

Performance Comparison of VSI based DSTATCOM and ZSI based DSTATCOM in a Distribution System Network

A Dissertation

Submitted in partial fulfilment of the requirements for the award of degree of

**MASTER OF ENGINEERING
IN
POWER SYSTEMS & ELECTRIC DRIVES**



Submitted By:

Ruban Preet Kaur

Roll No- 821141009

Under the supervision of:

Mr. PARAG NIJHAWAN

Assistant Professor, EIED

ELECTRICAL AND INSTRUMENTATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

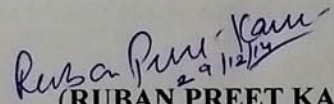
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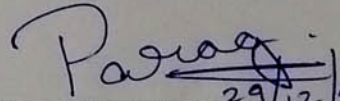
CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "Performance Comparison of VSI based DSTATCOM and ZSI based DSTATCOM in a Distribution System Network", in partial fulfilment of the requirements for the award of Master of Engineering in POWER SYSTEM AND ELECTRIC DRIVES submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala is an authentic record of my own work carried out under the supervision of **Mr. PARAG NIJHAWAN**, Assistant Professor EIED, Thapar University and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.


(RUBAN PREET KAUR)

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.



(PARAG NIJHAWAN) 29/12/2014

Assistant Professor

Electrical & Instrumentation Engg. Department,

Thapar University, Patiala

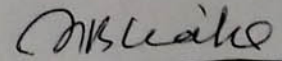
Countersigned by:


(Dr. Ravinder Agarwal)

Professor & Head

Electrical & Instrumentation Engg. Department

Thapar University, Patiala


(Dr. S. S. Bhatia)

Dean (Academic Affairs)

Thapar University, Patiala

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ABSTRACT

Power Quality problem in a system leads to various disturbances such as voltage fluctuations, transients and waveform distortions. Due to non linearity of load it leads to fluctuations in waveform. Modern industrial equipments produce distortion in load current and harmonic distortions. Present day power consumers are also aware enough regarding various Power Quality problems that lead to inconvenience. So engineers are also working in this field dedicatedly to improve the quality of power supply. One of the results of their research in this field is DSTATCOM (Distribution STATCOM) that performs various compensating functions in distribution systems.

A Distribution Static Compensator is a Voltage Source Converter based device. It is connected in parallel with the system to be compensated. This device injects compensating response at PCC into the system. Various Power Quality issues like voltage sag, swell, harmonics, power factor are compensated by this device.

In this work an attempt has been made to employ ZSI based DSTATCOM in a distribution network to improve the power quality level, further its performance has been compared with VSI based DSTATCOM in a distribution network in MATLAB/SIMULINK environment. The performance of DSTATCOM to improve THD level in source current, Power Factor Improvement and load balancing has been demonstrated in this work.

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Table 5.1: System Parameters

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LIST OF ABBREVIATIONS

ASD	Adjustable Speed Drives
BESS	Battery Energy Storage System
CPD	Custom Power Device
CSI	Current Source Inverter
DIN	Distortion Index
DVR	Dynamic Voltage Restorer
DSTATCOM	Distribution Static Compensator
ESS	Energy Storage System
FACTS	Flexible AC Transmission System
GTO	Gate Turn Off Thyristor
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IJETT	International Journal of Engineering Trends and Technology
MATLAB	Matrix Laboratory
PCC	Point of Common Coupling
PLC	Programmable Logic Controller
PQ	Power Quality
PWM	Pulse Width Modulation
SCMES	Super Conducting Magnetic Energy Systems
SME	Superconducting Magnetic Energy Storage
SMPS	Switch Mode Power Supply

SSSC	Static Synchronous Series Compensator
STATCOM	Static Compensator
SVC	Static VAR Compensator
THD	Total Harmonic Distortion
UCES	Ultra Capacitor Energy Storage
UPFC	Unified Power Flow Controller
UPQC	Unified Power Quality Conditioner
VSC	Voltage Source Converter
ZSI	Z Source Inverter

1.1 Overview

Electric energy plays an important role in the economic growth and technological progress across the globe. Electrical power is perhaps the most essential raw material used by commerce and industry today. The quality and reliability of power supplies associates intimately to the economic growth of a country. However, Power Quality disturbances create a lot of troubles in attaining a reliable and quality power supply [1]. Power Quality (PQ) problems mainly include unbalance voltage and current, flicker, harmonics and power interruption. These Power Quality problems lead to abnormal operations of facilities and tripping of protection devices. The maintenance and improvement of Power Quality is a matter of concern present days. Improved Power Quality is driving force for today's advanced society. Apart from this awareness among customers in concern of reliable and quality power supply has heightened. The term "load balancing" explains to balance unbalanced load and correct load power factor nearly unity [2]. Load compensation is very important in context of today's load. So, the FACTS devices are introduced to electrical system in order to enhance the Power Quality of the system. Types of FACTS device are DVR, UPQC, STATCOM, DSTATCOM, UPFC, SVC, SSG, TCR, TSC, TSR, SSSC and etc. STATCOM used in distribution system is termed as DSTACOM (Distribution-STACOM). D-STATCOM is a high speed and control reactive power, to provide voltage stabilization and flicker suppression.

A DSTATCOM includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt [3], capable of generating and /or absorbing reactive power. It is accompanied by the energy storage device like flywheels, SMES, capacitors. It performs the function of injecting compensating current in case system is encountered by various Power Quality problems. It is preferred device over the distribution systems due to its very fast and provides adequate reactive power compensation for the affected system. It can exchange both active and reactive power with the distribution system by varying the amplitude and phase angle of the inverter voltage with respect to the PCC voltage, if an Energy Storage System (ESS) is included into the dc bus. The addition of energy storage through an appropriate interface to the power custom device leads to a more flexible integrated controller. The ability of the DSTATCOM-ESS to supply effectively active power allows expanding its compensating actions, reducing transmission losses and enhancing the operation of the electric grid [4]. In this paper we present simulation results with DSTATCOM using ZSI and VSI in various cases for comparison of their performance.

1.2 Literature Survey

Till now rich research has been done in the filed of DSTATCOM. A brief literature survey till now is listed below.

Alka Singh, et al. [1] presented the performance of DSTATCOM for the load compensation of linear and non-linear loads in steady and dynamic conditions. In this paper DSTATCOM and BESS have been simulated using MATLAB. Performance of DSTATCOM has been analysed to regulate voltage at PCC under unbalanced load conditions. BESS performance with equal load sharing and constant current has been found to be satisfactory. According to this paper both devices has enough scope in improving Power Quality in distribution system.

Wei-Neng Chang, et al. [2] discussed the design and implementation of DSTATCOM for load compensation of unbalanced loads. In this paper new feed forward compensation scheme is derived and employed with symmetrical components method and accordingly a hardware prototype is built. Simulation results as compared to existing SVC, DSTATCOM has less space demand, higher response time and generates lower noise. This concludes that DSTATCOM will gradually replace SVC in near future.

D.Masand, et al. [3] compares the linear and non linear methods of current regulation referring DSTATCOM performance using synchronous reference frame through this paper. In this paper merits and demerits of each regulation method are stated. Here it is concluded that when the PWM with carrier technique in reference frame is implemented, fixed switching of VSC results in overshoot of about 2.5 times more as compared to hysteresis current controller. In case of non linear load the THD in fixed switching frame is far higher than that in variable switching frame. Here it is concluded that hysteresis based DSTATCOM in SRF frame is feasible for load compensation at distribution level.

M.G. Molina, et al. [4] describes the modelling and control design of DSTATCOM coupled with Ultra-Capacitor Energy Storage (UCES) for improving Power Quality of system. In this the control technique employed is instantaneous power theory based, synchronous-rotating dq reference frame. This fast response device proved to be very effective in improving quality of power. Power Quality problems like voltage sag, swell, flicker and power factor are lessened with this device.

Arvind Dhingra, et al. [5] has discussed monitoring and measuring of Power Quality issues. Various Power Quality improving devices are discussed in this paper such as DSTATCOM, DVR, SVC, UPQC etc. Here Power Quality monitoring over the internet is also discussed.

Sandeep G J S M, et al. [6] has produced the importance of active filters for the improvement of Power Quality. This paper mainly discusses about the new AF technology and different topologies for the Power Quality improvement.

P.Prasad, et al. [7] has discussed the Unified Power Quality Conditioner (UPQC) with storage device for Power Quality problems. This device combines a shunt active filter together with a series active filter in a

back to back configuration, to compensate the load current and supply voltage or to mitigate any type of fluctuations in supply and correction of power factor in distribution network. Here in this paper series inverter is controlled by using DC-DC link capacitor storage device and its working is verified by MATLAB/SIMULINK software. It's concluded here that this system can replace UPS as well.

Jose M.R. Baptista, *et al.* [8] deals in this paper with disturbances that reach electric power systems on the connection of unbalanced or non linear load. In this paper it is concluded that the waveform signals of voltage and current are very different. As a result to minimize the Power Quality problems active harmonic filters are used. This equipment is good enough, decreasing THD level.

Shalini Bajpai, *et al.* [9] proposed a scheme in this paper in which a pulse width modulation ac-ac converter along with auto transformer is used. Over the occurrence of disturbances this scheme supplies the missing voltage and helps to maintain rated voltage at terminal of critical load. Here 4 step switching technique is used that derives the ac-ac converter to realise snubber less operation. In this paper design is presented for 440V, 50 Hz system. This technique identifies and mitigates the disturbance to a desired magnitude. Simulation analysis is performed for the 27% voltage sag for 3 phase system and simulation results presents the effectiveness of device in compensation of voltage sag disturbances.

Prafull A. Desale, *et al.* [10] presents a review paper on Custom Power Devices for the improvement of Power Quality. This paper presents a comprehensive survey of these devices in distribution system to eliminate various Power Quality disturbances like voltage sag/swell, dip, flicker, lower power factor etc. according to this paper shunt connected DSTATCOM provides better Power Quality in both transmission and distribution system, UPQC can compensate both voltage and current related problems at same instant.

Vijayakumar.R., *et al.* [11] discussed here regarding Dynamic Voltage Restorer (DVR) as most efficient and effective custom device to be used in distribution system. Its main features apart from Power Quality improvement, described are low cost, fast response and small size. In this paper the design and applications of DVR are presented.

M. Anuj Gargeya, [12] proposed a PWM based control technique, that requires only voltage measurement for DSTATCOM. This paper presents the voltage regulation in parallel distribution feeders using multi converter DVR (MC-DVR). It is connected in shunt between 2 parallel feeders originating from different substations, supplying 2 non-linear loads. It has been concluded that bi-directional power flow between 2 feeders is possible i.e. in case of voltage sag in supply of one feeder can be accomplished by supplying power from another feeder.

T.Devaraju, *et al.* [13] presented a review of Power Quality enhancement Custom Power Devices. In this paper various Custom Power Devices are discussed like DSTATCOM, DVR and UPQC. A PWM base control scheme has been employed to control the VSC implemented in DSTATCOM and DVR. From simulations it has been concluded that DVR provides excellent voltage regulation capabilities.

