parameters change continuously. When subjected to a transient disturbances, the stability of the system depends on the nature of the disturbance as well as the initial operating condition. The disturbance can be small or large. Small disturbance in the form of load changes occurs continuously, and the system adjust to changing conditions. The system must be able to operate properly under these conditions and successfully met to the load demand.

Economies of developed countries are generally influenced by rapid advances in energy system technologies. Electricity is a key input for fast economic growth of any nation. The transmission and distribution networks are important link between power generation and energy consumption or utilization. The technology sophistication presently available do not match the consumer's power quality and reliability demands effectively. Transmission and distribution congestion make a centralized grid inefficient and less reliable. In addition to this, there is an increasing risk for failure with increased peak demand. These factors, added to increased power consumption due to population growth further stretch the traditional grid to its limits, raising serious concerns on economic impact of blackouts and interruptions being seen today. While most recently (31^{st} of July 2012), the Indian grid failure has affected half of the country with millions hit by power cut caused by excessive power absorption, leading to massive snags in rail transport and medical facilities.

Smart energy devices leads to grid transformation which has provided the chance of enhancing efficiency of grid at reduced tariffs. It is also responsible for green i.e. clean power generation. In smart energy ,main concept is communication which entails basically digital information technology to be used in different applications to power system network optimization. Whereas , smart grid which is a common heard today , is the application of such topology for generation ,transmission and distribution of electricity through its various building blocks like efficient meters, intelligent control devices and most importantly a communication system that enables a consumer to provide excess energy back to the grid.

A distribution system is an interface between bulk power and custom powers, which maintains balance between two for the maintenance of continuous healthy operation of our system. The control of distribution system, usually means a system which is capable to enhance system overall efficiency by considering features like loss reduction and power quality control. In recent years, some of the distribution side equipment's such as transformers, capacitor bank, synchronous machines, static volt-ampere reactive compensators (SVCs) and other compensating FACTS devices including DSTATCOM are applied for such controls. However, there are various challenges faced by the system with respect to smart-grid de-centralizing function which affect power system, such as voltage and reactive power compensation (now known as Volt-VAR optimization), power factor correction (PF), distribution system automation (DSA), phase current balancing, low loss transformers (for efficiency improvement), low loss transformers and some energy storage facilities (at consumer side).

For understanding power quality issues, we classify losses of distribution lines and transformers into resistive and reactive components. Among these losses, resistive losses cannot be avoided at any cost while reactive power losses which arises from capacitive and inductive circuit properties (should cancel each other) can be avoided. But the increase in demand of reactive power at the load side increases amount of current flowing through lines being responsible for energy losses. Distribution sides transformers often work at higher efficiency almost 97% as a result negligible core losses are produced. However, total losses of transmission and distribution system together constitute 9% of the total losses from generation to the consumer's end. Another effect of significant current waveform distortion is caused because the utility supply has a finite impedance The distorted current produces a voltage distortion due to the simple V=IR effect. This type of voltage distortion can in turn seriously affect other products powered from the same utility outlet.Various academic groups in the world are presently doing research into control of DSTATCOM to remove power quality problems. In particular, with the evolution of current wave of smart grid, many multinational electricity companies are taking interest in DSTATCOM technologies with the hope of integrating such with the smart grid. These companies are Hitachi Europe, ABB, S & C Electric Company, GE, Schneider, and Siemens. Addressing the issues of Volt-VAR compensation & harmonic elimination aspect of solving the PQ problems at the distribution network is the theme of the present work.

1.2 Facts Controllers

The IEEE Power Engineering Society (PES) Task Force of the FACTS Working Group has defined FACTS and FACTS Controller.*Flexible AC Transmission System (FACTS)* are alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability.

1.2.2 Classification of Flexible AC Transmission & Custom Power (FACTS) Devices

FACTS controller can be broadly divided into two groups:

(a) Line impedance and angle control (Series Compensation)

(b)Voltage control (Shunt Compensation)

First generation of FACTS controllers are:

(i) Static Compensators (SVC)

(ii) Thyristor Controlled Compensation (TCSC)

(iii) Thyristor Controlled Voltage Regulator (TCVR)

(iv) Thyristor Controlled Phase Angle Regulator (TCPAR)

Second generation of FACTS controllers are:

(i) Static series Synchronous Compensator (STATCOM)

(ii) Static shunt Synchronous Series Compensator (SSSC)

(iii) Unified Power Flow Controller (UPFC)

(iv) Inter-Line Power Flow Controller (ILFC)

1.2.3 Benefits and applications of FACTS Controllers

A number of electrical loads in the world have forcefully been utilizing FACTS systems for decades. Traditional reasons are:

(i) Provide better power flow control

(ii) Increase the transmission capacity

(iii) Improved voltage profile

(iv) Better utilization of existing transmission system assets

(v) Increased transient, dynamic and local grid stability

(vi) Increased sensitive quality of supply for industries

1.2.4 Implementation of FACTS controllers

Control strategy for active filters is implemented in five stages. In first stage, voltage, current and power signals are sensed using either instrumentation transformer or Hall Effect sensors to take system information. In second stage, various control methods are used to derive the amount of compensation of voltage or current signals. In third and last stage gating signals for controlled switches are derived using pulse width modulation (PWM), hysteresis current controller (HCC) or fuzzy logic based control techniques. For designing of controlling part in real time various equipments like DSP, FPGA OR d-SPACE can be used; earlier this work was achieved through complex analog and digital circuit.

a) Signal Conditioning

For implementing instantaneous voltage and current signals control algorithm. These values are used to evaluate various parameters like power factor, THD, crest factor, active and reactive power, etc. Voltage signals to be senses are supply voltage of phases and dc bus voltage. Current signal are load current, supply current and compensating current. Current and voltage signals have to be filtered to avoid any noise or interference problems. In hardware these filters are designed using analog circuit.

b) Compensating Current

Compensating signals can be of voltage signal or current signal. To draw compensating signals some control algorithm based on either frequency domain or time domain has to be designed.

i. **Frequency Domain Algorithm:** Fourier analysis is generally used to extract compensating in frequency domain. Switching frequency for device is kept twice of highest frequency component for accurate and effective compensation. Fourier transform has a disadvantage of producing large response time in the system.

ii. **Time Domain Algorithm:** Instantaneous values of compensation current or voltages are generally derived from polluted current or voltage signals. In time domain large number of control methods has been derived as synchronous reference frame, instantaneous active and reactive power theory, etc.

iii. **Generation of Gating Signals:** General approaches for gating signal generation is based on PWM voltage or current method, hysteresis current control method, etc.

1.3 Development in Static Series Synchronous Compensator (STATCOM)

There are a growing list of power electronic systems that are being used to control and enhance the performance of AC transmission networks. These include such traditional devices as the Static Var Compensators (SVCs), which are based on the use of thyristor control reactors (TCRs). This device is used to create a variable susceptance in shunt with a transmission line, which can be used to electronically control the power factor at the point of connection. Similarly there are series connected thyristor based power electronic devices that can effectively alter the transmission line impedance, and thereby control the power flow. AC transmission networks that are augmented by the use of these power electronic systems are often collectively known as FACTS (Flexible AC Transmission Systems). Traditional FACTS power electronics was almost exclusively based on thyristor technology. Consequently the switching frequency (and hence the transient performance) was limited by the natural commutation limitations of thyristors. In addition, thyristor based systems tended in generate significant current and/or voltage harmonics on the network, and hence significant filtering is required to keep the harmonics at acceptable levels.

The advent of high power/high voltage IGBT devices some 15 years ago has created a new version of the static compensator based on the use of IGBT inverter topologies. These compensators are able to exploit the high switching frequency characteristics of IGBTs to enhance the functionality of the SVC beyond that of the thyristor based systems. Static compensators based on hard switched IGBT technology are often known by the collective term of STATCOMs (Static Compensators).STATCOMs can not only provide Var compensation for power factor control or voltage support, but in addition have the capability of implementing active filters, provides flicker suppression, support for voltage dips and swells, and a limited capability to rebalance unbalanced loads and sources. This is significantly more functionality than that provided by the conventional SVC. A number of power circuit STATCOM topologies have been developed.

1.4 Distortion in Supply Current

As far as energy efficiency is concerned in a building power distribution system, the two dominant factors in power quality are its harmonic distortion and unbalanced distortion. Harmonic currents will generate additional heat in conductors due to skin and proximity effects, causing accelerated cable ageing and insulation breakdown. Unbalanced distortion in three-phase supply voltages will create negative sequence component causing additional power losses in conductors and motors. Both distortions will add undesirable currents and voltage drop in neutral conductors.

Generally, high current waveform distortion degrades the power factor of the load, causing wasteful heating effects in the supply cables and transmission lines. In three phase distribution networks this also causes high neutral current. Most neutral conductors in balanced three phase systems are not sized for significant current. Another effect of significant current waveform distortion is caused because the utility supply has a finite impedance. The distorted current produces a voltage distortion due to the simple V=IR effect. This type of voltage distortion can in turn seriously affect other products powered from the same utility outlet. A further problem is the effect of significant power being drawn at higher than fundamental frequency. For example, at a fundamental frequency of 50 Hz, products having high seventh harmonic load current will draw significant power at 350 Hz. This can cause major problems for devices such as power factor correction capacitors and transformers connected to the network. IEC 1000-3-2 specifies the limits of harmonic current either in absolute values or a percentage of the fundamental current for four distinct classes of electronic equipment.

1.4.1 Distortion due to Load

Devices causing harmonics are present in all industrial, commercial and residential installations. Harmonics are caused by ***non-linear loads***. A load is said to be **non-linear** when the current it draws does not have the same wave form as the supply voltage. Devices comprising **power electronics** circuits are typical non-linear loads. Such loads are increasingly frequent and their percentage in overall electrical consumption is growing steadily. Some examples includes industrial equipment (welding machines, arc furnaces, induction furnaces, rectifiers)**,**variable-speed drives for asynchronous and DC motors**,** office equipment (PCs, photocopy machines, fax machines, etc.)**,**household appliances (television sets, microwave ovens, fluorescent lighting, etc.)**,**UPSs. Saturation of equipment (essentially transformers) may also cause non-linear currents.

1.4.2 Distortion due to Source

The power quality of the ac mains can also deteriorate due to voltage fluctuations caused by devices such as electronic ballasts and light dimmer switches. The phase-controlled ac input of these devices may cause large rms current changes on the ac mains, which result in substantial rms voltage deviations. System harmonics voltage distortion is caused by the flow of harmonic currents through system impedance, namely inductive reactance.For each frequency at which harmonic current is flowing there is corresponding inductive reactance associated with system and thus a voltage drop at that frequency. The factors that affect the system inductive reactance are the generator, transformer, series line reactors and circuit conductors.

When the load current consist of fundamental current and 5^{th} harmonic current, there will be a voltage drop across the system impedance at both the frequencies. The presence of any harmonic voltage causes distortion of system voltage.

1.5 OBJECTIVE OF THE WORK

The main objectives of the present work are as follows;

To study different control algorithms for various types of load for harmonic filtering, load balancing and reactive power compensation such as Instantaneous reactive power (IRP) theory, Enhanced phase locked loop (EPLL), Power balance theory and Adaptive filter theory based algorithms and their application for the operation of distribution static compensator(DSTATCOM) through simulation study in MATLAB. And also analyze the conventional algorithm performance on the three phase system when source voltage is also distorted and contains 5^{th} and 7^{th} harmonics.

1.6 OUTLINE OF THESIS

The chapter wise description of this dissertation is given as under:

Chapter-1 gives the introductory view of the overall work that has been presented in this thesis. This chapter also gives a brief introduction of FACTS devices and their use in series and shunt compensation.

Chapter-2 presents brief literature review of FACTS devices, D-STATCOM, control algorithm of D-STATCOM.

Chapter-3 discusses D-STATCOM modeling. In this chapter Simulation model of system is presented.

Chapter-4 presents the details of control algorithms and there designing approach used. This chapter also presents the implementation of control algorithms for operation of D-STATCOM in SIMULINK environment of MATLAB.

Chapter-5 presents the simulation and results.

Chapter-6 gives the main conclusion and future scope of the work.

CHAPTER 2

LITERATURE REVIEW

2.1 General

As technology advances, its impact in both enhanced and degraded way is visible. Use of solid state devices enhanced the use of DC system in AC environment. But its effect in AC power quality can't be ignored on large scale. The emergence of power loads electronic in commercial and industrial application is a concern serious in the field of electric power engineering current/voltage due to distortion the loads. Power electronic devices with high rating as well as high switching frequency are most demanding in many power applications. Power electronic power supply devices shown applied in electric equipment, such as the uninterruptible, switching power supply, AC/DC motor driver, trolley car, battery charger, and power appliances.

PQ problems are nothing but the deviation of voltage and current signals from there described nature. These deviations in technical terms are known as distortions. With advancement, worldwide economy in technology organizations have evolved towards globalization of many and the profit margins tend to activities decrease. Sensitivity towards vast majority of processes (industrial, even residential, services) to PQ problems the electric power availability of quality a crucial in every factor for competitiveness activity sector. Due to disturbance, losses may happen huge financial, with the consequent loss productivity of competitiveness. This all leads to design of compensation for reactive currents as an factor both for utilities and industries to feed costly and sensitive equipment with quality power; thereby malfunction and revenue. Shunt active filters (SAPFs), also power line called active conditioners or active conditioners, are best known tool harmonic elimination reactive power compensation, load balancing and regulation of voltage. They are used as compensating current based technique in which load current harmonic filtering and reactive power compensation are employed. General configurations proposed by researchers are shunt, series, and unified power quality conditioners.

Distribution Static Compensators (DSTATCOMs) of voltage source converter (VSC) is a popular and effective active filter used to filter associated with AC distribution system. Performance of DSTATCOM estimation depends on the reactive, active and harmonic currents. Control algorithm reference current used for generation decides the system of DSTATCOM. From few decades, many reported control algorithms in literature synchronous reference frame theory, instantaneous reactive power theory, and some Artificial intelligence based techniques. In this section brief literatures review on static synchronous compensator is presented. In the last few decades about 25 books and more than 400 journal papers have been published in the area of power quality.

2.2 Distribution Static Compensator (D-STATCOM)

Narain G. Hingorani [1] has described the basics of FACTS devices. It described all types of compensation devices which are connected in series, shunt or in both. It suggested that application of FACTS devices in all electrical energy areas. Power semiconductor devices offer high speed reliability of switches and variety in circuits enhances the value of electricity. This book provides basic depth in understanding FACTS devices. DSTATCOM basics are taken by this book along with the basic method of compensating techniques.

Arindham Ghosh [2] has described all the power quality related problems arise in existing power system. Main problem of power quality is due to the use of power electronics devices. It describes basics of harmonics and there effects in the existing power supply. This book also describes the basic principle of DSTATCOM and use of it in different modes along with the effect of PQ problems on grid and there effects.

H. Akagi et al. [3] have explained basic theory of active filters (shunt and series). In this book, basic concept of control scheme is also discussed. Along with basic concept role of other controllers are also described.