Micheal P. Bahrman, *et al.* [14] describes the fundamental reason behind the selection of VSC technology for various projects. It's concluded in this paper that VSC may not be the most economical solution for all applications but its ease of application provides special benefits.

Mirjana Milosevic, [15] discussed 2 hysteresis current control methods (hexagon and square hysteresis based controls) of VSI.

Parag Nijhawan, *et al.* [16] states various applications of DSTATCOM for the Power Quality improvement in a distribution system with induction furnace load. In this system ample current harmonics are introduced in to the system due to induction furnace. And in this paper the behaviour of DSTATCOM is investigated to reduce the harmonics and is found to be effective enough.

P. Bapaiah, *et al.* [17] presents the compensation provided by DSTATCOM for power factor improvement. Different control schemes are available for the DSTATCOM. But it's concluded that control scheme used for it must provide complete reactive power compensation, correction of power factor and voltage regulation and the harmonics are also checked for achieving improved Power Quality levels at distribution end.

P. Venkata Kishore, *et al.* [18] deals with the Power Quality improvement of 30 bus system using DSTTACOM in this paper. Here the simulation results of 30 bus system with and without DSTATCOM are presented where the improved voltage stability and reliability and Power Quality is depicted.

Paulmathew, *et al.* [19] investigates different Dc-link voltage control strategies in 3 phase 4 wire Z-source hybrid active power filter for reactive power compensation. Here it's concluded that the proposed hybrid active power filter can compensate current harmonics components, reactive power and also leads to improvement in load power factor. This paper shows through its discussions regarding effectiveness of the proposed dc-link voltage control methods.

Suresh K, *et al.* [20] presents a detailed analysis, design of impedance network and implementation in this paper. In this control methods with the insertion of shoot through states of Z-source inverter have been studied. Results show that both buck and boost operations can be obtained in Z-source inverter by varying Modulation Index or Boost Factor.

F.Z. Peng *et al.* [21] discussed maximum boost control method and presented that it has greatest modulation index and highest voltage gain.

Miaosen Shen *et al.* [22] discussed maximum constant boost control method of ZSI and obtained maximum voltage gain at any given modulation index without producing any low frequency ripple that is related to the output frequency.

Parag Nijhawan *et al.* [23] presents the performance analysis of four control strategies like simple boost control, maximum boost control, maximum constant boost control and third harmonic injected maximum constant boost control of ZSI feeding induction furnace load. Simulation results for all methods are shown that illustrates the comparison of all four strategies of ZSI for reducing harmonic distortion in the load current with induction furnace load.

Bhim Singh, et al. [24] has introduced new control approach for capacitor supported DSTATCOM in 3 phase 4 wire distribution systems under non- ideal supply voltage conditions based on SRF theory. It has been concluded in this paper that SRF theory employed in DSTATCOM improves the performance of the system. it fulfils the objective of load balancing, harmonic current compensation, indirect current control and neutral current compensation.

1.3 Gap in Literature Survey

- Application of ZSI based DSTATCOM to show the power quality improvement in distribution system
- Comparison of performance of VSI based DSTATCOM with ZSI based DSTATCOM in distribution system for power quality improvement.

1.4 Problem Formulation

In this dissertation, it is proposed to analyse and compare the performance of VSI based DSTATCOM and ZSI based DSTATCOM in Power Quality improvement process.

Initially performance of the system without compensating device i.e. DSTATCOM is analysed. Then the performance analysis of the system is compared for the system with VSI based DSTATCOM and ZSI based DSTATCOM.

1.5 Objective of Work

- To improve the performance of distribution system using DSTATCOM.
- To analyse the simulation models of distribution system to show power quality improvement.

2.1 Power Quality

In earlier times generating and transmitting power to farther areas used to be the matter of concern. But with changing times challenges has changed to the reliability of the power delivered, as well as the quality of power supplied to various industries, commercial establishments and residences. As defined by Standard IEEE1100 'Power Quality is the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment' [5]. Power Quality these days have very serious affects for the power consumers, utilities and electrical equipment manufacturers.

2.2 Requirement of Power Quality

These day's electrical and electronic equipments are more prone to malfunction or even failure when faced one or more Power Quality problems. Due to intolerance of various equipments towards Power Quality problems has lead to increased importance of Power Quality improvement.

Concern regarding Power Quality is increasing also due to:

- a. Increased focus on improved overall efficiency that lead to growth in device applications like capacitors for power factor correction to reduce losses and adjustable speed motor drives. This lead to increased harmonic levels in power systems.
- b. Nowadays network contains interconnections i.e. integrated networks. So failure to even single equipment is a relevant issue.
- c. New and improvised load equipments with new control techniques are more sensitive to Power Quality variations than the equipments used earlier.
- d. Consumers are becoming more aware regarding Power Quality issues and are looking forward to get improved power delivery.

2.3 Various Power Quality Problems

Ideal power supply would always have a steady magnitude and a sinusoidal wave shape without any disruption. But any condition that cause change in this ideal situation is known as disturbance. Due to inherent non- linearity of power electronic devices, they draw harmonics and reactive power from the supply. In multiple phase systems such as 3 phase system they could also cause unbalance and draw excess neutral currents [6]. Due to these reactive power loads, unbalance, harmonics and excess neutral currents it leads to low efficiency of system and poor power factor.

Apart from this, power system also confronts transients like voltage sags, swells, and flickers etc [7]. These transient problems impact voltage at distribution level.

Various Power Quality Problems are as listed below-

- Voltage swell / over voltage
- Voltage dip / under voltage
- Harmonic distortion in Voltage and current signals
- Voltage and current transients
- Voltage flicker
- Power frequency variation
- Electrical noise
- Interruptions

2.3.1 Voltage Swell

The instantaneous increase in rms voltage supplied by mains beyond normal tolerance for the duration more than one cycle up to few seconds as shown in Fig 2.1.

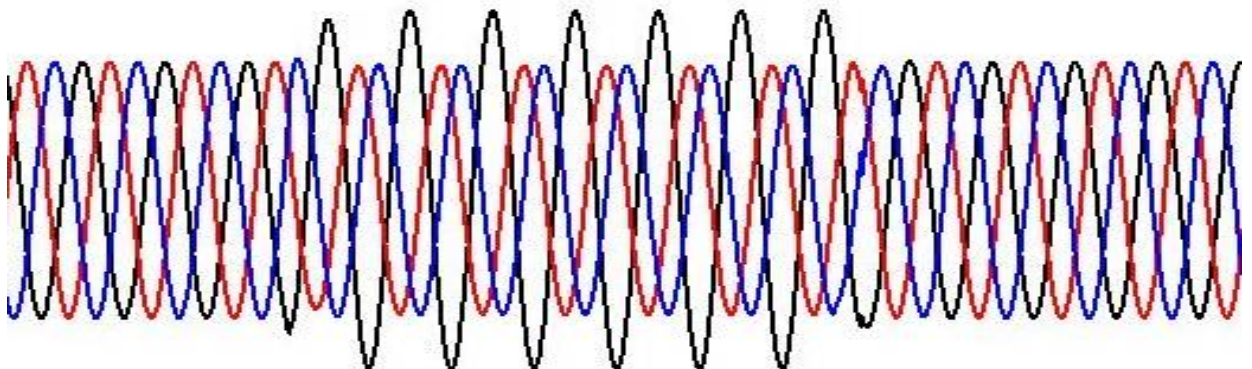


Fig 2.1: Voltage Swell

2.3.2 Voltage Sag or dip

A brief drop in the rms voltage, about 10- 90 % of nominal line voltage. It lasts for 0.5 cycles to 1 minute as shown in Fig 2.2.

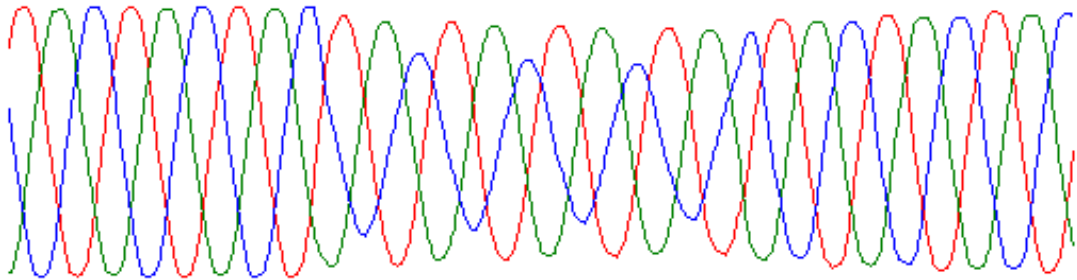


Fig 2.2: Voltage Sag

2.3.3 Harmonic Distortions

These are Sinusoidal voltages or currents with frequencies that are integer multiples of the frequency at which the system is designed to operate i.e. termed as fundamental frequency up to 50-60 Hz as shown in Fig 2.3. These harmonics rise due to non linear characteristics of devices and loads connected to the system.

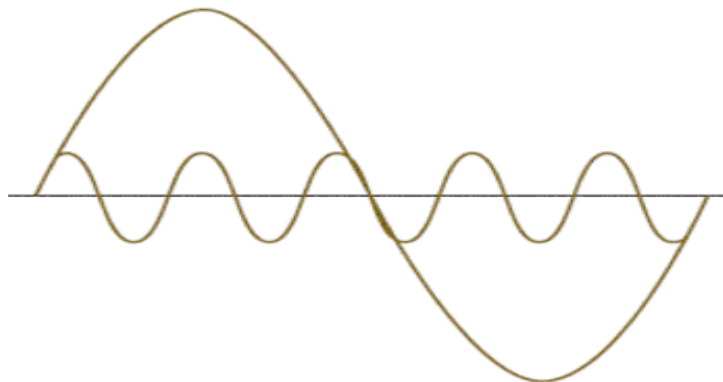


Fig 2.3: Harmonic Distortions

The waveform represents the sum of different sine-waves with different magnitude and phase, with frequencies that are multiples of power system frequency. Harmonics are resultant of electrical machines that work beyond knee of the magnetization curve, DC brush motors, arc furnaces, rectifiers, welding machines, and non-linear loads that include power electronics equipment including SMPS, data processing equipment etc. Harmonic distortion levels are depicted by calculating total harmonic distortion (THD) that measures the overall harmonic spectrum with magnitudes and phase angles of each single harmonic component. THD is presented with the square-root of sum of the squares of each harmonic component. V_{THD} is given by

$$V_{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \quad (2.1)$$

V_1 = rms magnitude of fundamental component,

V_n = rms magnitude of component n,

$n=2, \dots, \infty$

There is a problem with this approach i.e. THD equates to infinity in case fundamental component is absent.

In order to avoid this ambiguity an alternate definition is used that represents harmonic distortion. This is known as distortion index- DIN and given by-

$$DIN = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{\sqrt{\sum_{n=1}^{\infty} V_n^2}} \quad (2.2)$$

DIN and THD are related to each other by

$$DIN = \frac{THD}{\sqrt{1+THD^2}} \quad (2.3)$$

$$THD = \frac{DIN}{\sqrt{1-DIN^2}} \quad (2.4)$$

2.3.4 Transients

Consists of 2 types-

2.3.4.1 Impulsive Transients- it is a brief single directional variation in current, voltage or both on a line. Switching of inductive loads or switching in distribution system, lightning strikes are most common causes of impulsive transients. Impulsive Transient response is shown in Fig 2.4.

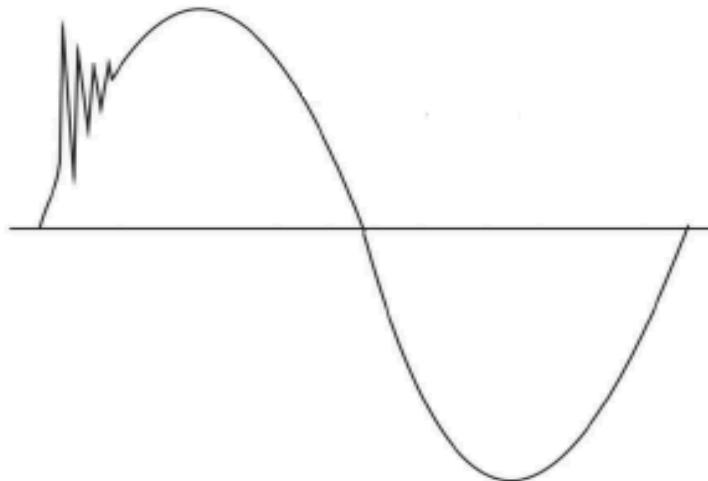


Fig 2.4: Impulsive Transients

2.3.4.2 Oscillatory Transients- it is a bidirectional variation in voltage, current or both on a line. Main reason behind these is power factor correction capacitors or transformer Ferro resonance. Oscillatory Transient response is shown in Fig 2.5 below.

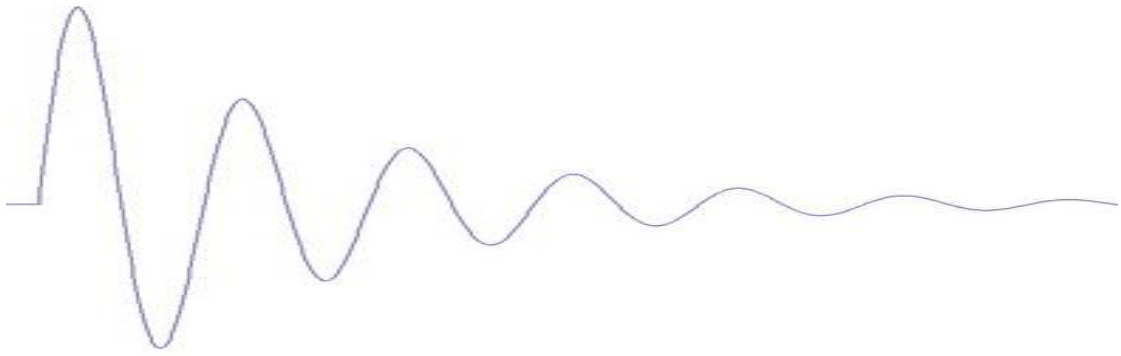


Fig 2.5: Oscillatory Transients

2.3.5 Voltage Flicker

In this voltage exhibits alterations in magnitude or/and phase angle in a time scale of seconds or less.

2.3.6 Power Frequency Variation

Any deviation of the fundamental frequency (60-Hz) is power frequency deviation as shown below in Fig 2.6.

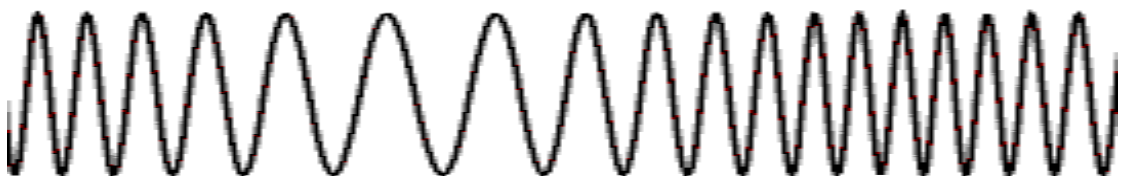


Fig 2.6: Frequency Variations

2.3.7 Electrical Noise

These are unwanted electrical signals with frequency lower than 200 KHz superimposed over the power system voltage or current [8]. These noises can be due to power electronic devices, arcing equipments, loads equipped with rectifiers, control circuits and switching power supplies. The noise response is shown as below in Fig 2.7.



Fig 2.7: Noise

2.3.8 Interruption

It is defined as a reduction in line voltage or current to less than 10 % of the nominal value, less than 60 sec in length. Interruption is of two types-

2.3.8.1 Very Short Interruption

It is defined as total interruption of electrical supply for duration from few milliseconds to one or two seconds. Reason behind this is failure of insulation, lightning, faults in system, failure of equipment and insulator flashover. The short interruption results in loss of information and malfunction of data processing equipment, tripping of protection devices and failure of sensitive equipment. Fig 2.8 shows the Short Interruption response.

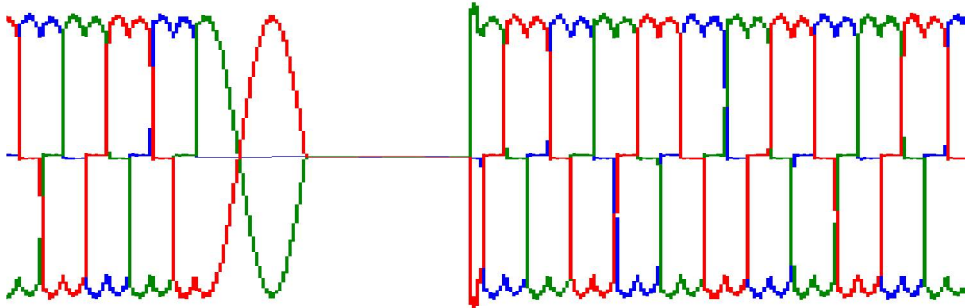


Fig 2.8: Short Interruption

2.3.8.2 Long Interruptions

These are defined as loss of utility power for more than 2 minutes due to major local area or regional electrical events. These are caused due to equipment failure in the power system network, objects and storms striking poles or lines [9], power system faults and control malfunctioning. The results of long interruptions as shown in Fig 2.9 are failure of all equipment.



Fig 2.9: Long Interruptions

2.4 Poor Power Quality leads to:-

Load device may draw non-sinusoidal current from the source on distortion of power supply. This also leads to various technical problems like extra heating, malfunctions, before time maturation of the devices etc., to the customer's devices at his installation. The current with non- sinusoidal waveform also causes extra losses and other problems to various components.

Moreover, poor PQ also has financial consequences to the customers.

Apart from above listed problems are also included-

1. Unexpected power supply failures
2. Equipment overheating leading reduction in its lifetime.
3. Interferences in electronic communications system.
4. Equipment failure or malfunctioning.
5. Increase of system losses.
6. Damage to sensitive equipment.

2.5 Reasons behind poor Power Quality

Recent equipments with semiconductor devices introduces harmonic burden into the system. In addition utility switching and fault clearing give rise to disturbances that lead to affect on quality of delivered power.

1. Reactive power, as it overburdens supply system.
2. Harmonic pollution, as it leads to over stress on the networks and reduces equipment efficiency,
3. Load imbalance,
4. In office building applications, the unbalanced loads may result in excessive voltage imbalance resulting in burden on other loads connected to the same network, and leading to an increase in neutral current and neutral to earth voltage builds up,
5. Fast variations in voltage results in flicker.

Other primary sources of Power Quality Problems-

- a. Power Electronic Devices
- b. IT and Office Equipments

- c. Arcing Devices
- d. Load Switching
- e. Large Motor Starting
- f. Embedded Generation
- g. Radiations and Cables
- h. Storm and Environment Related Causes etc.

2.6 Custom Power

2.6.1 Introduction

In order to improve the performance of the distribution system the concept of Custom Power Devices was introduced. Custom Power Devices based on power electronic controllers are used in distribution network to supply reliable and high quality power [10] to consumers just like the FACTS devices are used for transmission systems. Custom Power Devices have taken place at very fast pace due to rise in demand and speedy development. A custom power specification includes provision for:-

1. Tight Voltage regulation along with short duration sags or swells,
2. Low harmonic Voltages,
3. No power interruption,
4. Handling of fluctuating and non-linear loads without effect on terminal voltage.

2.6.2 Need of Custom Power

These days' electric power systems are facing immense stress and instability along with out of control power flows and increased losses. Increased gap between generation and demand, modified trends and limitations over the construction of additional lines are the main reason behind this. Electrical power is the requirement of each and every industry. In modernised industries, load equipments use modified electronic controllers that are sensitive to poor voltage quality and will close down if the supply voltage is lowered and may malfunction in other ways if harmonic distortion in the supply voltage is beyond limit.

The distributed use of electronic equipment, such as adjustable speed drives (ASD), electronic fluorescent lamp ballasts, arc furnaces, IT equipments and programmable logic controllers (PLC) have drastically modified the nature of electric loads. These loads are victimised with the Power Quality problems. Due to the non-linear nature of loads, they introduce disruptions in the voltage waveform. The over sensitivity of various processes including industrial, services and even residential to PQ problems affects the accessibility of electric power with quality, this is a crucial factor for competitiveness in every

sector. Industries with continuous processes and IT applications are vital. Over disruptions, huge financial losses are faced accompanying productivity losses.

There are loads with immense sensitivity and require disruption free and quality power else the loads are effected by Power Quality problems for instance voltage sags can affect sensitive loads.

There are standards for the current and voltage harmonics based on THD. Specifically, the voltage THD should be below 5% as per IEEE-519 standards. The requirement of compensating equipment to improve Power Quality and meet the specific standard is being a matter of concern. It is very important to provide compensation for reactive power to improve power factor or regulate voltage.

2.7 Custom Power Devices

Various schemes regarding compensation of load are introduced.

These schemes compensate the effect of imbalance and distortion in current and also rectify the power factor at the load bus. The FACTS devices provide steady, rapid and reliable control across the transmission parameters, like voltage, line impedance and phase angle between the sending and receiving end. On contrary the custom power is Applicable for low voltage distribution, melioration of poor quality and reliability of supply affects the sensitive loads.

There are various Custom Power Devices. These devices include Surge Arrester, Solid State Transfer Switch, Active Power Filter, Static Electronic Tap Changer, Super Conducting Magnetic Energy Systems (SCMES), and distribution series capacitor, Solid State Fault Current Limiter, Static Var Compensator (SVC), Distribution Static Compensator, Dynamic Voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC) [11]. Categorisation of Custom Power Devices is grounded on their controllers working on power electronic devices. There is further categorisation of these controllers as network reconfiguration devices also called switchgear devices, that consists of the solid state or current limiting, current transferring, and current breaking components and other type is the compensating type devices that are used for active filtering, correction of power factor, balancing load, and voltage regulation. They are connected in shunt or in series or both. These are designed to modify or improve the quality of power at the point of installation of the power distribution system. They are not mainly contrived to enhance the Power Quality of the entire system. The classification of CPDs is given in following sections.