Kalyan K Sen [4] have described theory and modelling technique of FACTS device STATCOM using electromagnetic transient program simulation. This paper explains working of solid state VSI. This paper also verifies the function of STATCOM model by regulating reactive current flow through the tie line.

Dong Ju Lee et al. [5] have described the simulation of STATCOM in this paper. Along with simulation part, this paper shows that STATCOM is better in continuous control of reactive power flow from other devices like SVC. This paper explains basic principle of STATCOM. It also verifies the basic operating characteristics by simulation.

Tariq Masood et al. [6] have presented an analysis of STATCOM behaviour against SVC controller. In this paper some operating parameters like stability, response time power losses and capability of real and reactive power exchange of STATCOM is compared with SVC. This paper concluded that STATCOM than SVC in improving transient stability.

Dong Shen et al. [7] have analyzed performance of STATCOM under distorted system voltage. In this paper of STATCOM is done by per-unit mathematical model under system voltage. This paper showed 3-D curves to reveal relationship between main circuit parameters.

S. H. Hosseini et al. [8] have described STATCOM as a synchronous condenser. In this paper transmission capacity and transient stability of system is increased by STATCOM. For validation of STATCOM performance, a 230kV line for a two machine transmission system is used as a system.

Wang Chao et al. [9] have presented exact method of non-linear control to linearize the non-linear equations of STATCOM. In this paper, comparison of STATCOM operation under state control and using PI controller is compared.

M. Tavakoli Bina et al. [10] have introduced average circuit model for STATCOM. This average circuit model produced mush faster simulation than produced by their exact models. This model is checked on both PSPICE and MATLAB environment to validate its performance.

Javid Akhtar et al. [11] have presented status of active power based on power electronics devices. In this paper description of PQ problems is described and role of active power filters for mitigation of PQ problems is defined. A comparison of active filters to that of conventional techniques is also discussed.

Boon Teck Ooi et al. [12] have implemented a novel topology for STATCOM control operation. Advantage of this topology is direct voltage control by controlling gating pattern and reduction in dc bus capacitor. Order of dominant harmonics is also high, which can be filter easily.

Jianye Chen et al. [13] have proposed a STATCOM where thyristor used as switching device. This paper showed thyristor based VSC can supply reactive power also by firing angle.

Kamal Al-Haddad et al. [14] have explained a comprehensive filters review basically active filters, component selection, control strategies and other technical and economic considerations. This paper provides a detail review of the PQ issues and scope of prospective Active filters.

G. Casaravilla et al. [15] have described possible methods of calculation when a selective shunt active filter is designed. This could be done by extraction of selective harmonic sequences based on modulation- filter- demodulation method. This method is generally based on p-q theory. To prove this method arc furnace current showing high harmonic content is used.

2.3 Different Control Algorithm in DSTATCOM

2.3.1 Anti-Hebbian Learning Algorithm

Sabha Raj Arya et al. [16] have described a neural based control algorithm. In this control scheme Anti-Hebbian is used, which is based on extraction of components of active and reactive component in terms of weights. These weights are used to derive reference currents. Anti- Hebbian algorithm use least mean square (LMS) approach for error calculation.

S. Janpong et al. [17] have presented a review on neural network application in SAPF. It shows three components like harmonic detection component, DC bus voltage control and compensating current based neural network technique. Objectives of papers are to increase efficiency, accuracy, robustness, etc.

Liu Kaipei et al. [18] have showed a basic total least square estimation algorithm based harmonic detection. In this method for error detection TLS scheme is used, which estimate the error, then square it and reduces this by the use of filters. Also discussed harmonic detection based on least mean square (LMS). There is always a contradiction between steady state error and convergence rate. This paper proposes a new algorithm which controls dynamic detection of iteration process.

Keqin Gao et al. [19] have described an anti-hebbian learning scheme which is constrained. In this paper also TLS estimation is used and application of different filters like FIR and IIR is considered.

Qun Wang et al. [20] have described an adaptive noise cancelling technology (ANCT). This paper presents a neuron based adaptive detection approach. It also describes an analog circuit based realization scheme for the system.

Wang Xuhong et al. [21] have presented a RBF neural network based controller. It predicts future harmonic current in the system. Optimization technique is used to produce values of control vector. Adaptive learning algorithm is used to make predictive model simpler and tighter. Space vector PWM technique is used to generate gating pulse of the inverter.

Abdelaziz Zouidi et al. [22] have suggested a new control algorithm based on neural network (ANN). In this paper a three layer neural network is used to analyze frequency same as FFT. Input for ANN is load current and target values are individual harmonic amplitudes which are calculated using FFT. These values are used to generate reference current. And presented an intelligent technique for harmonic detection. This method is based on again artificial intelligence technique named as ANN. In this paper focus is on adaptive linear neuron (ADALINE) for harmonic extraction.

2.3.2 Instantaneous Reactive Power Theory (IRPT)

V. Rajagopal et al. [23] have described instantaneous reactive power theory-based electronic load controller (ELC) for regulating the voltage and frequency of an isolated induction generator system (IG) that can supply electricity in remote areas. In this paper, the control strategy is based on the IRPT algorithm and proportional-integral (PI) controllers for an ELC to control the voltage and its frequency.

C.Christober Asir Rajan et al. [24] have explained that the main reason for reactive power compensation in a system: 1) the voltage regulation; 2) increased system stability; 3) better utilization of machines connected to the system; 4) reducing losses associated with the system; 5) to prevent voltage collapse as well as voltage sag. The impedance of transmission lines and the need for lagging V AR by most machines in a generating system results in the consumption of reactive power.

Bhim Singh et al. [25] have explained the performance of DSTATCOM depends on the control algorithm used for extraction of reference current components. For this purpose, many control schemes are reported in literature, and some of these are instantaneous reactive power (IRP) theory, instantaneous symmetrical components, synchronous reference frame (SRF) theory, current compensation using dc bus regulation, computation based on per phase basis, and scheme based on neural network techniques.

S.S.Murthy et al. [26] have analysed the design of static compensator (STATCOM)-based voltage regulator for self-excited induction generators (SEIGs). The analysis, design, and selection of these STATCOM components are presented for five different rating machines to operate at vary ing power factor loads. Two criteria (full and reduced rating of STATCOM) are considered while designing STATCOM-SEIG systems. The detailed design procedure, along with design data, are presented for these machines to provide a novel voltage control system for the SEIG.

S.S.Murthy et al. [26] have explained the Distribution STATic COMpensator (DSTATCOM) has proved to be a useful custom power device to eliminate harmonic components and to compensate reactive power for balanced/unbalanced linear/nonlinear loads. This paper presents a novel approach to calculate the reference compensation current of three phase DSTATCOM under distorted utility condition at instantaneous state. The proposed approach is compared with reviewed control strategies viz. instantaneous p-q theory, synchronous reference frame Method(SRF), Modified SRF Method(MSRF), instantaneous symmetrical component theory(ISCT) and Average unit power factor theory(AUPFT) for different three conditions. The performance of the system simulated in MATlab Platform and evaluated considering the source current total harmonic distortion. In this paper performance of five control strategies such as instantaneous p-q theory[6], instantaneous symmetrical component theory[12], SRF Method[7][8], Modified SRF Method[11] and AUPF theory[13] are investigated in three phase three wire system for balanced/distorted source and non-linear balanced and unbalanced Load. The measures of the performance are the source current total harmonic distortion.

Ilango K et al. [27] have presented the renewable energy sources play an important role in electric power generation with growing environmental concerns. The inter connection of renewable energy sources are incorporated using power electronics converters, with the aim of improving power quality at the point of common coupling (PCC). This paper presents a novel idea where a STATCOM is used innovatively as i) a load reactive power compensator ii) an interface unit between the grid and renewable energy source, and iii) as an effective method for real power exchange between the dynamic load system, grid and renewable energy source. A controller unit is proposed for the STATCOM based on modified I cosφ algorithm by which reactive power compensation and power factor correction is done and also real power support is provided by renewable energy source through STATCOM. The performance of the proposed algorithm is compared with the modified Instantaneous Reactive Power Theory (IRPT) control algorithm to achieve the above objectives.

The theme of the paper is to improve the power quality of supply in locations where electric grids are weak or sensitive loads need to be protected against problems such as low power factor, voltage regulation, and reactive power compensation. This paper also compares the performance of proposed modified I cosφ algorithm with the modified IRPT algorithm for STATCOM control.

Ilango K et al. [27] have presented a novel idea where a STATCOM is used innovatively as i) a load reactive power compensator ii) an interface unit between the grid and renewable energy source, and iii) as an effective method for real power exchange between the dynamic load system, grid and renewable energy source. A controller unit is proposed for the STATCOM based on modified I cosφ algorithm by which reactive power compensation and power factor correction is done and also real power support is provided by renewable energy source through STATCOM. The performance of the proposed algorithm is compared with the modified Instantaneous Reactive Power Theory (IRPT) control algorithm to achieve the above objectives.

2.3.3 Synchronous Reference Frame (SRF) Theory

Tejas Zaveri et al.[28] have presented comparative study of the reference current generation techniques using voltage source converter based DSTATCOM for reactive power compensation, source current balancing and harmonic mitigation in delta connected load. Different control techniques such as Instantaneous reactive power theory, Synchronous reference Frame theory and Symmetrical component theory have been used in this paper. Reference currents generated by control techniques have been tracked by the compensator in a hysteresis band control scheme. Dynamic simulation of the DSTATCOM for different control strategies has been carried out in MATLAB/Simpower system environment. Simulation results demonstrate the performance and feasibility of various control techniques for DSTACOM.

Syed.Karimulla et al.[29] have focused on power quality improvement of small isolated alternator feeding a three phase three wire distribution system with a linear load. Voltage regulation and rectification of linear loads, efficiency of power such as power factor correction are studied and implemented with the help of DSTATCOM. And also various control algorithms specified are reviewed and analyzed through digital simulations. The models are developed and simulated in MATLAB using simulink and power system block set (PSB) tool boxes. It is observed that DSTATCOM is effective in compensating reactive power and improving the power quality of distribution systems.

Carlos A. C. Cavaliere et al.[30] have investigated how power phenomena and properties of three-phase systems are described and interpreted by the Instantaneous Reactive Power (IRP) p-q Theory. This paper demonstrates that this theory misinterprets power properties of electrical systems or provides some results that at least defy a common sense or meaning of some notions in electrical engineering. For example, it suggests the presence of an instantaneous reactive current in supply lines of purely resistive loads and the presence of an instantaneous active current in supply lines of purely reactive loads. Moreover, it suggests that line currents of linear loads with sinusoidal supply voltage contain a non sinusoidal component. This paper shows, moreover, that the IRP p-q Theory is not capable to identify power properties of three-phase loads instantaneously. A pair of instantaneous values of and powers does not allow us to conclude whether the load is resistive, reactive, balanced, or unbalanced. It is known that a load imbalance reduces power factor. However, the IRP p-q Theory does not identify the load imbalance as the cause of power factor degradation.

Bhim Singh et al. [31] have dealt with different control strategies for DSTATCOM (Distribution Static Compensator) for power quality improvement for a three-phase, three-wire distribution system. A three-leg voltage source inverter (VSI) configuration with a dc bus capacitor is employed as DSTATCOM. The hysteresis as well as PWM current controllers are designed, analyzed and compared for PI controller and sliding mode controller. The capability of the DSTATCOM is demonstrated through results obtained using MATLAB and Simulink based developed model of the DSTATCOM system. The performance of the DSTATCOM acting as a shunt compensator is found satisfactory under varied load perturbations.

Reyes S. Herrera et al. [32] have presented the five main formulations of the instantaneous reactive power theory have been chosen to study nonlinear load compensation. They are $p - q$ original theory, $d - q$ transformation, modified or cross-product formulation, $p - q - r$ reference frame, and vectorial theory. The obtention of the compensation current according to each formulation has been established. Next, the behaviour of an active power filter (APF) that is implemented with those different control algorithms has been studied. On one hand, a simulation platform with control, APF, and load has been built to test them. Results obtained in an unbalanced and non-sinusoidal three-phase four-wire system have been compared by means of the most adequate indexes. On the other hand, the APF control strategies have been implemented in an experimental platform constituted by a 20-kVA power inverter and a 400-MHz digital signal processing controller board. The final analysis shows that, in general, the five theories present a different behaviour, which depends on supply voltage, with respect to distortion. However, all of them widely decrease the waveform distortion. Moreover, a more general compensation objective is possible. It obtains balanced and sinusoidal source current in any conditions of the supply voltage.

2.3.4 Unit Template Control Algorithm

Fang Zheng Peng et al. [33] have presented harmonic and reactive power compensation based on a generalized theory of instantaneous reactive power for three-phase power systems. This new theory gives a generalized definition of instantaneous reactive power, which is valid for sinusoidal or non-sinusoidal and balanced or unbalanced three-phase power systems with or without zero sequence currents and/or voltages. The properties and physical meanings of the newly defined instantaneous reactive power are discussed in detail. A harmonic and reactive power compensator based on the new theory for a three-phase harmonic-distorted power system with zero-sequence components in the load current and/or source voltage is then used as an example to show harmonic and reactive power measurement and compensation using the new theory. Simulation and experimental results are presented.

Bhim Singh et al. [34] have dealt with the design of static compensator (STATCOM)-based voltage regulator for self-excited induction generators (SEIGs). SEIG has poor voltage regulation and it requires adjustable reactive power source with varying load to maintain constant terminal voltage. The required reactive power can be provided by a STATCOM consisting of ac inductors, a dc bus capacity or, and solid-state self-commutating devices. Selection and ratings of these components are quite important for design and control of STATCOM to regulate the terminal voltage of SEIG. The analysis, design, and selection of these STATCOM components are presented for five different rating machines to operate at varying power factor loads. Two criteria (full and reduced rating of STATCOM) are considered while designing STATCOM-SEIG systems.

Bhim Singh et al. [35] have dealt with a modified instantaneous reactive power theory (IRPT) based control of a grid interfaced solar photovoltaic (SPV) power generation which also mitigates power quality problems in three-phase four wire (3P4W) distribution system. This is a double stage SPV power generating system which accommodates wide varying input voltage. The proposed grid interfaced SPV generating system consists of a PV array, a DC-DC boost converter, a three leg VSC (Voltage Source Converter), an isolated Y-Δ transformer, a grid and connected linear/nonlinear loads. The DC bus voltage of a three-phase VSC is regulated using a PI (Proportional Integral) voltage controller. The SPV energy is injected in to the DC bus of VSC during sunshine hours. The proposed SPV power generating system provides the zero voltage regulation (ZVR) or power factor correction (PFC) along with harmonics elimination, load balancing and neutral current compensation in 3P4W distribution system.