2.7.1 Distribution STATCOM (DSTATCOM)

A DSTATCOM is a compensating device that operates with VSC that is connected in parallel with the distribution system to compensate reactive power. In order to compensate irrelevant components of current DSTATCOM injects compensated current at the point of common coupling. In distribution system the power

exchange between this device and the AC system is primarily reactive. The VSC converts the DC voltage across the storage device into a set of three-phase ac output voltages [12]. Mentioned voltages are in phase and coupled with the AC system through the coupling transformer reactance. Applicable adjustment of the phase and magnitude of the DSTATCOM output voltages permits effective control of active and reactive power exchanges between the DSTATCOM and the AC system. Fig 2.10 below shows the DSTATCOM.

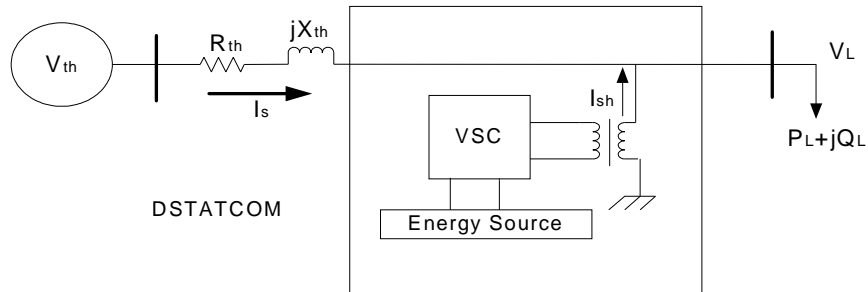


Fig 2.10: DSTATCOM

The Voltage Source Converter connected in parallel with the system offers three different functions:

- 1) Elimination of harmonics in source current;
- 2) Regulation of Voltage and reactive power compensation;
- 3) Power factor correction [13].

2.7.2 Dynamic Voltage Restorer (DVR)

The DVR is an effective controller that is generally applied for voltage sags mitigation at the point of connection. The DVR resembles in terms of blocks used the DSTATCOM, but here the coupling transformer is connected in series with the ac system. The primary function of DVR is compensation for reactive power, voltage regulation; voltage sags and swells compensation and imbalanced voltage compensation. It operates as harmonic isolator in order to avoid harmonics travelling in the source voltage that reaches load and also the voltage balancing and regulation. Fig 2.11 illustrates the DVR device.

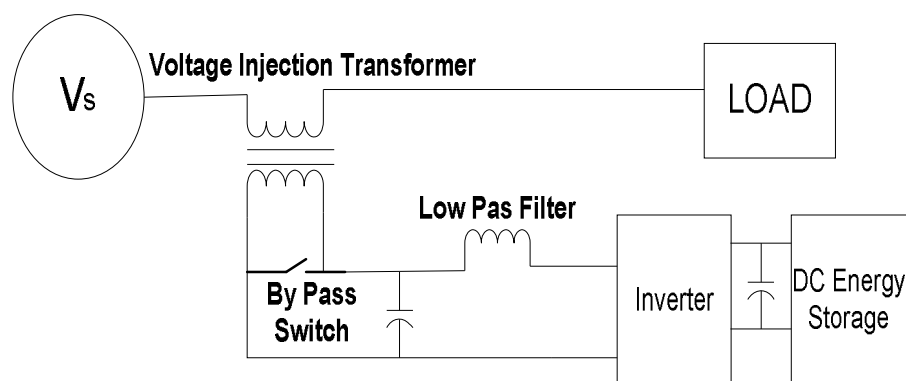


Fig 2.11: DVR

2.7.3 Unified Power Quality Conditioner (UPQC)

A unified Power Quality conditioner (UPQC) permits the mitigation of voltage and current disturbances that are potential danger for sensitive electrical loads while compensating the reactive power. UPQC comprises of combined series and shunt active power filters for simultaneous mitigation of voltage and current disturbances and reactive power. Refer fig 2.12 below for UPQC device.

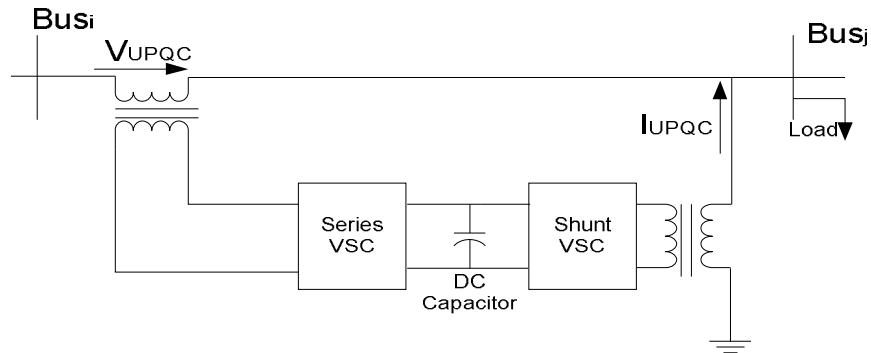


Fig 2.12: UPQC

DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

3.1 Introduction

DSTATCOM is one of the Custom Power Devices used in distribution systems, it is normally shunt colligated solid state device, in order to offer regulation for disturbances at load side. It is actually a STATCOM (static compensator), a member of a FACTS devices that is used in transmission systems. When this STATCOM is used for distribution system it is known as DSTATCOM (Distribution STATCOM). DSTATCOM is employed at the distribution level for improving power factor and regulating voltage.

Fig 3.1 demonstrates line diagram of DSTATCOM.

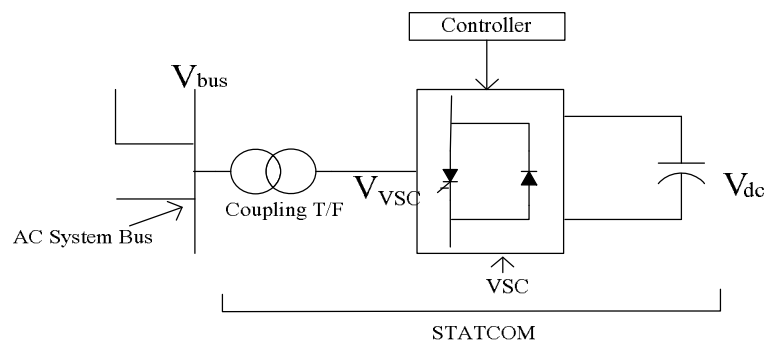


Fig 3.1: DSTATCOM

DSTATCOM is power electronics technology based VSC which is itself a versatile device which counterbalances the reactive power in ac systems. The reactive power compensation is attained through regulation of a VSC behind leakage impedance of a transformer. It analyses the waveform with reference to a reference ac signal and therefore, it provides nearly the accurate amount of leading or lagging reactive compensation to reduce fluctuations in voltage.

It is also termed as a shunt active filter that mitigates Voltage sags and swells and brings down total harmonic distortion level and also compensates for unbalance or distortions in the current at source.

DSTATCOM is colligated to the system at PCC (point of common coupling) in order to deliver current to the coupled system at the instant of connection of unbalanced or non-linear load. The positioning of DSTATCOM is in shunt to the distribution system. It is a device with lower capital cost, better dynamics, and absence of inertia, lower operating and maintenance cost.

3.2 Basic Elements of DSTATCOM

The basic configuration of DSTATCOM consists of:

- Voltage Source Converter
- L-C Passive Filter
- Coupling Transformer
- Control Block
- Energy Storage Device

Fig 3.2 demonstrates different components of DSTATCOM as shown below

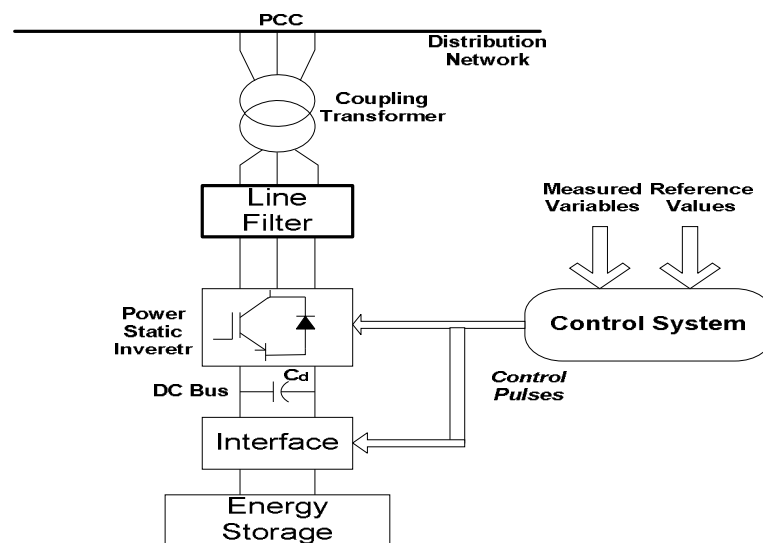


Fig 3.2: Components of DSTATCOM

3.2.1 Voltage Source Converter

A voltage-source converter (VSC) according to the compensation required offers the regulated output voltage in terms of magnitude and phase angle to result in either leading or lagging reactive current. It uses semiconductor technology to perform its operation. It helps in conversion of DC voltage stored in storage device to 3 phase AC output.

Features of VSC-based transmission [14]:

- Independent control of reactive and active power
- Reactive control independent of other terminal(s)
- Simpler interface with ac system
- Provides continuous ac voltage regulation
- Operation in extremely weak systems

- No commutation failures
- No polarity reversal needed to reverse power
- Variable frequency

3.2.2 L-C Passive Filter

The LC filter helps in suppressing harmonics and also couples inverter output impedance to that of inverter in order to partake current. The choice of LC filter is established on the grounds of the character of the system and the anticipated harmonics.

3.2.3 Coupling Transformer

Coupling transformer is the medium to couple resultant voltage of VSC to the AC system. This purpose is served by the coupling transformer reactance.

3.2.4 Control Block

The Control block performs the function of recognising Power Quality problems like sags and swells in voltage due to load disturbance or fault and compensate for those problems by generating trigger pulses and terminating triggers when the disturbance instant has ended. These trigger pulses are fed to power electronics based PWM inverter. Various control theories and algorithms are the basis of control blocks designing. The main objective of the control scheme is to sustain voltage at constant magnitude level at the instant whenever a sensitive load is connected that leads to system disturbances. Control technique measures the voltage at the point of common coupling that is to be compensated as per the requirement. The switching pulses for the inverter are derived from the PWM hysteresis control technique. The input to the controller consists of an error signal obtained from the comparison of terminal voltage and reference voltage. Such error is processed by a PI controller the output is the angle δ , which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

3.2.4.1 Basic Hysteresis Controller

Among various PWM techniques the hysteresis current controller is more used due to its simple implementation. It does not need any information regarding any load parameters. Its implementation is entirely based on deriving of switching signals from the fixed tolerance band and current error comparison [15]. In this the actual phase current is compared with the predefined tolerance band. In this the switching frequency can be varied depending upon the load conditions leading to inverter operations as irregular.

3.2.4.2 Design of Hysteresis Controller

It is for the track down of reference current. Instantaneous source current and reference current are compared within the small hysteresis band and the resultant error signal is 1-5% of the current level. Here the logic used is as

$$I_{Sa} < i_{Sa}^* - h_b$$

For better track down of source currents a narrow hysteresis band is preferred with condition of higher switching frequency. Fig 3.3 shows Hysteresis Controller as below.

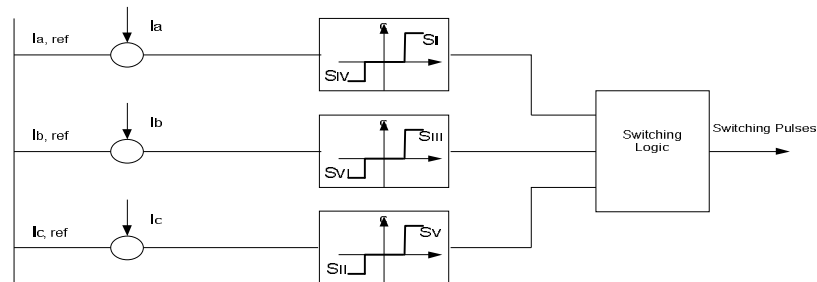


Fig 3.3: Hysteresis Controller

3.2.5 Energy Storage Device

Energy storage units like flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors store energy [16]. DC source and the DC capacitor is the general device that stores reactive power. It is plugged in parallel to the system and carries the ripple current of the converter. A battery is separately employed for the charging of DC capacitor or converter charges itself.

The energy demand by the VSC for the voltage generation to be injected in the system is met by the help of storage devices.

3.3 Main features of DSTATCOM

- Power factor correction.
- Elimination of harmonics present in source current.
- Regulation and compensation of voltage and reactive power respectively.

3.4 Basic Principle of DSTATCOM

A DSTATCOM consists of a switching device such as GTO or IGBT along with storage device like capacitor, flywheel etc. and a controller to inject the controlled switching pulses for the semiconductor device and the whole system is connected to an AC system through a coupling transformer. Basic operating principle of a DSTATCOM is resembles to that of synchronous machine. As synchronous machine will provide lagging current when under excited and leading current when over excited. Similarly, DSTATCOM generates and absorbs reactive power and interchange real power in case external DC source is provided [17].

The DSTATCOM is linked to the power networks at a PCC, where the voltage quality problem is an issue [18]. All the requisite voltages and currents are measured and are fed to the controller to compare with the reference values. Then the feedback is performed by the controller and outputs a set of switching pulses to drive the main semiconductor switches of the power converter.

VSC based on IGBT converts the DC voltage from the storage device into a set of three-phase ac voltages. These voltages are in phase and coupled with the AC system through the reactance of the coupling transformer. Possible alterations of the magnitude and phase of the DSTATCOM output voltages permits effective control of active and reactive power exchanges between the DSTATCOM and the main bus system.

3.4.1 Exchange of Reactive Power

Amplitude regulation of the DSTATCOM output voltage controls the reactive power exchange of the DSTATCOM with the AC system. The reactive power supplied by the DSTATCOM is given by-

$$Q = \frac{(V_i - V_s) * V_s}{X} \quad (3.1)$$

Where,

Q is the reactive power.

V_i is the magnitude of DSTATCOM output voltage.

V_s is the magnitude of system voltage.

X is the equivalent impedance between DSTATCOM and the system.

Power exchange within DSTATCOM and AC system is given by:-

Case I: $V_i = V_s$,

The reactive current is zero and the DSTATCOM does not Generate /absorb reactive power.

Case II: $V_i > V_s$, (capacitive mode)

The lagging current flows through the transformer reactance from the DSTATCOM to the AC system.

Case III: $V_i < V_s$, (inductive mode)

Then the leading current flows from the AC system to the DSTATCOM,

3.4.2 Exchange of Active Power

There is a requirement of a DC capacitor to provide real power to the switching devices used in the DSTATCOM. When direct voltage control is required, real power exchange is demanded by an AC system in order to maintain capacitor voltage constant. In case of distribution system with very low voltage or faults, external DC source is provided in DSTATCOM to regulate voltage when there is a real power exchange with the AC system. If the system voltage lags the VSC voltage then real power from the DC source will be injected to the AC system in order to regulate system voltage or to maintain constant capacitor voltage.

3.5 Z-Source inverter (ZSI)

Z-source converter is a unique x-shaped impedance network also known as Z-source impedance network that connects the power source to the converter main circuit [19]. This inverter has unique features in terms of voltage (both buck & boost) compared with the already available inverters. A two port network that consists of a split-inductor and capacitors that are connected in X shape is applied to provide an impedance source (Z-source) coupling the inverter to the dc source, or another converter. The DC source/load can be either a voltage or a current source/load [20]. Circuit diagram of ZSI is shown below in Fig 3.4.

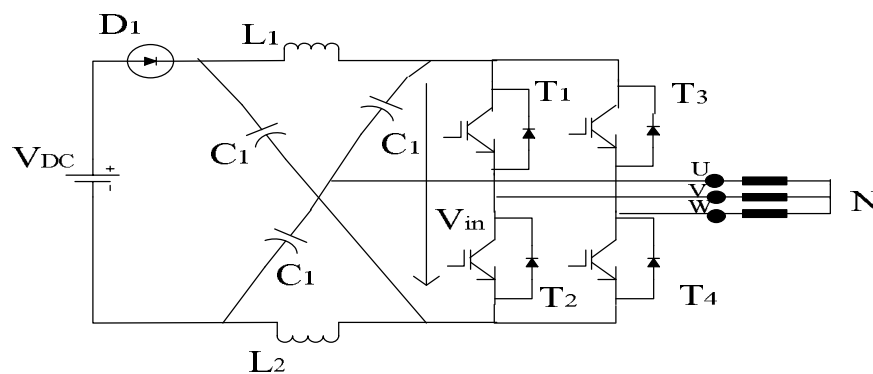


Fig 3.4: ZSI

The advantages of Z-source inverter are listed as follows,

The source can be either a voltage source or a current source. The DC source of a ZSI can either be a battery, a diode rectifier or a thyristor converter, a fuel cell stack or a combination of these.

- The main circuit of a ZSI can either be the traditional VSI or the traditional CSI.

- Works as a buck-boost inverter.
- The load of a ZSC can either be inductive or capacitive or another Z-Source network.

3.5.1 Control Techniques for Z- Source Inverter

There are several PWM based control methods for Z Source Inverter. Below are listed two control techniques as:

1. Simple Boost Control Method.
2. Maximum Constant Boost Control.
3. Maximum Boost Control Method.

3.5.1.1 Simple Boost Control Method-:

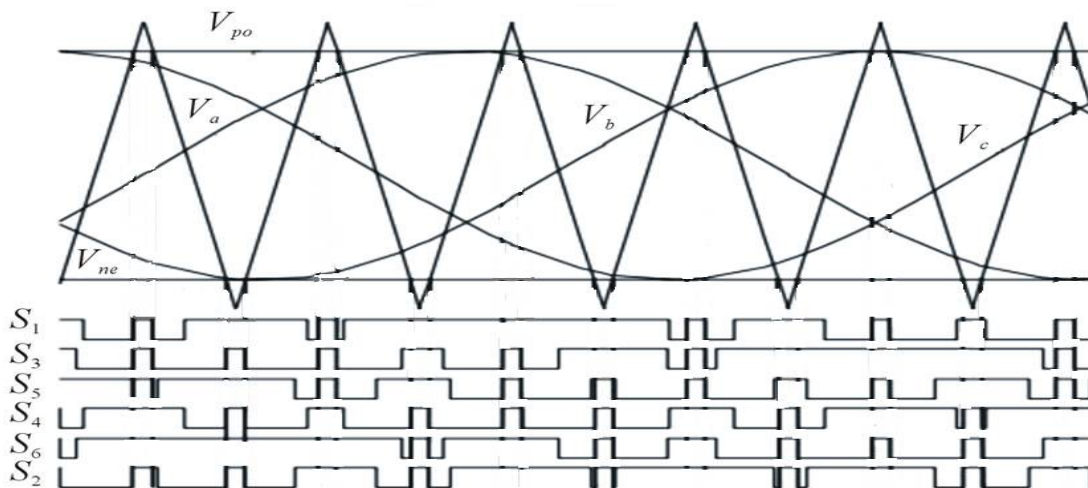


Fig 3.5: Simple Boost Control waveform

Simple Boost Method is one of the easiest methods to be utilized. In this there are two straight lines envelope equal to or greater than the maximum value of the three phase references to control shoot-through duty ratio in a conventional sinusoidal PWM.

Carrier triangular wave is more than the upper shoot-through envelope V_p or lower than bottom shoot-through envelope V_n , inverter is switched to a shoot-through state as in Fig 3.5.

This method produces high voltage stress across the switches as the max shoot-through duty ratio is extended to $(1-M)$. As modulation becomes equal to one, shoot-through duty ratio becomes zero.

Total switching period= T;

Zero state time period = T_o ,

Shoot-through duty ration = D_o

Duty ratio and Modulation index:

$$D_o = 1 - M; \quad (3.2)$$

$$G = MB = \frac{M}{1 - 2D_o} \quad (3.3)$$

$$G = \frac{M}{1 - 2D_o} = \frac{M}{1 - 2(1 - M)} = \frac{M}{2M - 1} \quad (3.4)$$

$$V_{out} = \frac{MV_o}{2} \quad (3.5)$$

Voltage stress across the inverter is given by:

$$V_{inv} = BV_o \quad (3.6)$$

$$B = 2G - 1 \quad (3.7)$$

$$V_{inv} = (2G - 1)V_o = V_o / (2M - 1) \quad (3.8)$$

3.5.1.2 Maximum Boost Control Method:-

In this method there are 6 active states that remain at same state and all zero states get switched into shoot through states [21]. For any value of Modulation Index the maximum value of T_o and B are achieved without any distortion or disturbance in waveform at output. Circuit gets into shoot-through state at the moment when triangular carrier wave is either smaller or more than the maximum curve. Shoot through state go through iterations every $\pi/3$.