Rinchin W. Mosobi et al. [36] have presented modelling and power quality analysis of an integrated renewable energy system (RES) aimed at supplying electrical power to communities residing at remote locations, far from the grid supply. A decentralized power generation in the form of integrated system is proposed comprising of a solar photovoltaic (PV) system, a wind energy system (WES) and a micro hydro system (MHS) to supply required electric loads. The PV system is modelled with a dc-dc converter for regulating dc output voltage; a maximum power point tracking system (MPPT) is incorporated in order to achieve a reliable power output. The WES is modelled with a variable speed wind-turbine set with fixed pitch angle and the set drives a capacitor excited asynchronous generator (CAG). The CAG, in turn, is modelled with a closed loop turbine input system to account for the drooping characteristics of the asynchronous generator. The MHS consists of a constant power CAG. The three different sources are integrated and connected to a common ac bus and the performances of the system under varying loads are presented. A static synchronous compensator (STATCOM) is proposed in this work for reactive power compensation which, in turn, is expected to improve the power quality of the integrated system. The STATCOM is realized by means of a three-phase IGBT based current controlled voltage source inverter (CC-VSI) with a self-supporting dc bus.

2.3.5 Improved Linear Sinusoidal Tracer (ILST)

Bhim singh et al. [37] This paper presents two different control schemes for load sharing in the presence of utility grid. A single renewable source (modeled in the form of battery) is available to meet the load real and reactive power requirement. Load receives power partially from the distributed generation (DG) and remaining power from the utility grid. The sharing of the real and reactive powers is regulated by two control schemes. Current sharing with d-q theory and instantaneous p-q theory are discussed.

Bhim singh et al. [38] have presented active power filters (APFs) are used to compensate harmonics, reactive current and negative sequence fundamental frequency current of load current drawn by nonlinear loads. The flexibility of selective compensation, if provided in the control scheme, makes APF versatile device for compensation of reactive power, harmonic currents and unbalance in source currents and their combinations, depending upon the limited rating of the voltage-source inverter employed as an APF. The proposed scheme decomposes the load current into positive and negative sequence fundamental frequency active components, reactive component and harmonic components in synchronous reference frames. The control scheme performs with priority-based scheme, which respects the limited rating of the APF. The simulated results in MATLAB environment and experimental results of the developed prototype of APF are presented to validate the effectiveness of the proposed control scheme. Digital signal processor based implementation of control scheme is also detailed for selective compensation of power-quality problems with details of developed prototype.

G.-C. Hsieh et al. [39] have described Phase-locked loop (PLL) is a technique which has contributed significantly toward the technology advancement in communication and motor servo control systems in the past 30 years. Inventions in PLL schemes combining with novel imtegrated circuit (IC) technology have made PLL devices important system components. The development of better modular PLL IC's is continuing. As a result, it is expected that it will contribute to improvement in performance and reliability for future communication systems. It will also contribute to the development of higher accuracy and higher reliability servo control systems, such as those involved in machine tools. This paper serves as an introduction for this PLL Special Section. It provides a concise review of the basic PLL principles applicable to communication and servo control systems, gives the configurations of PLL applications and reports a number of popular PLL chips.

B. Widrow et al. [40] have presented a least-mean-square adaptive algorithm for complex signals is derived, which can adapt the real and imaginary parts of the weight vector simultaneously at each sampling instant while minimizing in some sense the real and imaginary error signals. The original LMS adaptive algorithm is derived, and then the complex algorithm is derived in the same way, except that the rules of complex algebra are observed.

2.4 Conclusion

This literature review provides a basic knowledge in the area of PQ. It provides a knowledge about types of control algorithms already implemented in past, there advantages, disadvantages, etc. this review provides a knowledge about what are those parameters which can be controlled to provide better performance of the system. A SRF theory introduces a time delay in the circuit, so there is a chance of flow of high amplitude current, whenever this algorithm is implemented in hardware. Other methods which are new in these fields are artificial intelligence based algorithms. These algorithms are ruling over other algorithms in terms of efficiency, accuracy, performance, etc. Algorithms based on soft computing techniques show better performance than conventional algorithms. Some conventional algorithms like CTF is good in terms of simplicity because it uses only multipliers, summers, etc. Anti- hebbian like neural network techniques works better in condition of dynamic changes in the loads.

CHAPTER 3

MATHEMATICAL MODELLING & CONTROL OF DSTATCOM

3.1 General

In this chapter modeling and control of the shunt compensation device have been presented in detail. Model of voltage source converter and its control scheme is essential for simulation study and design of PQ compensating devices for a particular application.

3.2 Description of shunt controller

The system under consideration is shown in Fig 3.1.The nonlinear load injects harmonics in the supply system, the DSTATCOM which acts as a shunt current controller injects the different current in the system without changing the load current.

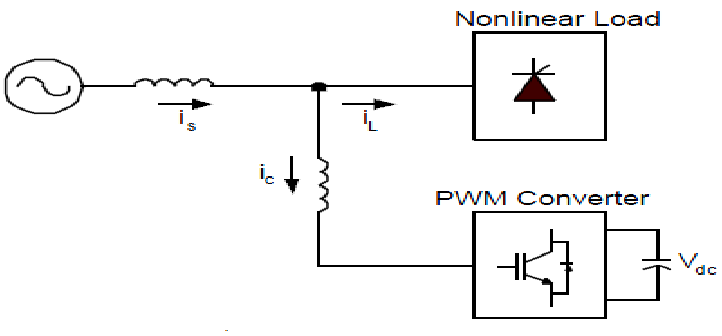


Fig. 3.1 Basic Structure of DSTATCOM

Fig 3.2 shows schematic diagram of a DSTATCOM system supporting the reactive power and harmonic current to power electronics based non-linear load. This system shows a balanced three phase supply connected to a balanced three phase load. The source resistance (R_s) and reactance (X_s) are included in model equation to represent the characteristics of distorted system. Source resistance is generally low in stiff supply system. The source, load and VSC are connected together and their interfacing point is referred as point of common coupling (PCC).

There are two types of load shown in this diagram, one is linear and other is non- linear. Our concern is non -linear loads; because they draw reactive power along with that they are responsible to impart some non- linearity in the system. Linear loads draws only fundamental component of current, whether they are connected to pure supply or polluted supply.

Main aim is to generate reference current which get compared with the actual source current and error between both will generate gate signal for DSTATCOM.

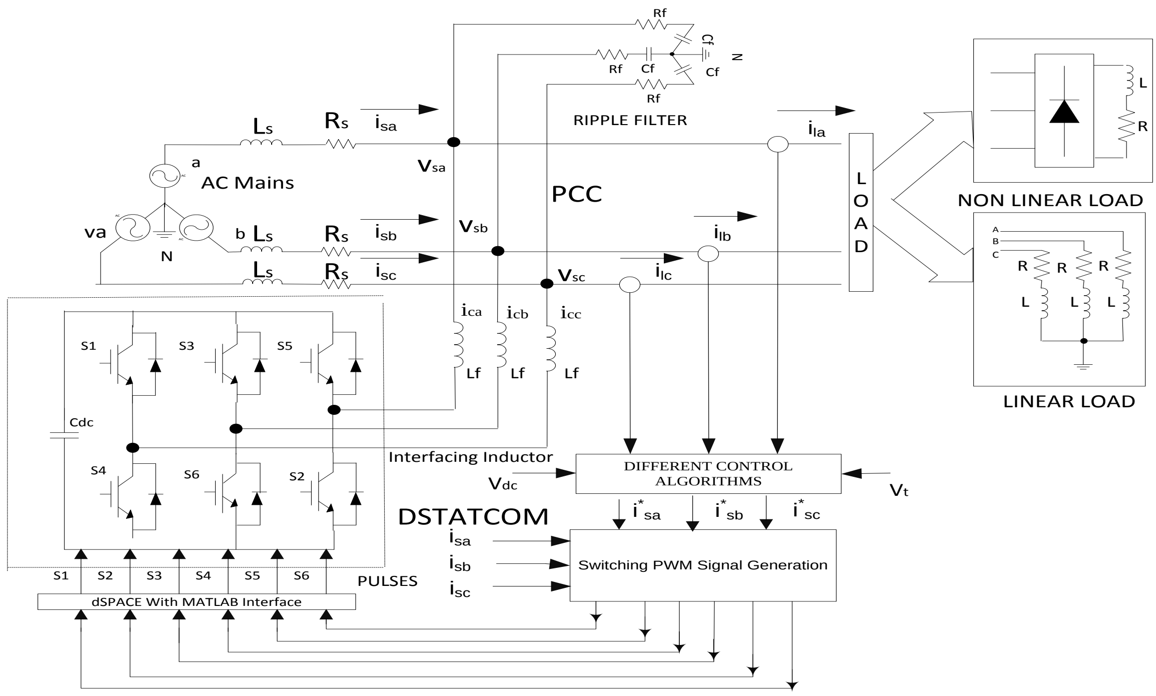


Fig 3.2 A schematic diagram of a DSTATCOM for reactive power compensation and harmonic elimination in non-linear load

DSTATCOM is a VSC with capacitor at dc side. If battery is connected at the dc side then it can supply only active power but when capacitor is connected, it will supply or absorb reactive power. To operate VSC, there is a need of six gating pulses for its power switch i.e. IGBT, these pulses can be obtained by either pulse width modulation (PWM) or hysteresis current controller (HCC). The HCC provides good response by reducing some of high order disturbances but it makes speed of the system slow. A HCC is easily implemented in software but its implementation using dSPACE causes time delay.

3.3 Mathematical modeling of DSTATCOM

Fig 3.3 shows equivalent circuit DSTATCOM which connected to a distribution through filter inductors. In Fig.3.3 v_a, v_b, v_c are three phase line-to-neutral voltages at PCC. e_a, e_b, e_c, represent the fundamental line-to-neutral output of the DSTATCOM's converter. The resistance (R_f) and inductance (L_f) represents reactance of interfacing inductors. i_a, i_b, i_c represents currents flowing through VSC. C_{dc} is effective capacitance on DC side of converter.

From Fig.3.3 KVL equations at PCC can be written as

$$e_a = i_a R_f + L_f \frac{di_a}{dt} + v_a \tag{3.1}$$

$$e_b = i_b R_f + L_f \frac{di_b}{dt} + v_b \tag{3.2}$$

$$e_c = i_c R_f + L_f \frac{di_c}{dt} + v_c \tag{3.3}$$

In matrix form these equations can be written as

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & 0 & 0 \\ 0 & \frac{-R_f}{L_f} & 0 \\ 0 & 0 & \frac{-R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_f}\begin{bmatrix} e_a - v_a \\ e_b - v_b \\ e_c - v_c \end{bmatrix} \tag{3.4}$$

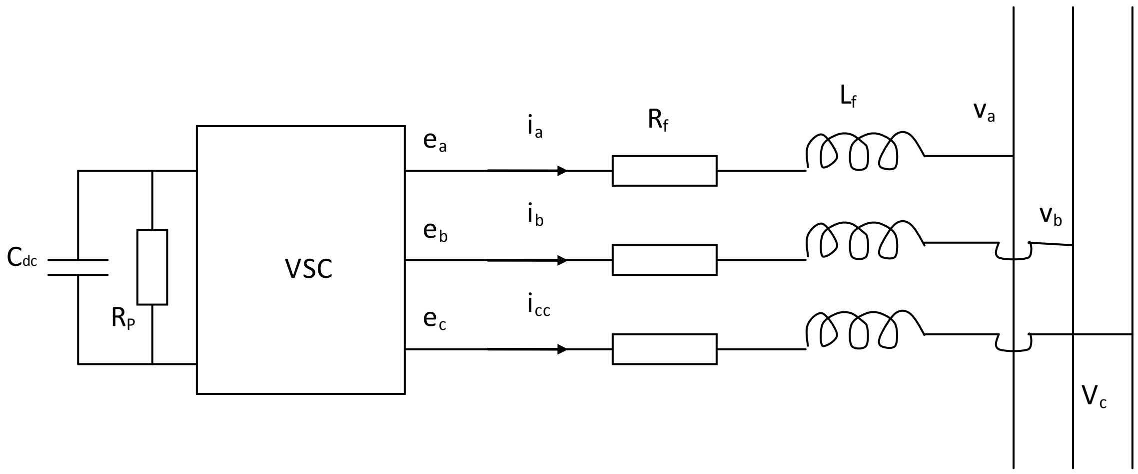


Fig.3.3 Equivalent circuit of DSTATCOM

If $\frac{d}{dt}$ is represented as p, then above eq. (3.4) becomes

$$p\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & 0 & 0 \\ 0 & \frac{-R_f}{L_f} & 0 \\ 0 & 0 & \frac{-R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_f} \begin{bmatrix} e_a - v_a \\ e_b - v_b \\ e_c - v_c \end{bmatrix} \tag{3.5}$$

Converting a-b-c to d-q quantities using Parks transformation using eqn. (3.6), we can write

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} Cos\theta & Cos\,(\theta - \frac{2\pi}{3}) & Cos\,(\theta + \frac{2\pi}{3}) \\ -Sin\theta & -Sin\,(\theta - \frac{2\pi}{3}) & -Sin\,(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

(3.6)

Where i_d, i_q and i_0 are direct, quadrature and zero sequence component of current. θ is transformation angle.

Using eq. (3.6), eq. 3.5 can be written as

$$p\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & \omega \\ -\omega & \frac{-R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_f} \begin{bmatrix} e_d - v_d \\ e_q - v_q \end{bmatrix} \tag{3.7}$$

Where, $\omega = \frac{d\theta}{dt}$

Equation (3.7) may be written in the following form:

$$p\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & \omega \\ -\omega & \frac{-R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \tag{3.8}$$

Where $x_1 = \frac{1}{L_f}(e_d - v_d)$ (3.9)

$x_2 = -\frac{1}{L_f}(e_q)$ (3.10)

Neglecting the Voltage produced by inverter, we can write equation for e_d and e_q

$$e_d = k v_{dc} cos\alpha \tag{3.11}$$

$$e_q = k v_{dc} sin\alpha \tag{3.12}$$

where k is for the inverter relates the DC-side voltage to the peak of the phase–to-neutral voltage in inverter AC-side terminals, v_{dc} is dc side voltage and α is the angle of inverter voltage leads the line voltage vector.

3.4 Designing of PI controllers

To design PI-controllers, (DC link voltage and AC voltage regulator regulator) following factors must be considered while dealing with Hit-and-trail method. It is desirable control system be under-damped from the quick response. An control system exhibits exponentially in the transient period. For performance of a made between control system convenient adjustment has to be steady state error and maximum overshoot. The control action tends to stabilize while the integral control tends to reduce steady-state error to various inputs. Integral control action steady while removing tuning offset or steady-state error, may lead to slowly decreasing amplitude even or after even increasing amplitude, both of which undesirable.

Except for applications where oscillations can be tolerated, it is desirable that transient response be sufficiently damped. Both overshoot and the rise time can't be made smaller simultaneously. If one of them is maximum made smaller, the other increases. The gain constant K_I controls the rate of integration and thus the speed of response. The diagram of PI controllers is shown in Fig.3.4.

Fig 3.4 shows a block diagram of PI controller for regulating AC voltage. The peak amplitude of AC side phase voltage ($\mathbf{V_m}$) is estimated using sensed three-phase supply voltage.