Shoot-through duty ratio over one switching cycle is illustrated as below in particular interval:

$$\frac{T_o}{T} = \frac{2 - (M \sin \theta - M \sin(\theta - \frac{2\pi}{3}))}{2} \quad (3.9)$$

Average Shoot-through duty ratio is required to calculate voltage gain, Average shoot-through ratio is as below:

$$\begin{aligned} \frac{T_o}{T} &= \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \frac{2 - M \sin \theta - M \sin(\theta - \frac{2\pi}{3})}{2} dV \\ &= \frac{2 - M3\sqrt{3}}{2\pi} \end{aligned} \quad (3.10)$$

Boost factor is given by:

$$B = \frac{1}{1-2\frac{T_0}{T}} \quad (3.11)$$

The voltage gain is calculated through Modulation Index M:

$$\frac{V_{ac}}{V_o/2} = MB = \frac{\pi M}{3\sqrt{3} M - \pi} \quad (3.12)$$

Maximum value of modulation index applicable for particular voltage gain is:

$$M = \frac{\pi G}{3\sqrt{3} G - \pi} \quad (3.13)$$

Voltage stress becomes:

$$V_S = BV_o = \frac{3\sqrt{3}G - \pi}{\pi} V_o \quad (3.14)$$

3.5.1.3 Maximum Constant Boost Control:-

In this method it eliminates the low frequency ripples present in inductor current by keeping shoot through duty cycle constant. A greater voltage boost for any given modulation index is also desired to reduce the voltage stress across the switches [22]. It is most suitable for high output frequency only. This method comprises of five modulation curves out of which three reference signals are, V_a , V_b , and V_c , and two shoot-through envelope signals, V_p and V_n . When the carrier triangle wave is more than the upper shoot-through envelope, V_p , or lesser than the lower shoot-through envelope, V_n , the inverter is turned to a shoot-through zero state as shown in Fig 3.5. In between, the inverter switches in the same way as in traditional carrier-based PWM control.

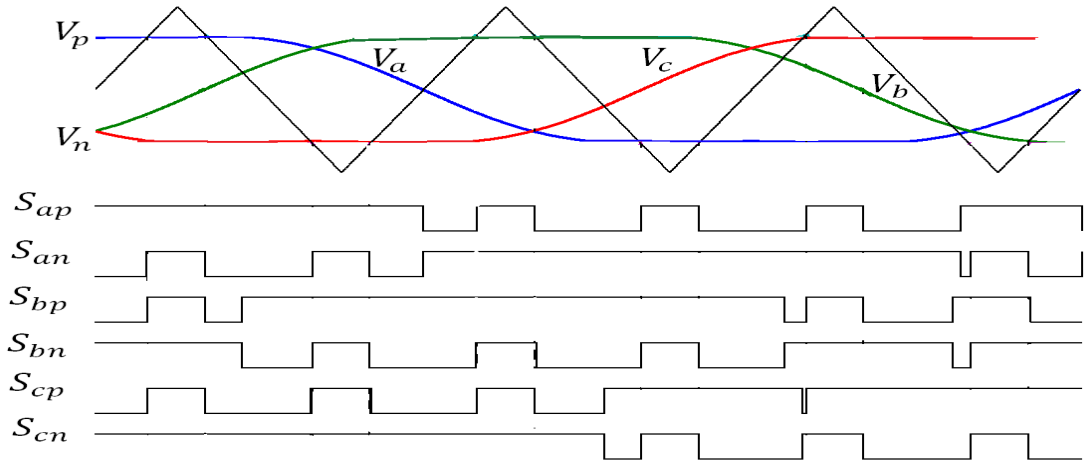


Fig 3.6: Maximum Constant Boost Control waveform

Boost factor is determined by the shoot-through duty cycle as in Eq (3.11)

The shoot-through duty cycle must be kept the same in order to maintain a constant boost.

The main point is to get the maximum B keeping it simultaneously constant all the time [23]. The upper and lower envelope curves are periodical and are three times the frequency at output. There are two half-periods for both curves in a cycle.

In the Fig 3.5 the upper and lower envelop curves are given by the equations

$$V_{p1} = \sqrt{3}M + \sin(\theta - 2\pi) M \quad 0 < \theta < \frac{\pi}{3} \quad (3.15)$$

$$V_{p1} = \sin\left(\theta - \frac{2\pi}{3}\right) M \quad 0 < \theta < \frac{\pi}{3} \quad (3.16)$$

When curves meet at interval $(\frac{\pi}{3}, 2\pi/3)$ presented by the equation

$$V_{p2} = \sin(\theta) M \quad \frac{\pi}{3} < \theta < 2\pi/3 \quad (3.17)$$

$$V_{n2} = \sin(\theta) M - \sqrt{3}M \quad \frac{\pi}{3} < \theta < 2\pi/3 \quad (3.18)$$

Distance between the curves is $\sqrt{3} M$. as this distance is constant so the shoot-through duty ratio is constant and expressed as:

$$\frac{T_o}{T} = \frac{2 - \sqrt{3}M}{2} = 1 - \frac{\sqrt{3}M}{2} \quad (3.19)$$

Voltage Gain is given as:

$$G = MB = \frac{M}{\sqrt{3M-1}} \quad (3.20)$$

$$M = \frac{G}{\sqrt{3G-1}} \quad (3.21)$$

Voltage Across the device is :

$$V_s = BV_{dc} = (\sqrt{3}G - 1)V_{dc} \quad (3.22)$$

DSTATCOM with VSI is used for compensation of Power Quality problems as in Fig 4.2

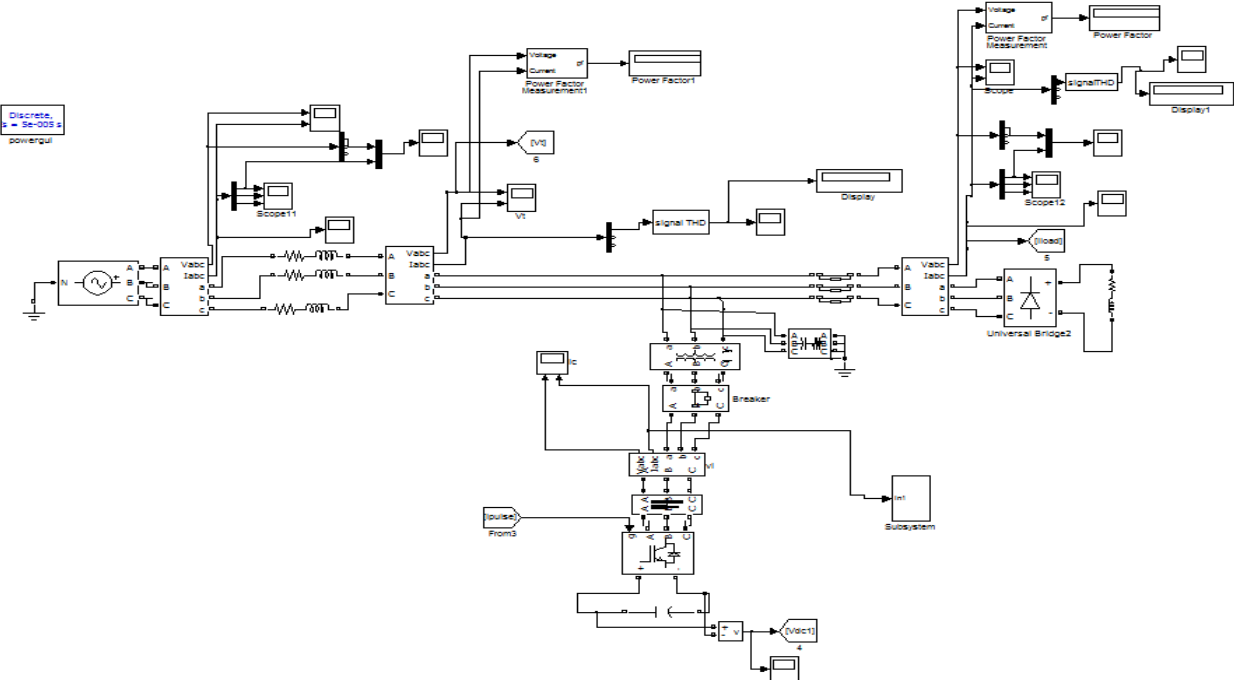


Fig 4.2: SIMULINK Model of System Compensated with DSTATCOM using VSI

DSTATCOM with VSI is used for compensation of Power Quality problems as in Fig 4.3

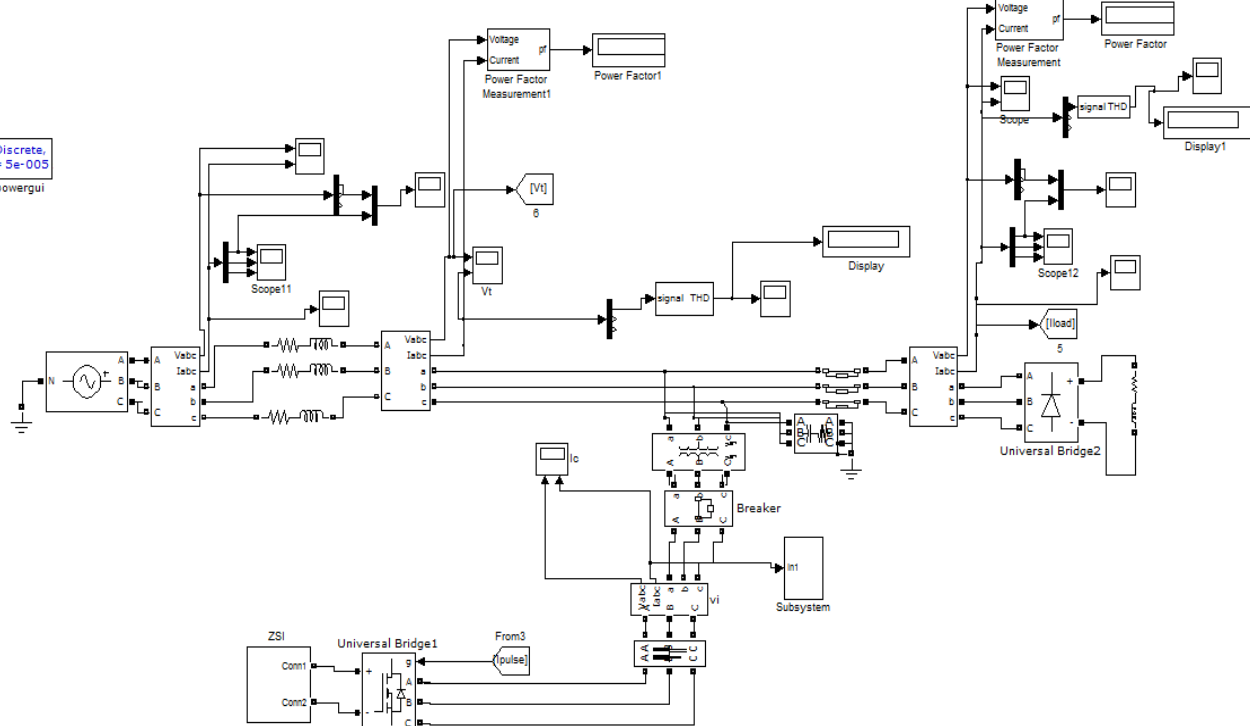


Fig 4.3: SIMULINK Model of System Compensated with DSTATCOM using ZSI

5.1 Introduction

Here various Power Quality problems are discussed as Power Factor, THD and load balancing. Performance of DSTATCOM is analyzed in such situations to note its Power Quality improvement function. DSTATCOM with VSI and ZSI are employed in SIMULINK model of the system to compare the performance of DSTATCOM with VSI and DSTATCOM with ZSI.

Here three cases as follows:

- Reduction in THD LEVEL
- Power factor Improvement
- Load Balancing

Are diagnosed and respective results are demonstrated in following figures.