3.4.1 AC Voltage Regulator

The peak amplitude is compared of both AC voltage the reference AC voltage ($\boldsymbol{V_m^*}$) and error is corrected by PI controller. The constants $\boldsymbol{K_{P2}}$ and $\boldsymbol{K_{I2}}$ are adjusted suitably to determine the magnitude of needed reactive power component of compensating current ($\boldsymbol{i_q^*}$). Primary function of D-STATCOM is to regulate ac bus voltage to which it is connected. AC regulator regulates the ac bus voltage by modulating the magnitude of the STATCOM bus voltage by varying the modulation $\boldsymbol{m_a}$ of the converter

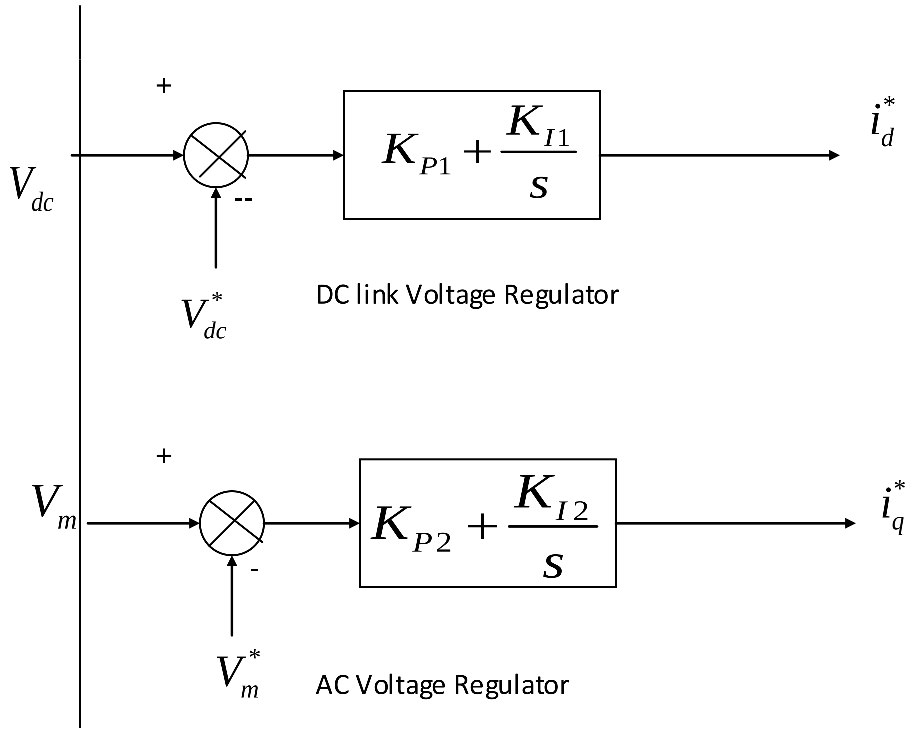


Fig. 3.4 PI-controllers

3.4.2 DC Voltage Regulator

Fig 3.5 shows transfer function of DC voltage regulator. DC regulator is a PI controller which maintains DC bus voltage constant after any disturbance. It maintains power balance between DSTATCOM and power system. K_{P1} and K_{I1} are the proportional gain and integral gain of the DC voltage regulator V_{dc}.

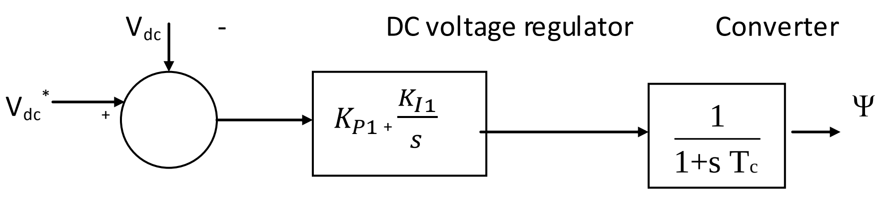


FIG 3.5 Transfer function of a DC voltage regulator

CHAPTER 4

MATHEMATICAL DESCRIPTION OF CONTROL ALGORITHMS USED FOR OPERATION OF DSTATCOM

4.1 General

DSTATCOM performance purely depended on the control algorithms used for reference current generation. Many algorithms based on mathematical approach and soft computing techniques as neural-fuzzy algorithm, etc. are reported in literature. Main application of control algorithms is to estimate reference current. Nowadays artificial intelligence based techniques mainly neural network based techniques are used in large scale. In this chapter few control algorithms based on different approaches are explained.

4.2 Classification of control algorithms

Objective of control scheme is to extract fundamental component of current from polluted current signal. In this dissertation few control algorithms are described. Some of these control algorithms are:

(i) Instantaneous Reactive Power (IRP) Theory

(ii) Synchronous Reference Frame (SRF) Theory

(iii) Unit Template Control Algorithm

4.3 Description of control algorithms

The mathematical description of various control algorithms used in this thesis are described as under

4.3.1 Instantaneous Reactive Power (IRP) theory

IRP theory was initially proposed by Akagi. This theory is based on the transformation of three-phase quantities to two-phase quantities in *α–β* frame and the calculation of instantaneous active and reactive power in this frame . A basic block diagram of this theory is shown in Fig. 2. Sensed inputs v_a, v_b, and v_c and i_{La} , i_{Lb} and $i_{Lc}$are fed to the controller, and these quantities are processed to generate reference current commands (i^*_{sa}, i^*_{sb}, and i^*_{sc})which are fed to a hysteresis-based pulse width modulated (PWM) signal generator (shown in Fig. 2) to generate final switching signals fed to the DSTATCOM; therefore, this block works as a controller for DSTATCOM .

The AC side terminal voltages are given as :

$$v_a = V_m \sin(\omega t) \tag{4.1}$$

$$v_b = V_m \sin(\omega t - {}^{2\pi}/_{3}) \tag{4.2}$$

$$v_c = V_m \sin(\omega t - {}^{4\pi}/_{3}) \tag{4.3}$$

and the respective load currents are given as :

$$i_{La} = \sum I_{Lan} \sin \{n(\omega t) - \theta_{an}\} \tag{4.4}$$

$$i_{Lb} = \sum I_{Lbn} \sin \{n(\omega t - {}^{2\pi}/_{3}) - \theta_{bn}\} \tag{4.5}$$

$$i_{Lc} = \sum I_{Lcn} \sin \{n(\omega t - {}^{4\pi}/_{3}) - \theta_{cn}\} \tag{4.6}$$

In *a–b–c* coordinates, *a, b,* and *c* axes are fixed on the same plane, apart from each other by 2*π/*3. The instantaneous space vectors v_a and i_{La} are set on the "*a*" axis, and their amplitude varies in positive and negative directions with time. This is true for the other two phases also. These phasors can be transformed into *α–β* coordinates using Clark's transformation as follows:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & -{}^{1}/_{2} & -{}^{1}/_{2} \\ 0 & {}^{\sqrt{3}}/_{2} & -{}^{\sqrt{3}}/_{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{4.7}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & -{}^{1}/_{2} & -{}^{1}/_{2} \\ 0 & {}^{\sqrt{3}}/_{2} & -{}^{\sqrt{3}}/_{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \tag{4.8}$$

where $\propto and\ \beta$ and axes are the orthogonal coordinates. Conventional instantaneous power for three-phase circuit can be defined as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{4.9}$$

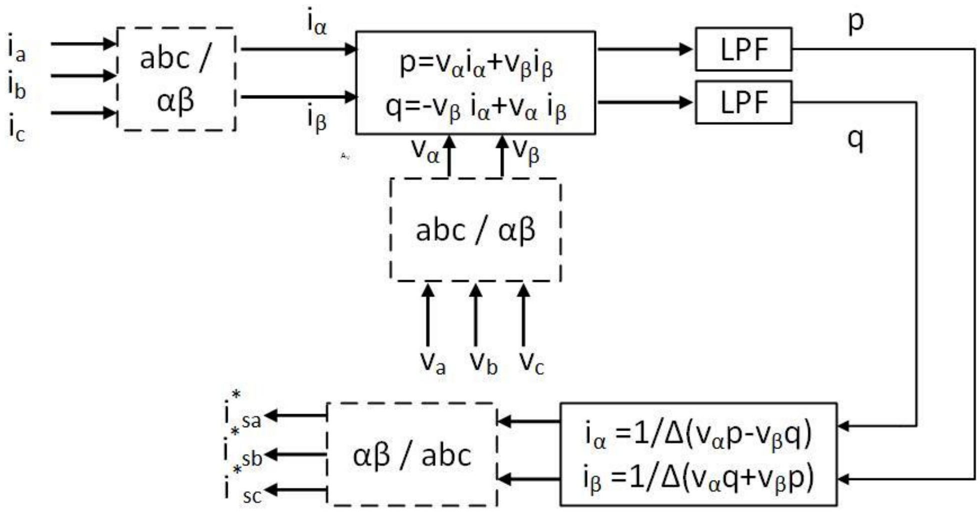


Fig 4.1 Reference current extraction using IRP theory

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \left(\frac{1}{\Delta}\right)\begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} p \\ q \end{bmatrix} \qquad (4.10)$$

Where $\Delta = v_\alpha^2 + v_\beta^2$;

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \frac{\sqrt{2}}{3}\begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_0 \\ i_\alpha^* \\ i_\beta^* \end{bmatrix} \qquad (4.11)$$

These are reference current generated. These reference currents are compared with actual current and error between both will be the required amount of reactive current supplied by DSTATCOM. Error of current is used to generate pulses for inverter. Inverter is equipped with a capacitor, which supplies necessary reactive power to the system.

4.3.2 Synchronous Reference Frame (SRF) theory

SRF theory is related to extraction of synchronously rotating d-q components of current from 3-phase load current. A diagram for this theory is shown in Fig 4.1. Controller used are the basic block of this algorithm. Controller takes source voltage and load current as input. Phase locked loop (PLL) tracks the phase of input voltage signal and generate unit voltage templates (sine and cosine components). These d-q components of currents passed by a filter which filter out high frequency harmonic components. Then again d-q frame is transformed back to 3-phase components. This current is going to be compared with source current and error between them is applied to Hysteresis-based PWM generator to produce final switching pulses which are the pulses for DSTATCOM.

The AC side terminal voltages are given as

$$v_{sa} = V_m \sin(\omega t) \tag{4.12}$$

$$v_{sb} = V_m \sin(\omega t - {}^{2\pi}/_{3}) \tag{4.13}$$

$$v_{sc} = V_m \sin(\omega t + {}^{2\pi}/_{3}) \tag{4.14}$$

and fundamental component of load current are given as:

$$i_{la} = I_m \sin(\omega t - \theta_n) \tag{4.15}$$

$$i_{lb} = I_m \sin(\omega t - {}^{2\pi}/_{3} - \theta_n) \tag{4.16}$$

$$i_{lc} = I_m \sin(\omega t - {}^{2\pi}/_{3} - \theta_n) \tag{4.17}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & -{}^{1}/_{2} & -{}^{1}/_{2} \\ 0 & {}^{\sqrt{3}}/_{2} & -{}^{\sqrt{3}}/_{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \tag{4.18}$$

Using equation (4.18), Current components in $(\alpha - \beta)$ coordinates are calculated.

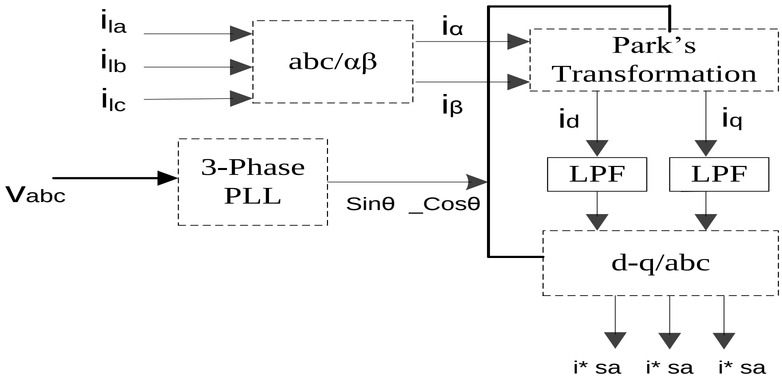


Fig.4.2 Reference current extraction using SRF theory

A PLL generally used for determine the transformation angle for converting $(\alpha - \beta)\ to\ (d - q)$ frame. After this, filter is then used to remove dc component from the currents, then$(d - q)$ component of current is converted to (α-β), equation (4.18).

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (4.19)$$

and to convert from$(\alpha - \beta)$ to a-b-c, equation (4.19) is used.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (4.20)$$

These are reference current generated. These reference currents are compared with actual current and error between both will be the required amount of reactive current supplied by DSTATCOM. Error of current is used to generate pulses for inverter. Inverter is equipped with a capacitor, which supplies necessary reactive power to the system.

4.3.3 Unit Template Control Algorithm

Unit amplitude templates are in phase and quadrature component of source voltage, which are of unit magnitude. These templates are used by reference current at the later part of the algorithm. They are used to provide phase difference to different components of current so that they can be compared with actual current for generation of firing pulses. For calculation of unit amplitude template, first terminal voltage, v_m, is calculated by the formula given in eq.(4.20), where v_a, v_b and v_c are phase voltages of the supply line.

$$v_m = Sqrt(\{(2/3)(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)\}) \quad (4.21)$$

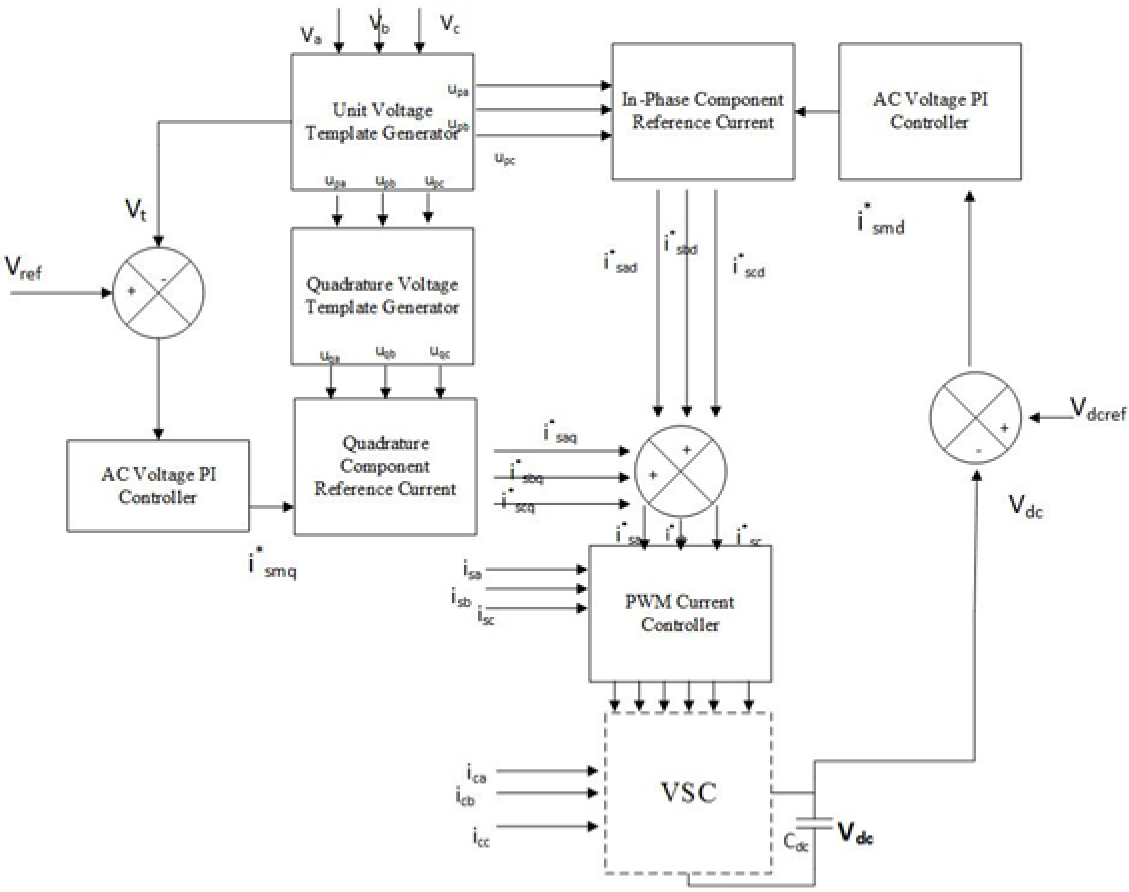


Fig.4.3 Reference current extraction using SRF theory

After that individual phase voltages get divided by terminal voltage, this will give unit amplitude with the phase angle of actual supply of phase voltage. In phase components are represented by u_{pa}, u_{pb} and u_{pc}, respectively for phase a, b and c. Quadrature components are represented by u_{qa}, u_{qb} and u_{qc}, respectively for phase a, b and c. Equation for calculation are given below.