5.2 System Parameters

Table 5.1: System Parameters

Line Impedence	$R_s = 0.01\Omega, L_s = 2\text{mH}$
Ripple Filter	$R_f = 5\Omega, C_f = 10\mu\text{F}$
DC Bus Capacitor	500μF
DS Bus Voltage	750V
AC Line Voltage	415V, 50Hz
Non- Linear load	Universal Bridge

5.3 Block diagrams

Fig 5.1 below illustrates the system with DSTATCOM based on VSI

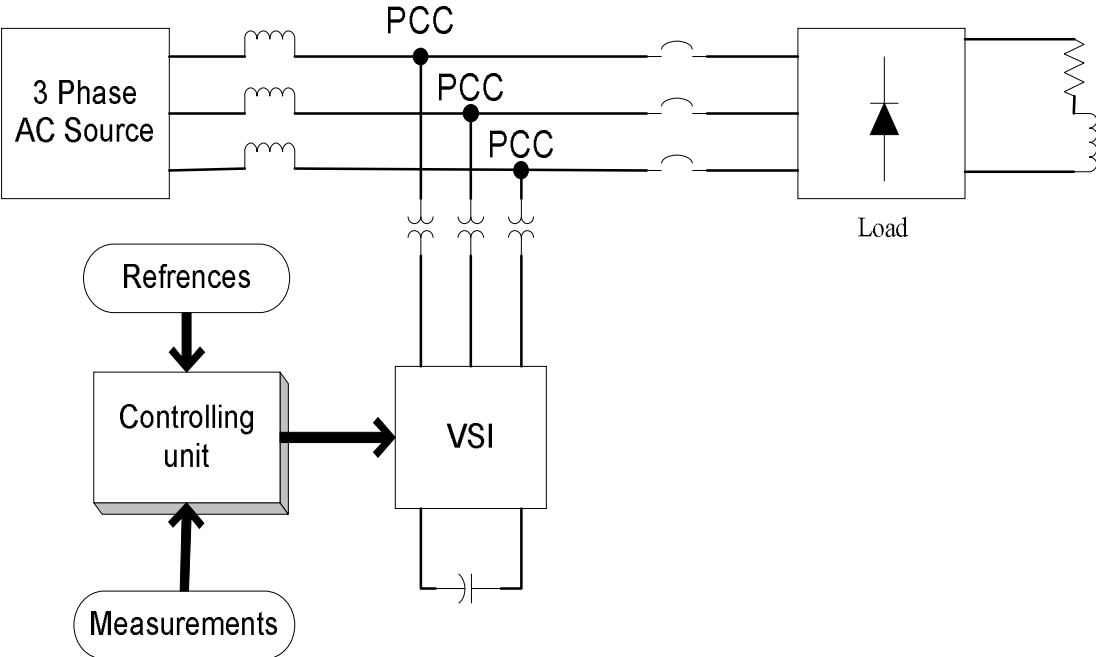


Fig 5.1: DSTATCOM with VSI

Fig 5.2 below illustrates the system with DSTATCOM based on ZSI.

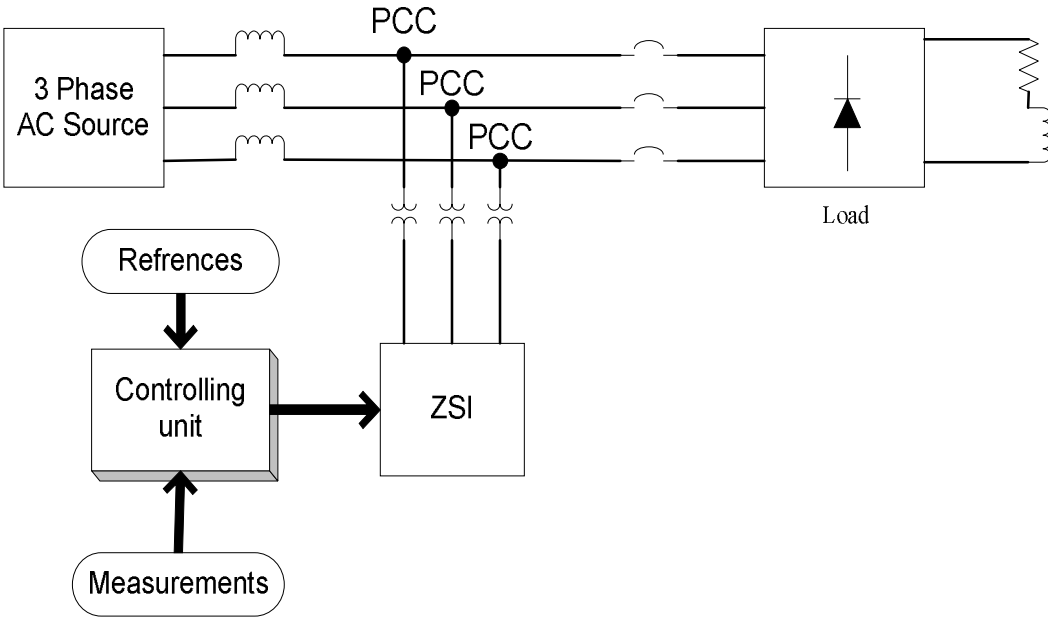


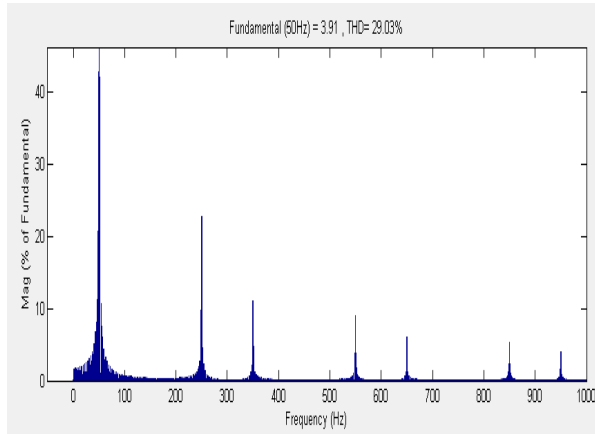
Fig 5.2: DSTATCOM with ZSI

5.4 Results and Discussions

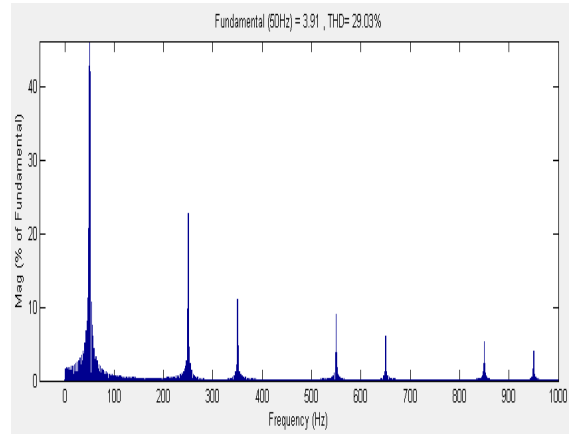
Case I: Reduction in THD level.

System Harmonic Distortion levels are compared and presented below to compare the reduction in THD levels on employing DSTATCOM with VSI and DSTATCOM with ZSI.

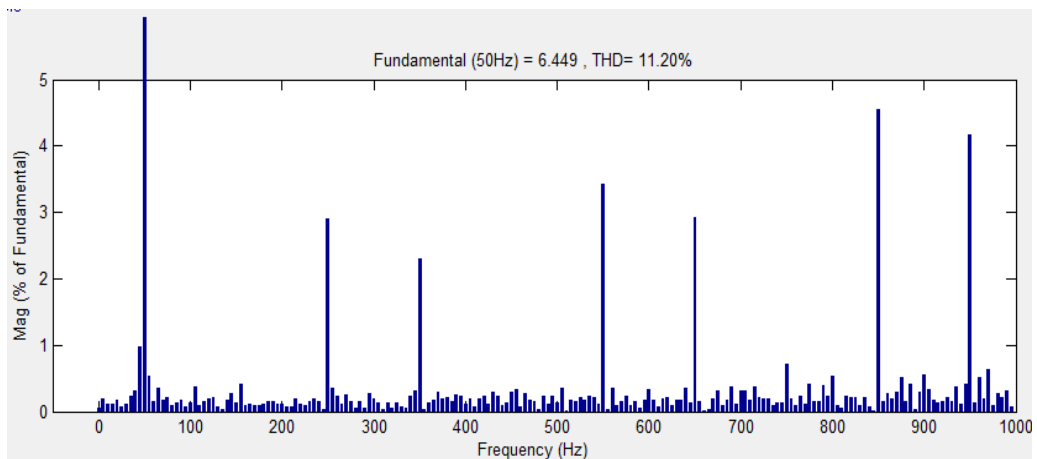
Source



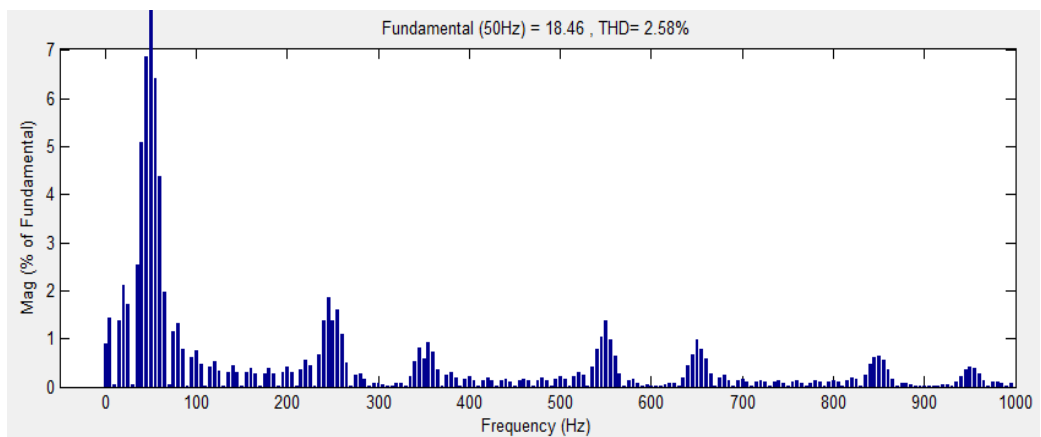
Load



DSTATCOM with VSI



DSTATCOM with ZSI



Case II: Power factor Improvement

Power factor in distribution system with Inductive load can be improved by implementing DSTATCOM. Here performance of DSTATCOM with VSI and that of with ZSI are compared in order to find out better combination for power factor improvement. Distribution system used here without DSTATCOM shows power factor of **0.9506** which is improved to **0.9567** when DSTAT with VSI is employed but when ZSI based DSTAT is used it improves power factor to **0.997**. This shows that if power factor improvement is required to more extent than ZSI based DSTAT will be the preferred device.

Case III: Load Balancing

The performance of DSTATCOM with VSI or ZSI is compared for load balancing.

The supply currents are balanced and in phase at all conditions [21]. At 0.1 sec load is changed to two phase load, at 0.2 sec load changes to single phase and at 0.4 sec load gets disconnected. And all phases of load are applied again at 0.45 sec.