$$u_{pa} = \frac{v_a}{v_m},\ u_{pb} = \frac{v_b}{v_m},\ u_{pc} = \frac{v_c}{v_m} \quad (4.22)$$

$$u_{qa} = -\, {u_{pb}}/{\sqrt{3}} + {u_{pc}}/{\sqrt{3}} \quad (4.23)$$

$$u_{qb} = \sqrt{3}\, {u_{pa}}/{2} + {(u_{pb} - u_{pc})}/{2\sqrt{3}} \quad (4.24)$$

$$u_{qc} = -\sqrt{3}\, {u_{pa}}/_{2} + {(u_{pb} - u_{pc})}/_{2\sqrt{3}} \quad (4.25)$$

4.3.3.1 In-Phase Component of Reference Source Currents: The dc bus voltage error V_{dcre} at *n*th sampling instant is

$$\mathrm{V_{dcer(n)}} = \mathrm{V_{dcref}} - \mathrm{V_{dc(n)}} \quad (4.26)$$

where V_{dcref} is the reference dc voltage and $\mathrm{V_{dc(n)}}$ is the sensed dc link voltage of the STATCOM. The output of the PI controller for maintaining the dc bus voltage of the STATCOM at the *n*th sampling instant is expressed as

$$\mathrm{I}^{*}_{smd\,(n)} = \mathrm{I}^{*}_{smd\,(n-1)} + K_{pd}\{\mathrm{V_{dcer(n)}} - \mathrm{V_{dcer(n-1)}}\} + K_{id}\mathrm{V_{dcer(n)}} \quad (4.27)$$

$\mathrm{I}^{*}_{smd\,(n)}$ is considered as the amplitude of the active power component of the source current. K_{pd} and K_{id} are the proportional and integral gain constants of the dc bus PI voltage controller, respectively. In-phase components of the reference source currents are estimated as-

$$\mathrm{i}^{*}_{\mathrm{sad}} = \mathrm{I}^{*}_{\mathrm{smd}}\mathrm{u_a}\,;\ \mathrm{i}^{*}_{\mathrm{sbd}} = \mathrm{I}^{*}_{\mathrm{smd}}\mathrm{u_b}\,;\ \mathrm{i}^{*}_{\mathrm{scd}} = \mathrm{I}^{*}_{\mathrm{smd}}\mathrm{u_c} \quad (4.28)$$

4.3.3.2 Quadrature Component of Reference Source Currents: The ac voltage error $\mathrm{V_{er}}$ at the *n*th sampling instant is-

$$\mathrm{V_{er(n)}} = \mathrm{V_{tref}} - \mathrm{V_{t(n)}} \quad (4.29)$$

where $\mathrm{V_{tref}}$ is the amplitude of the reference ac terminal voltage and $\mathrm{V_{t(n)}}$ is the amplitude of the sensed three-phase ac voltages at the SEIG terminals at *n*th instant. The output of the PI controller $\mathrm{I}^{*}_{smq\,(n)}$ for maintaining ac terminal voltage constant at the *n*th sampling instant is expressed as-

$$\mathrm{I}^{*}_{smq\,(n)} = \mathrm{I}^{*}_{smq\,(n-1)} + K_{pa}\{\mathrm{V_{er(n)}} - \mathrm{V_{er(n-1)}}\} + K_{ia}\mathrm{V_{er(n)}} \quad (4.30)$$

where $K_{pa}$and K_{ia} are the proportional and integral gain constants of the PI controller, $\mathrm{V_{er(n)}}$ and$\mathrm{V_{er(n-1)}}$ are the voltage errors in *n*th and $(n-1)$th instant, and $\mathrm{I}^*_{smq(n-1)}$ is the amplitude of the quadrature component of the reference source current at $(n-1)$th instant. The quadrature components of the reference source currents are estimated as-

$$\mathrm{i^*_{saq}} = \mathrm{I^*_{smq}\,w_a}\ ;\ \mathrm{i^*_{sbq}} = \mathrm{I^*_{smq}\,w_b}\ ;\ \mathrm{i^*_{scq}} = \mathrm{I^*_{smq}\,w_c} \tag{4.31}$$

4.3.3.3Total Reference Source Currents: Total reference source currents are sum of the in phase and quadrature components of the reference source currents as-

$$i^*_{sa} = \mathrm{i^*_{saq}} + \mathrm{i^*_{sad}} \tag{4.32}$$

$$i^*_{sb} = \mathrm{i^*_{sbq}} + \mathrm{i^*_{sbd}} \tag{4.33}$$

$$i^*_{sc} = \mathrm{i^*_{scq}} + \mathrm{i^*_{scd}} \tag{4.34}$$

4.3.3.4 PWM Current Controller*:* The reference source currents $(i^*_{sa}, i^*_{sb}, i^*_{sc})$ are compared with the sensed source currents (i_{sa}, i_{sb}, i_{sc}) The ON/OFF switching patterns of the gate drive signals to the IGBTs are generated from the PWM current controller. The current errors are computed as-

$$\mathrm{i_{saerr}} = \mathrm{i^*_{sa}} - \mathrm{i_{sa}}\ ;\mathrm{i_{sberr}} = \mathrm{i^*_{sb}} - \mathrm{i_{sb}}\ ;\mathrm{i_{scerr}} = \mathrm{i^*_{sc}} - \mathrm{i_{sc}} \tag{4.35}$$

These current error signals are amplified and then compared with the triangular carrier wave. If the amplified current error corresponding to phase a $(\mathrm{i_{saerr}})$ signal is greater than the triangular carrier wave signal, the switch S4 (lower device) of the phase "a" leg of VSI is ON, switch S1 (upper device) of the phase "a" leg of VSI is OFF, and the value of the switching function SA is set to zero. If the amplified current error signal corresponding to *i*saerr is less than the triangular carrier wave signal, switch S1 is ON, switch S4 is OFF, and the value of SA is set to one. Similar logic applies to other two phases "b" and"c," respectively.

4.4 Conclusion

In this chapter, a detailed description of various control algorithms is presented. By analyzing approach of control algorithms, we conclude that IRP theory is based on the transformation of three-phase quantities to two-phase quantities in α–β frame and the calculation of instantaneous active and reactive power in this frame.SRF is based on axis transformation, which is basic approach. In this approach PLL is used, which introduces some time delay in system. This time delay can create a problem in real time implementation of SRF theory. This time delay is reason for heavy amount of current flow in the system. In real time SRF theory is used only when time delay is less. Unit Template is very basic technique and it is used only for harmonic filtering.

CHAPTER 5

SIMULATION AND RESULTS

This chapter presents simulation analysis and hardware realization of a DSTATCOM unit for harmonic and reactive power compensation in a non-linear load using some intelligent control algorithms. In this chapter Synchronous reference frame (SRF) theory, Anti-Hebbain learning algorithm, character of triangle function (CTF) and improved linear sinusoidal tracer (ILST) based control algorithms are implemented for elimination of harmonics in source current and comparison on the basis of total harmonic distortion in source current with all four control algorithms are summarized.

5.1 System Configuration

Fig 5.1 shows schematic diagram of distribution system feeding a non-linear load and supported with DSTATCOM.

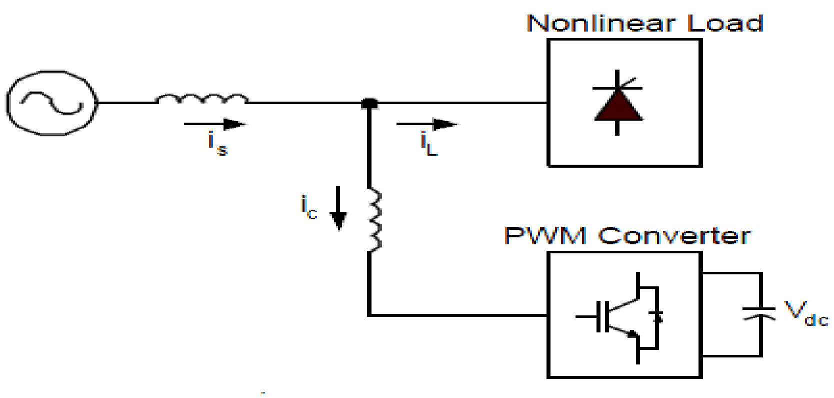


Fig.5.1 Schematic diagram of distribution system

The three-phase supply system is an ideal sinusoidal voltage source; but due to diode bridge rectifier the load current is non sinusoidal and distorted and contains harmonic components. The DSTATCOM is a three phase voltage source converter (VSC) with a seif supported DC bus capacitor. If battery is connected at dc side of DSTATCOM, it will supply active power only but to supply reactive power capacitor should be used. In this dissertation work only reactive power is supplied by DSTATCOM.

5.2 MATLAB model of DSTATCOM

MATLAB model is designed for the distribution system. Fig 5.2 shows MATLAB model for distribution system. In this system, three phase ideal source is supplying power to non-linear load. Non-linear load is shown by three-phase diode rectifier module connected to resistor-inductor (R-L) load. The DSTATCOM is an IGBT based three-phase voltage source converter. This converter is controlled to supply needed reactive power and harmonic current into the system. To interface DSTATCOM to distribution system, filter inductors are used. These inductors are used to limit circulating current flowing in the system.

To control the amount of power flow from DSTATCOM,IRP theory, SRF theory, Unit Template based control algorithms (shown by controller in the system) are designed.

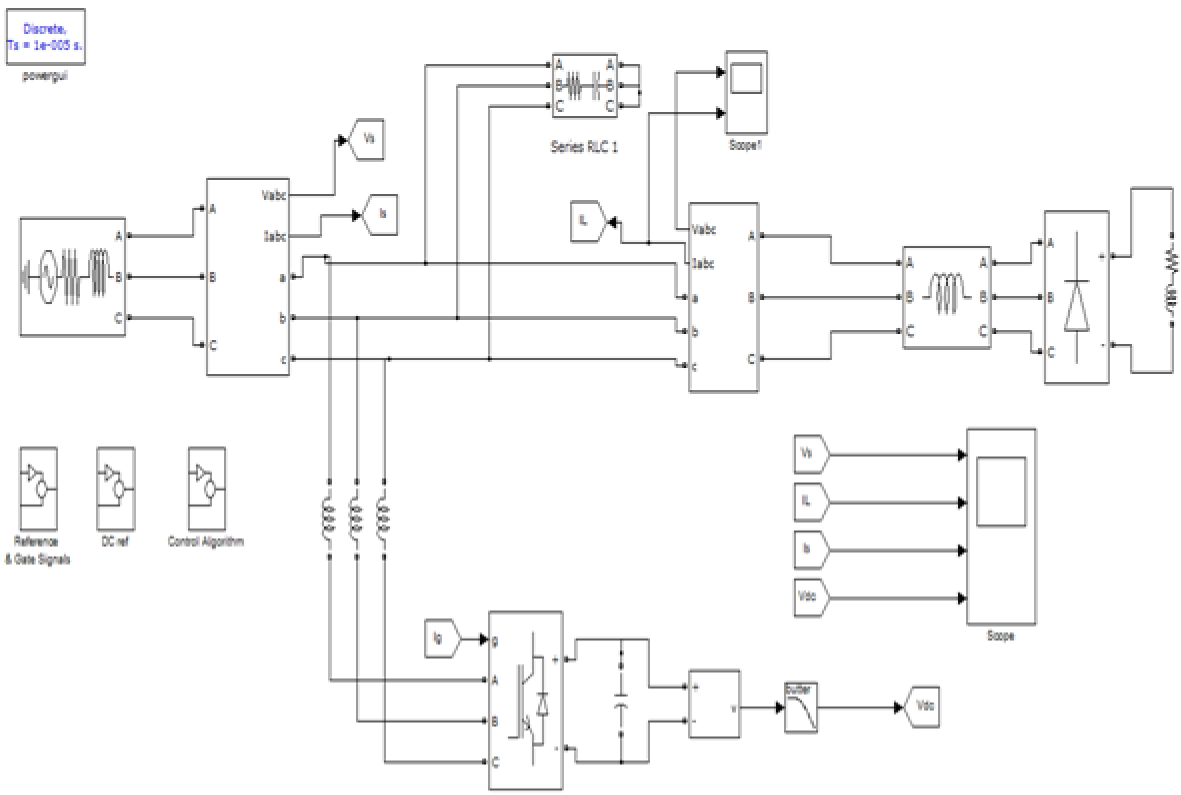


Fig. 5.2 MATLAB model of distribution system

These control algorithms are based on different approaches. A MATLAB model of the system is developed in simulink. The value of system parameters are described in

Appendix 1. Simulation is carried out in discrete mode at a maximum step size of 1x 10^{-5} with ode45 (Dormand-Prince).

A combination of resistor and capacitor is used to filter higher order harmonics of the system. The voltage across a capacitor, connected at DC side of VSC is measured and compared with a desired level and regulated to the reference value through a proportional and integral (PI) controller under different operating conditions. Time taken to maintain dc bus voltage of DSTATCOM is tracking time of the system. Less tracking time shows high efficiency of the system.

5.3 Control algorithm design

The simulation of three control algorithms IRPT, SRF and Unit Template based control algorithms are demonstrated through MATLAB simulation .

5.3.1 Instantaneous Reactive Power (IRP) Theory based control algorithm

Three phase source voltage (V_{abc}) and load current (I_{Labc}) are transformed to α- β frame using clark's transformation. These two axis voltages and load currents in α- β frame are used for calculating the instantaneous active and reactive powers which consist of ac and dc components. A set of low-pass filter is used for extracting the dc component from the instantaneous active and reactive powers. The real power required to maintain the voltage of d.c. link capacitor is supplied from VSC by adding the output of PI controller on dc component of power.From dc component of active and reactive power, we calculated the reference source current in α-β frame. The resultant i_α and i_β are further transformed to three-phase a-b-c component as a reference current for generating switching signals.

Filtered current signals are converted to a-b-c frame (i_{sa}^*, i_{sb}^* and i_{sc}^*) using Reverse Clark's transformation, which is fed to hysteresis controller for generating reference signal for the VSC.

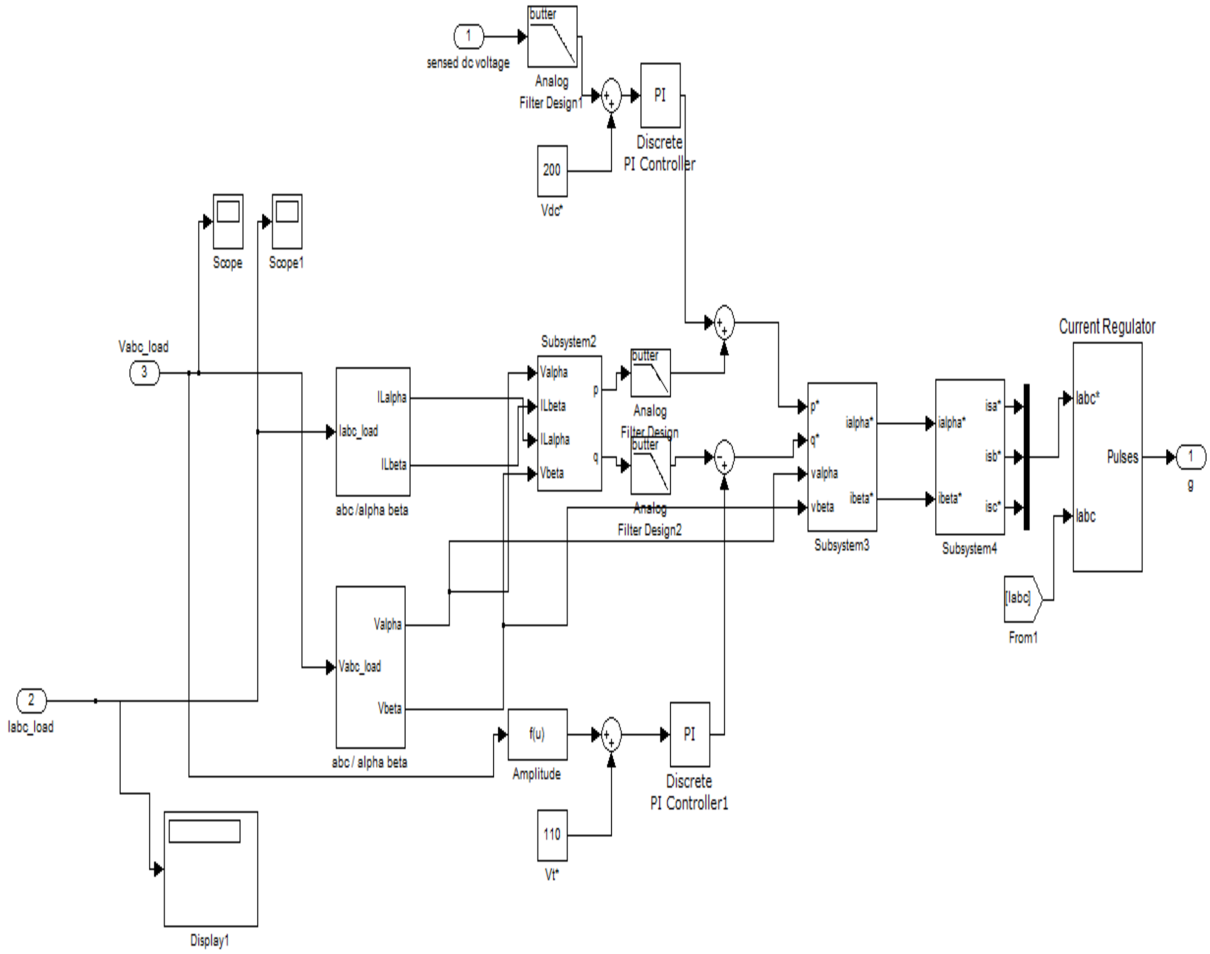


Fig 5.3 IRPT Controller for reference current extraction

5.3.1.1 Results and Discussions

Instantaneous Reactive Power (IRP) Theory based control algorithm is designed to eliminate harmonics of source current. It compensate reactive power and maintained the source at unity power factor (UPF).And also it balances the load.To calculate the amount of compensation provided by DSTATCOM, total harmonic distortion (THD) of source current is determined using FFT window of MATLAB before compensation and after compensation.

5.3.1.1.1 Simulation Result

A three-phase distribution system operating at voltage level of 415V (L-L) is considered for simulation study of the all three control algorithms. Load of 16 kVA is supplied by the supply system. Before connecting DSTATCOM, THD in source current is 24.93% as shown in Fig 5.4. After providing compensation by DSTATCOM, THD is 2.38% as shown in Fig 5.5.

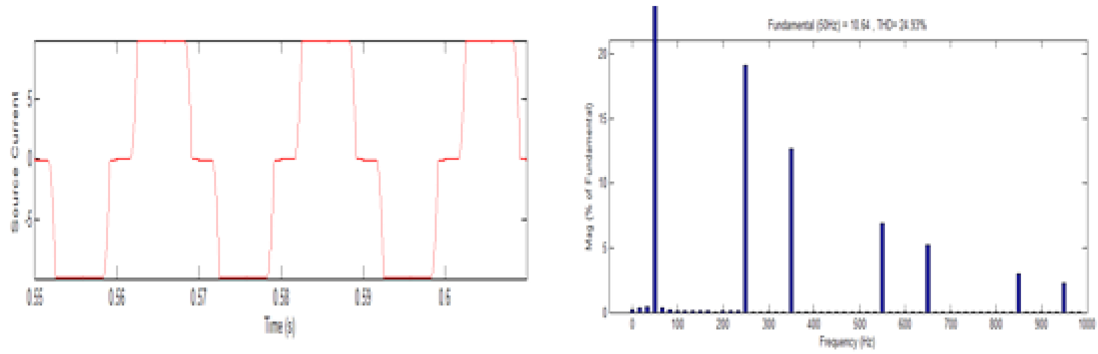


Fig 5.4 THD of source current before compensation

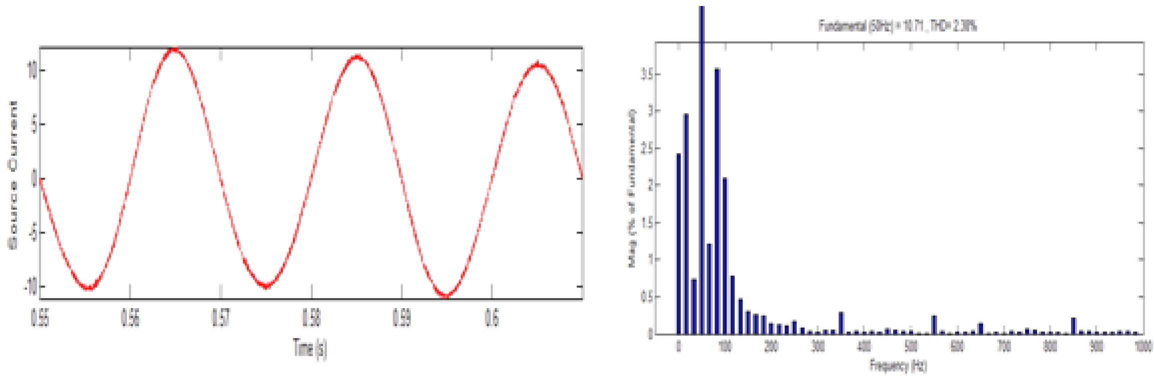


Fig 5.5 THD of source current after compensation using IRP theory based controller

According to IEEE standard THD limit for distribution system is 5%. This reduction shows that IRPT is good in terms of harmonic reduction.

For analyzing the load balancing capability using IRP theory,a circuit breaker is inserted in phase c for disconnecting the supply for 0.8sec to 0.9sec.Due to unbalancing of the load,source current disturbed for that instant of time but controller helps in regaining the source current to its original value and dc voltages dips momentarily but but PI controllers help to maintain this voltage again.

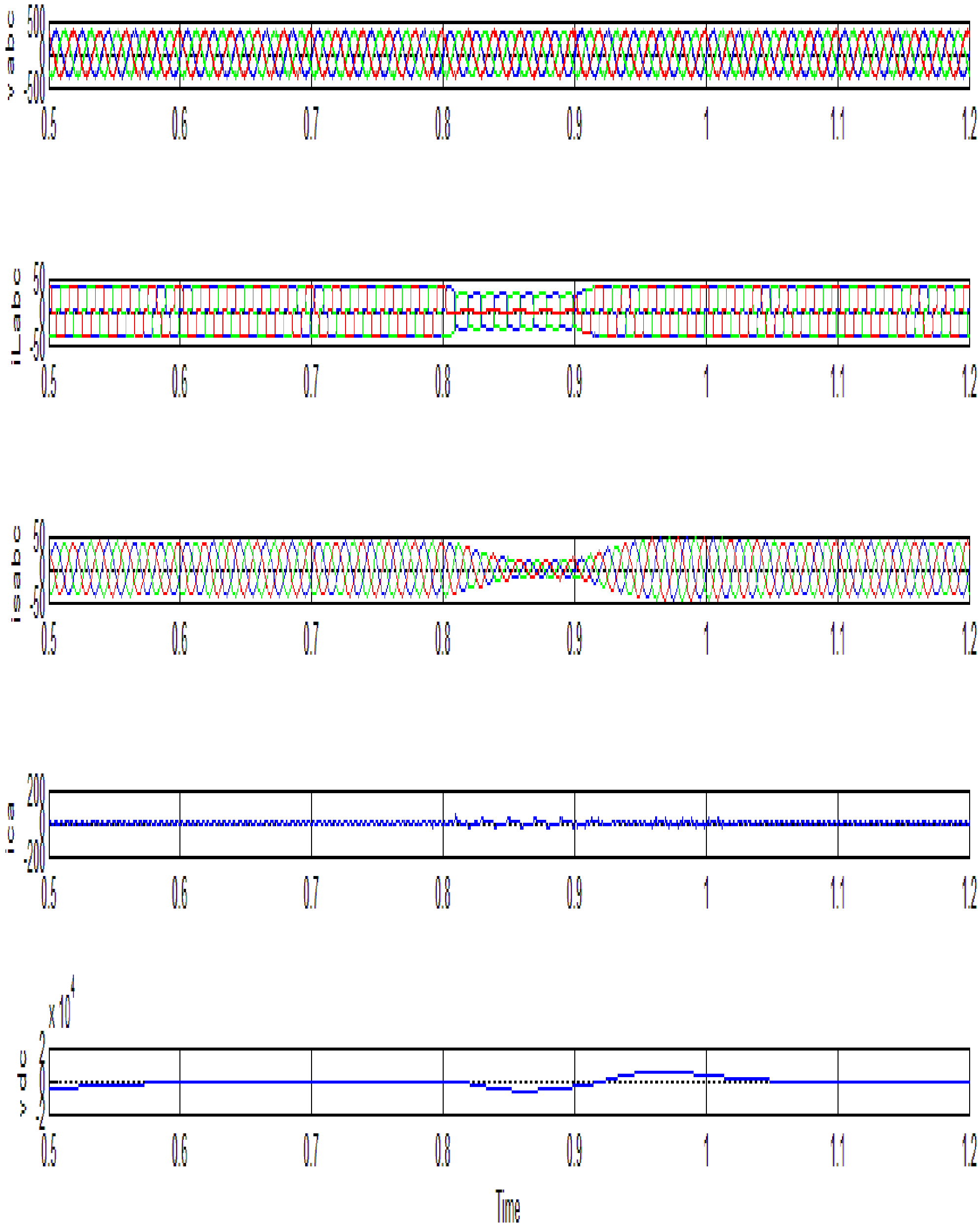


Fig 5.6 Performance of DSTATCOM with IRP Controller for creating unbalance in line for t=0.8sec to 0.9sec and waveform of 3-phase line voltage (v_{abc}), 3-phase load current (i_{Labc}), 3-phase source current (i_{sabc}), Compensating current (i_c) and DC link voltage (V_{dc}).

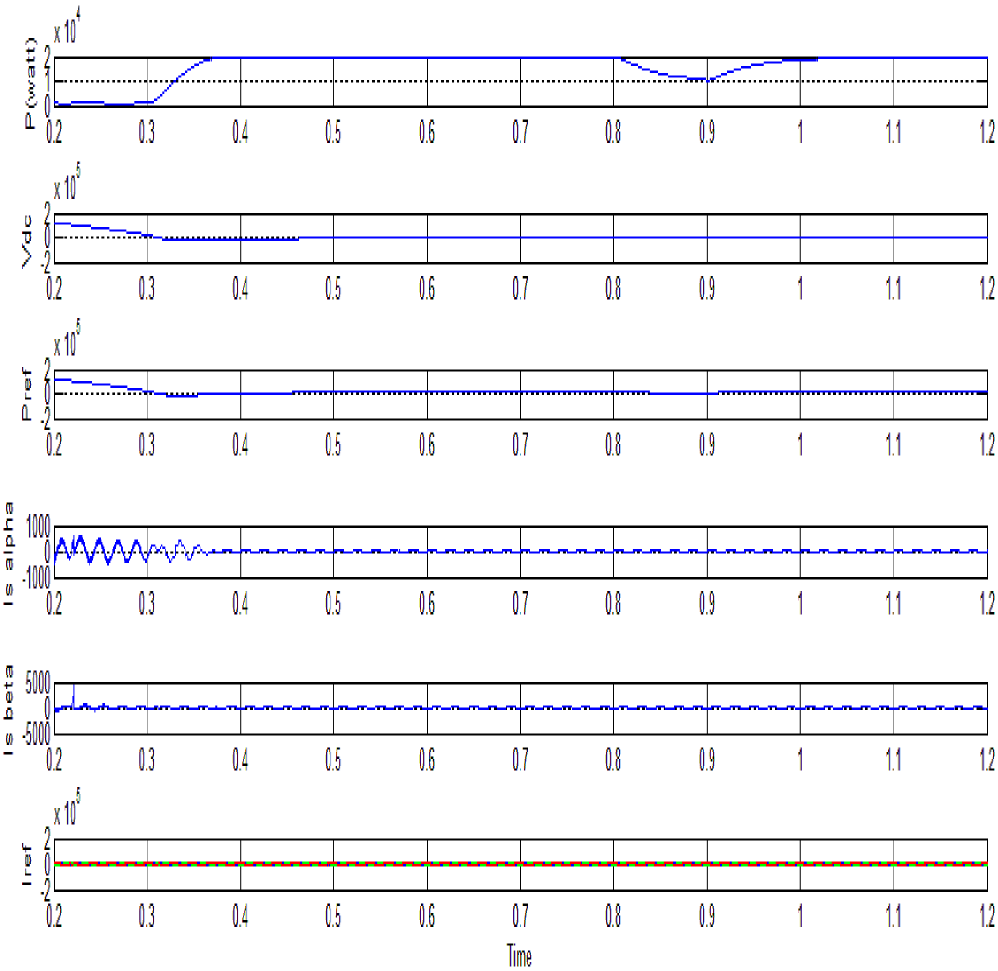
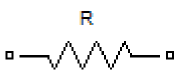
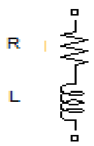
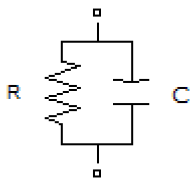
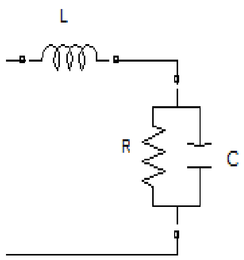


Fig 5.7 Performance of DSTATCOM with IRP Controller for creating unbalance in line for t=0.8sec to 0.9sec and waveform of active power (P-watt), DC link voltage (V_{dc}), reference power(Pref),reference source current in α-β frame Is alpha,Is beta,reference source current in abc frame(Iref).

5.3.1.1.2 THD of source current for different load using IRP theory

In Dstatcom based system various types of load is used to analyze the performance of algorithm on the system. In case of RC load maximum harmonics is shown by the system while the best load is RL in nonlinear loads.and the IRPT controller compensated well these harmonics

Table 5.1 THD of Source current for different load before compensation and after compensation using IRPT algorithm

S. NO.	TYPE OF LOAD	PARAMETE-RS	THD OF SOURCE CURRENT (in %) Before Compensation	THD OF SOURCE CURRENT(in %) After Compensation
1	RESISTIVE LOAD 	R = 15 Ω	25.22	8.13
2	R-L LOAD 	R=15 Ω L=100 mH	23.35	6.99
3	R-C LOAD 	R= 15 Ω C= 2000 µF	37.47	9.49
4	RLC LOAD 	R= 15 Ω C= 2000 µF L= 1 mH	34.19	6.54
		R= 15 Ω C= 2000 µF L= = 100mH	18.15	7.57
		R= 15 Ω C= 2000 µF L = 1H	26.90	6.72

5.3.2 Synchronous Reference Frame (SRF) Theory based control algorithm

Three phase source voltage (v_{abc}) is processed by PLL. Output of PLL is unit voltage template ($\sin\theta$ and $\cos\theta$). Load current (i_L) signals are transformed to d-q frame using Park's transformation.

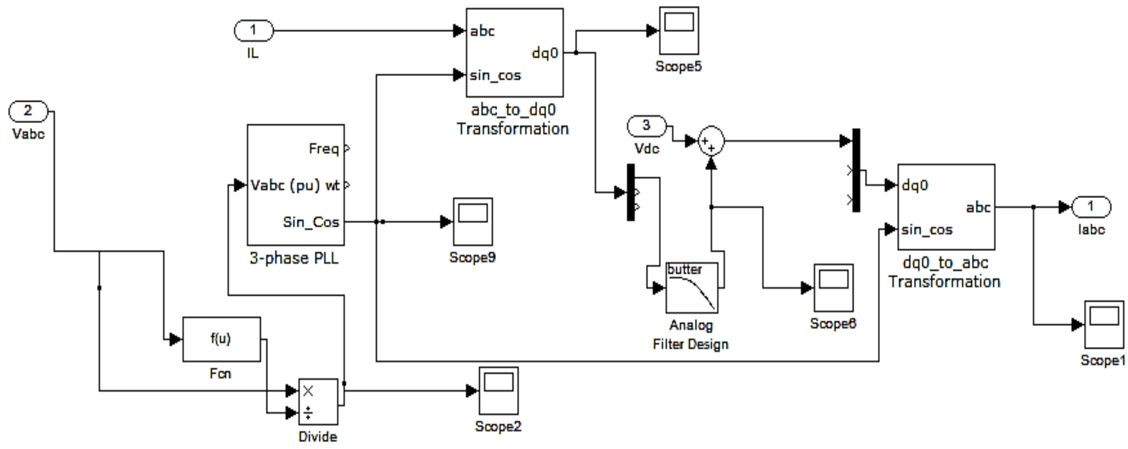


Fig. 5.8 SRF Controller for reference current extraction

A low pass filter (LPF) with cut-off frequency 100Hz is used to filter active and reactive current component. The real power required to maintain the voltage of d.c. link capacitor is supplied from VSC by adding the output of the PI controller on d.c. side to the direct current component (i_d) . The resultant i_d and i_q are further transformed to three-phase a-b-c component as a reference current for generating switching signals.

Filtered current signals are converted to a-b-c frame (i_{sa}^*, i_{sb}^* and i_{sc}^*) using Reverse park's and Clark's transformation, which is fed to hysteresis controller for generating reference signal for the VSC.

5.3.2.1 Results and Discussions

Synchronous Reference Frame (SRF) Theory based control algorithm is designed to eliminate harmonics of source current. To calculate the amount of compensation provided by DSTATCOM, total harmonic distortion (THD) of source current is determined using FFT window of MATLAB before compensation and after compensation.

5.3.2.1.1 Simulation Results

Load of 16 kVA is supplied by the supply system. Before connecting DSTATCOM, THD in source current is 24.3% as shown in Fig 5.9. After providing compensation by DSTATCOM, THD is 3.38% as shown in Fig 5.10. According to IEEE standard THD limit for distribution system is 5%. This reduction shows that SRF is good in terms of harmonic reduction.

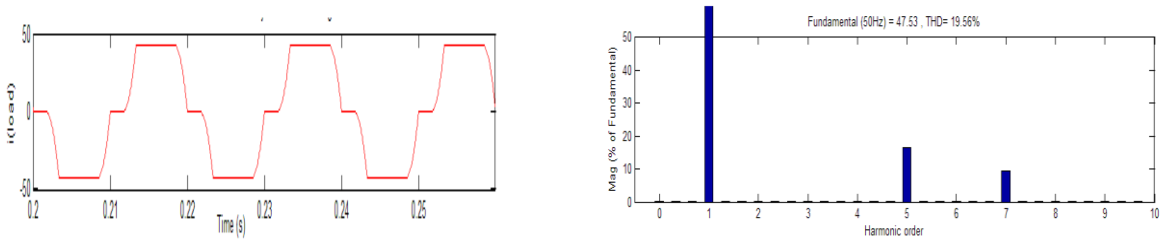


Fig 5.9 THD of source current before compensation

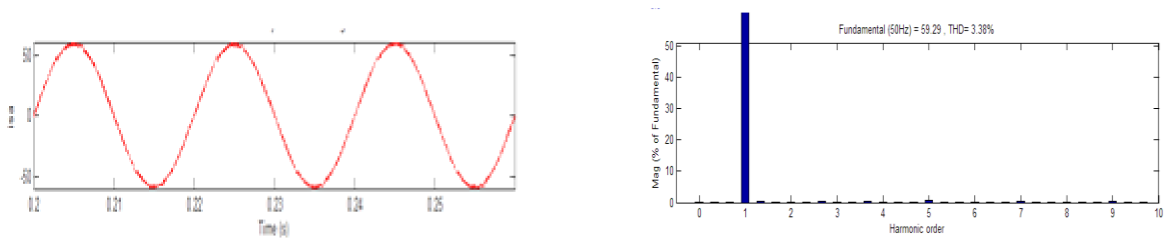


Fig 5.10 THD of source current after compensation using SRF theory based controller

For analyzing tracking capability of algorithm, load of 16kVA is suddenly increased to 32kVA at 0.3sec as shown in Fig 5.11. Due to switching of additional load on distribution network, the dc side voltage is momentarily dips but PI controllers help to maintain this voltage again.

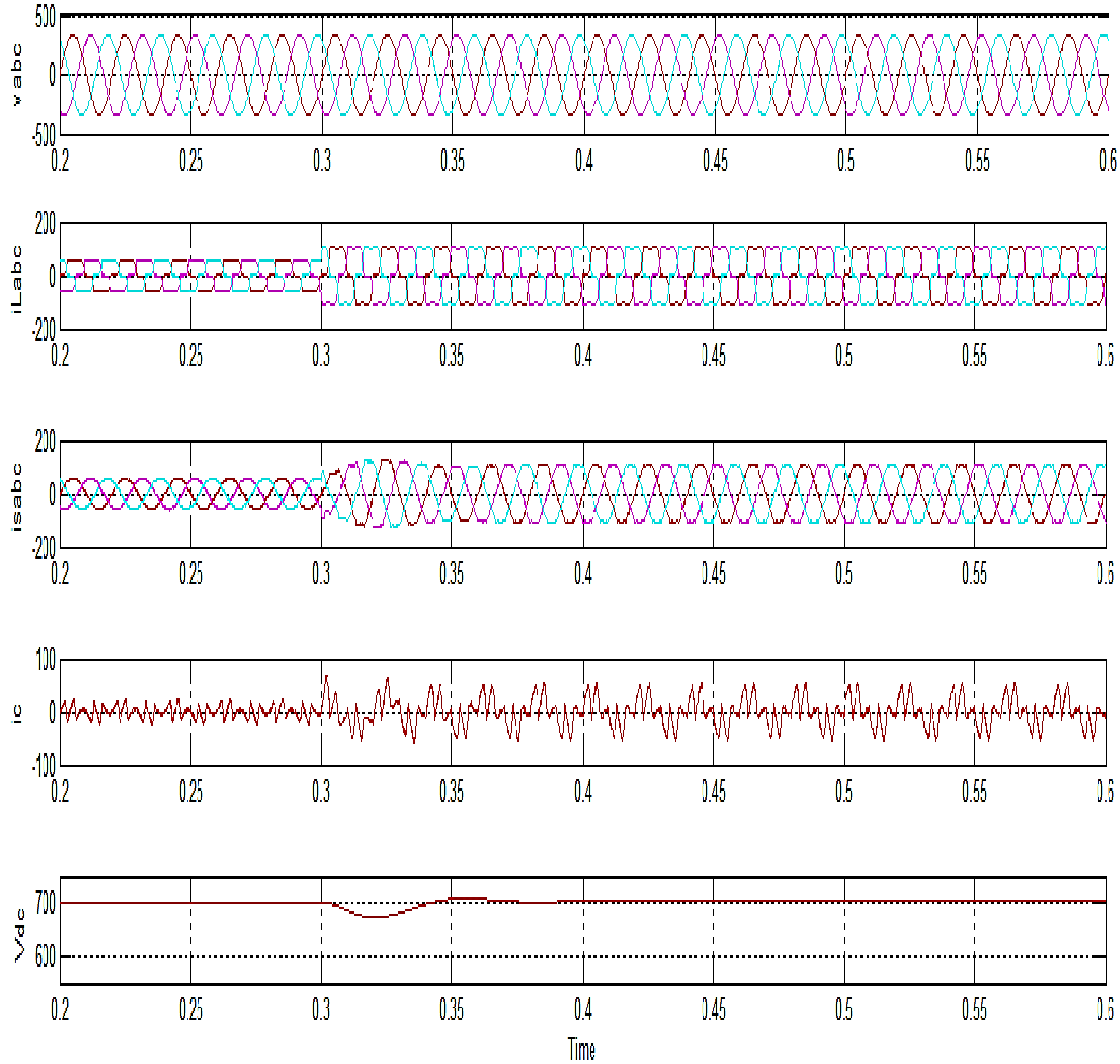
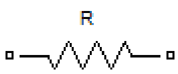
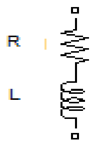
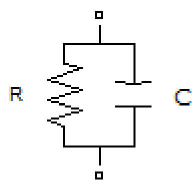
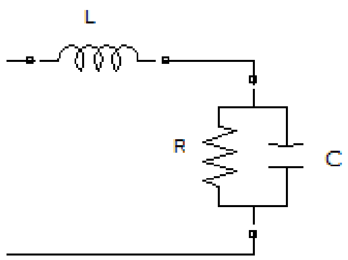


Fig 5.11 Performance of DSTATCOM with SRF Controller while sudden switching of additional load at t=0.3sec and waveform of 3-phase line voltage (v_{abc}), 3-phase load current (i_{Labc}), 3-phase source current (i_{sabc}), DC link voltage (V_{dc}), and Compensating current (i_c).

5.3.2.1.2 THD of source current for different load using SRF theory

In Dstatcom based system various types of load is used to analyze the performance of algorithm on the system. In case of RC load maximum harmonics is shown by the system while the best load is RL in nonlinear loads.and the SRF controller compensated well these harmonics

Table 5.2 THD of Source current for different load without compensation and with compensation using SRF Algorithm

S. N O.	TYPE OF LOAD	PARAMETERS	THD OF SOURCE CURRENT (in %) Before Compensation	THD OF SOURCE CURRENT(in %) After Compensation
1	RESISTIVE LOAD 	R = 15 Ω	24.23	3.29
2	R-L LOAD 	R=15 Ω L=100 mH	24.30	3.38
3	R-C LOAD 	R= 15 Ω C= 2000 µF	36.37	3.25
4	RLC LOAD 	R= 15 Ω C= 2000 µF L= 1 mH	33.15	3.22
		R= 15 Ω C= 2000 µF L= = 100mH	17.16	4.09
		R= 15 Ω C= 2000 µF L = 1H	25.80	4.01

5.3.3 Unit Template Control Algorithm

The in-phase unit vectors (u_a, u_b, andu_c) are three-phase sinusoidal functions, computed by dividing the ac voltages (v_a, v_b, and v_c) by their amplitude Vt. Another set of quadrature unit vectors (w_a, w_b, and w_c) is a sinusoidal function obtained from inphase vectors (u_a, u_b, andu_c). To regulate the ac terminal voltage, the amplitude of the terminal voltage (V_t) is computed from sensed instantaneous ac terminal voltages (v_a, v_b, and v_c) This amplitude of ac voltage (V_t) is compared with the reference voltage (V_{tref}), and the voltage error is processed in the proportional integral (PI) controller. The output of the PI controller (I^*_{smq}) for ac voltage control loop decides the amplitude of reactive current to be generated by the STATCOM.

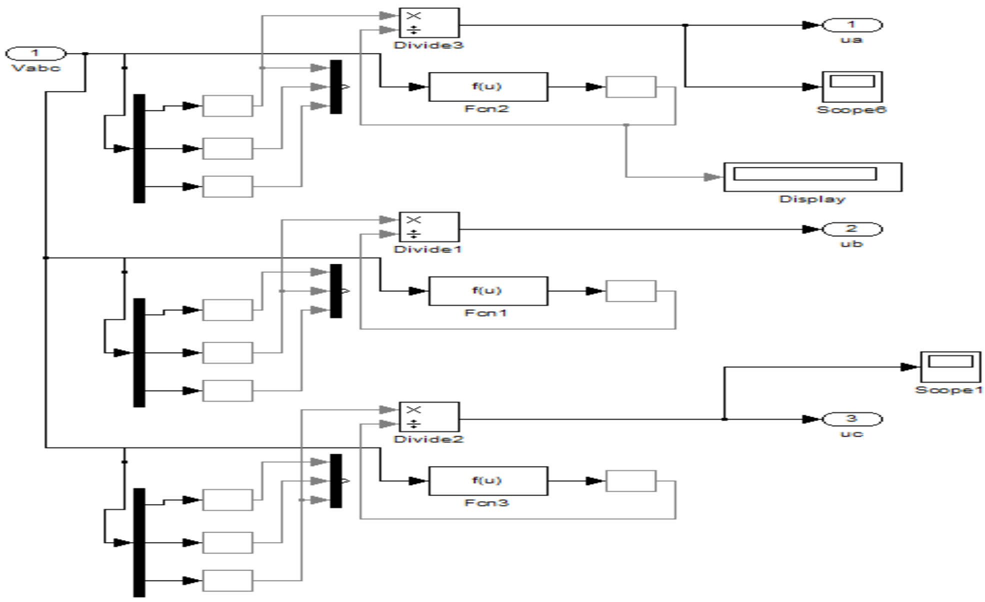


Fig. 5.12 In phase unit template calculation block

To provide a self-supporting dc bus of STATCOM, its dc bus voltage (V_{dc}) is sensed and compared with the dc reference voltage (V_{dcref}). The error voltage is processed in another PI controller. The output of the PI controller (I^*_{smd}) decides the amplitude of the active power component of the source current

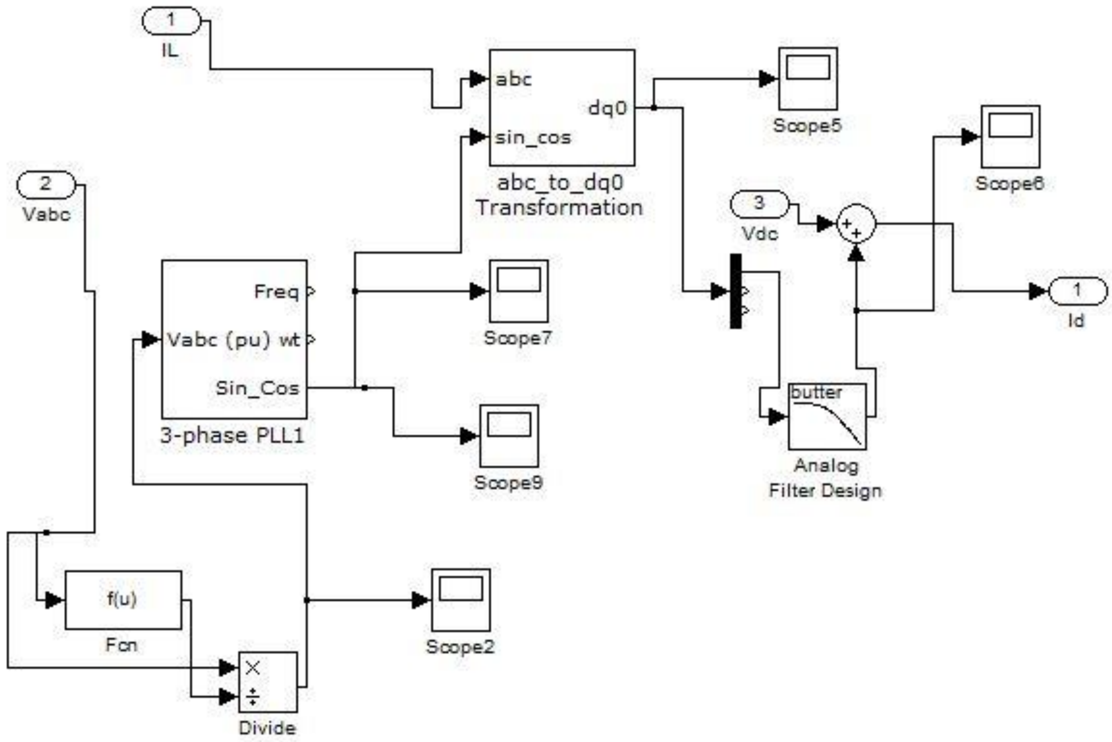


Fig. 5.13 Unit Template based Controller for reference current extraction

5.3.3.1 Results and Discussion

Unit Template based control algorithm is designed to eliminate harmonics of source current. To calculate the amount of compensation provided by DSTATCOM, total harmonic distortion (THD) of source current is determined using FFT window of MATLAB before compensation and after compensation.

5.3.3.1.1 Simulation Results

Load of 16 kVA is supplied by the supply system. Before connecting DSTATCOM, THD in source current is 24.23% as shown in Fig 5.14. After providing compensation by DSTATCOM, THD is 2.15% as shown in Fig 5.15. According to IEEE standard THD limit for distribution system is 5%. This reduction shows that unit template technique is good in terms of harmonic reduction.

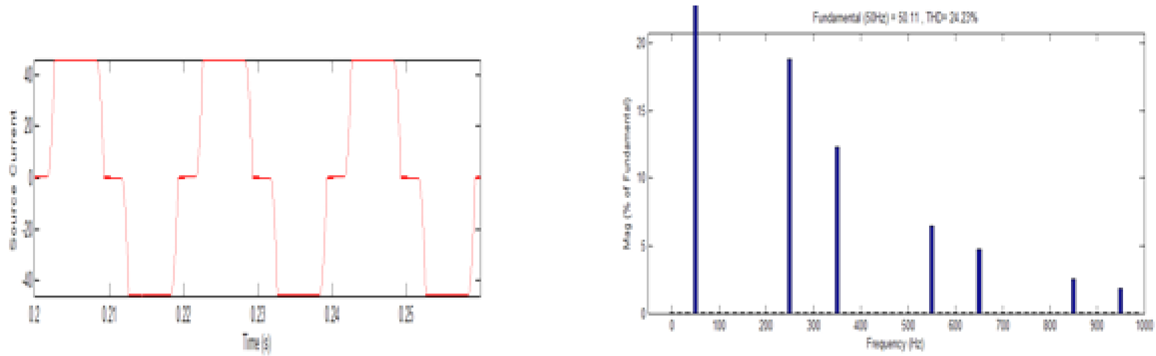


Fig 5.14 THD of source current before compensation

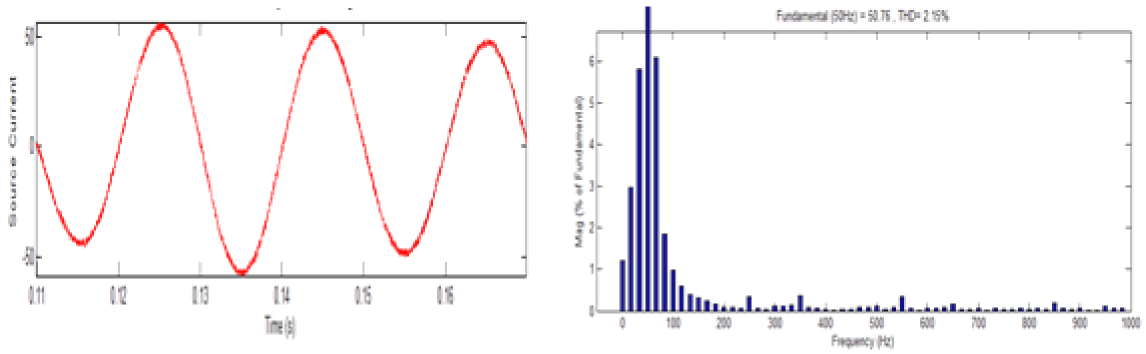


Fig 5.15 THD of source current after compensation using Unit Template based controller

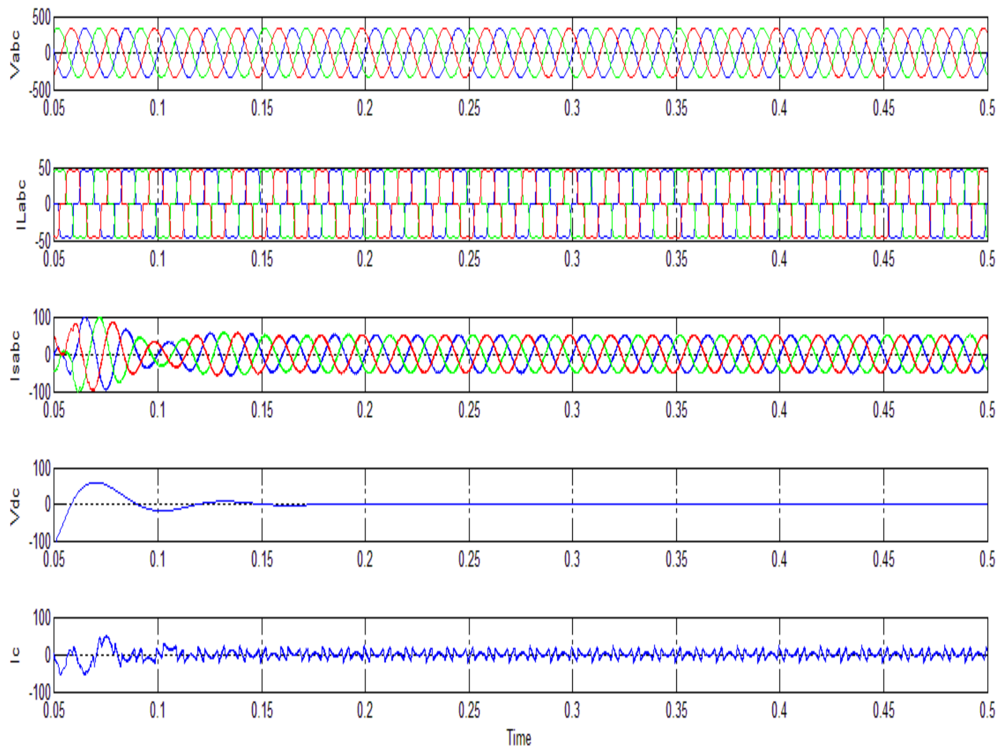
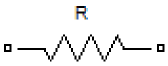
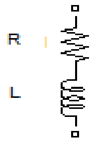
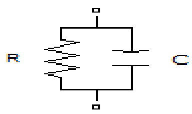
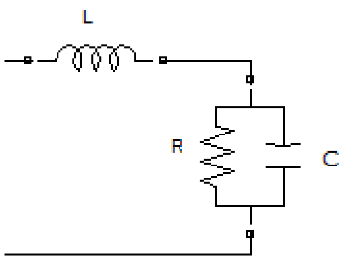


Fig 5.16 Performance of DSTATCOM with Unit Template based Controller. waveform of 3-phase line voltage (v_{abc}), 3-phase load current (i_{Labc}), 3-phase source current (i_{sabc}), DC link voltage (V_{dc}), and Compensating current (i_c).

5.3.3.1.2 THD of source current for different load using Unit template Control Algorithm

In Dstatcom based system various types of load is used to analyze the performance of algorithm on the system. In case of RC load maximum harmonics is shown by the system while the best load is RL in nonlinear loads and the Unit Template controller compensated well these harmonics

Table 5.3 THD of Source current for different load without compensation and with compensation using Unit Template Algorithm

S. NO.	TYPE OF LOAD	PARAMETERS	THD OF SOURCE CURRENT (in %) Before Compensation	THD OF SOURCE CURRENT(in %) After Compensation
1	RESISTIVE LOAD 	R = 15 Ω	25.22	3.86
2	R-L LOAD 	R=15 Ω L=100 mH	23.35	3.93
3	R-C LOAD 	R= 15 Ω C= 2000 μF	37.47	3.74
4	RLC LOAD 	R= 15 Ω C= 2000 μF L= 1 mH	34.19	3.55
		R= 15 Ω C= 2000 μF L= = 100mH	18.15	4.11
		R= 15 Ω C= 2000 μF L = 1H	26.90	4.04

5.4 Effect of Source Distortion on the system

The phase-controlled ac input of these devices may cause large rms current changes on the ac mains, which result in substantial rms voltage deviations. System harmonics voltage distortion is caused by the flow of harmonic currents through system impedance, namely inductive reactance. To see the effect harmonics of 5^{th} and 7^{th} order is introduced in Supply voltage. These values are taken according to the standard IEC 1000-3-2.IEC 1000 standard allows the voltage THD to 5.57% of fundamental and current THD to 35.33% of fundamental.

Table 5.4 Standard Values of THD

Frequency(Hz)	Voltage (pu)	Current (pu)
50	1	1
250	0.04	0.15
350	0.03	0.07
550	0.01	0.02

5.4.1 Analysis of THD without compensation

When harmonics is not introduced in the supply voltage ,THD of the current is comparatively less (24.72%) than the effect of harmonics in voltage

Here a 5% voltage harmonics is introduced by injecting 5^{th} and 7^{th} harmonics of standard value.

Table 5.5 THD of Voltage, Source Current ,Load Current without compensation

THREE PHASE AC SUPPLY WITHOUT DISTORTION			THREE PHASE AC SUPPLY WITH DISTORTION		
Total Harmonic Distortion(THD) in%			Total Harmonic Distortion(THD) in%		
Voltage	Source Current	Load Current	Voltage	Source Current	Load Current
0.00	24.72	24.72	5.00	27.72	27.72

5.4.2 Analysis of THD after compensation

Performance of all three algorithms in terms of harmonic filtering when 5% thd is introduced in source voltage.

Table 5.6 THD of Voltage, Source Current ,Load Current with compensation

S NO.	ALGORITHM	THD IN SOURCE VOLTAGE (in %)		THD OF LOAD CURRENT (in %)		THD OF SOURCE CURRENT(in %)	
		Without Source Distortion	With Source Distortion	Without Source Distortion	With Source Distortion	Without Source Distortion	With Source Distortion
1	UNIT TEMPLATE	0.00	5.00	24.23	24.23	3.47	4.23
2	IRP THEORY	0.00	5.00	23.35	23.35	6.99	8.92
3	SRF THEORY	0.00	5.00	24.30	24.30	3.93	5.43

CHAPTER 6

MAIN CONCLUSIONS AND FURTHER SCOPE OF WORK

6.1 General

In this dissertation four control algorithms are implemented for operation of DSTATCOM to eliminate harmonics in source current due to non-linear load. MATLAB simulation model are designed for all four systems and simulated results are analysed.

6.2 Main Conclusion

In this dissertation work, three control algorithms instantaneous reactive power (IRP)theory ,synchronous reference frame (SRF) theory and Unit Template based algorithm are implemented and compared for harmonic elimination, power factor correction and tracking capability to maintain DC bus voltage.With effect of sorce distortion these three algorithm are analysed.aThe three algorithm is also compared for harmonic compensation in different loading conditions. In these three algorithms, SRF algorithm has a disadvantage to produce some time lag in the system. This time delay is responsible for heavy circulating current in the system sometimes.Unit Template is very basic technique and used only for the harmonic filtering.

6.3 Further scope of work

There are various further areas where these FACTS devices (STATCOM, BESS, SSSC) will find the application. Some of the areas of application are mentioned below

(i) Power quality improvement with BESS

(ii) Damping of SSR (sub synchronous resonance) using BESS.

(iii) Enhancement in GRID stability with BESS.

(iv) Improvement of distributed generation stability using BESS

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