I_{Load} v/s Time waveform for the uncompensated system is presented as below in Fig 5.3

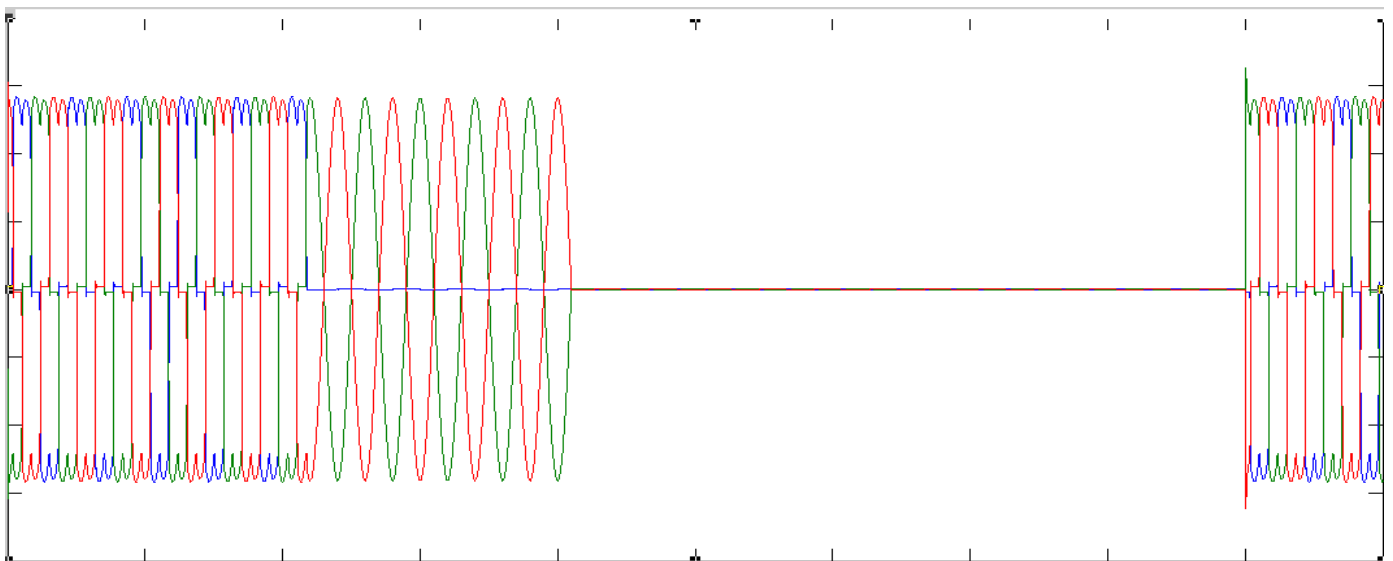


Fig5.3: Load Current (I_{load}) v/s Time Waveforms

I_{source} v/s Time Waveform for uncompensated system is shown as below Fig 5.4

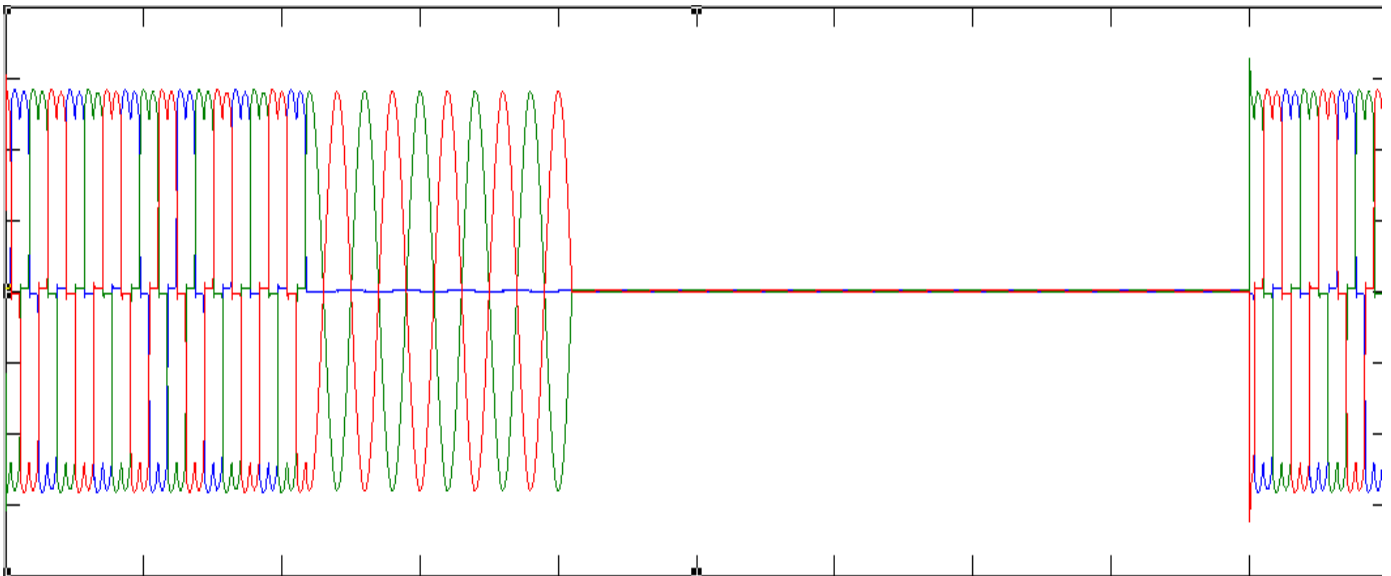


Fig5.4: Source Current (I_{source}) v/s Time Waveforms

a. *DSTATCOM with VSI. The results obtained from the simulation models are shown as below Fig 5.5.*

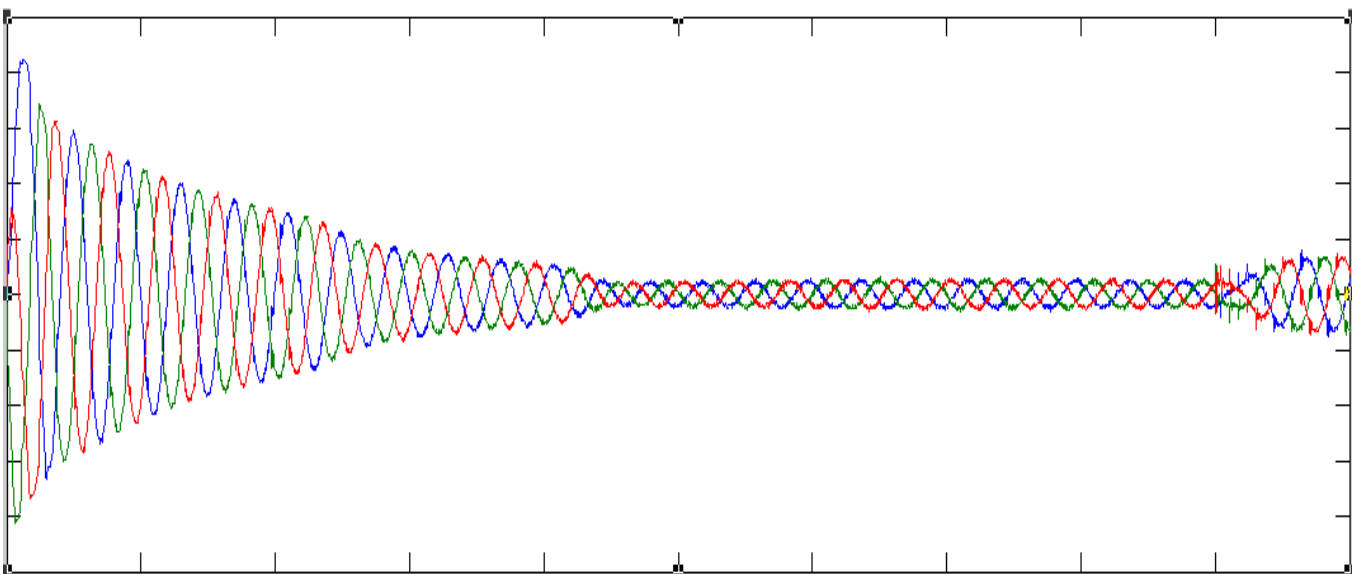


Fig5.5:Source Current (I_{source}) v/s Time Waveforms

b. DSTATCOM with ZSI. The results obtained from the simulation models are shown in Fig 5.6.

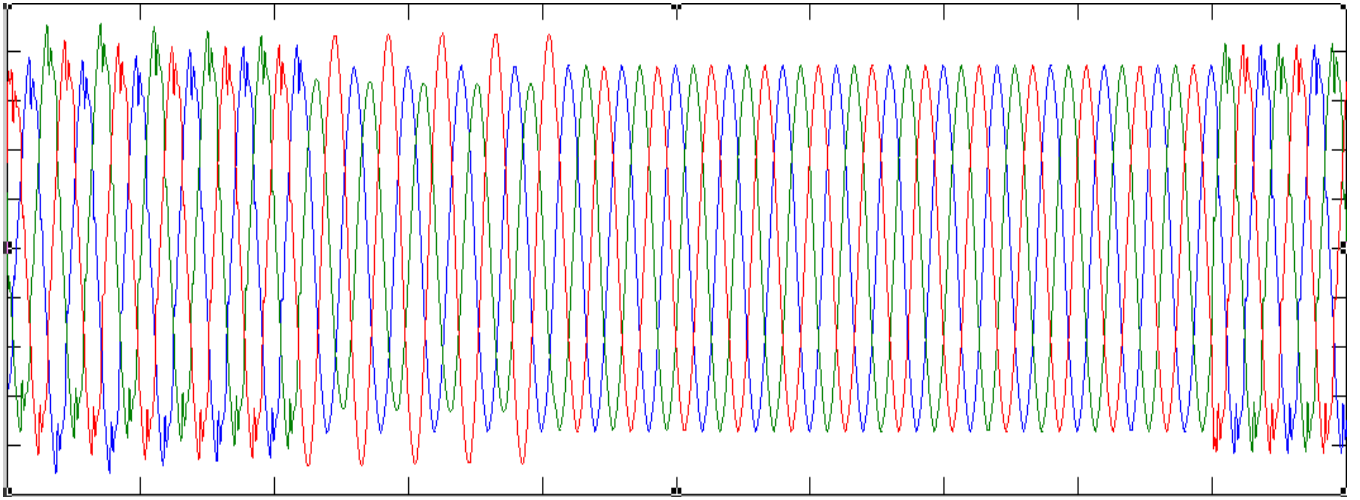


Fig5.6: Source Current (I_{source}) v/s Time Waveforms

CONCLUSIONS AND FUTURE SCOPE OF WORK

6.1 Conclusions

The Conclusions of this thesis work are as under:

1. The THD reduction in source current is more in the case of DSTATCOM based on ZSI as compared to that of DSTATCOM based on ZSI
2. Power factor improvement is comparatively better in ZSI based DSTATCOM than VSI based DSTATCOM.
3. Source current is compensated relatively well in case of ZSI based DSTATCOM as compared to VSI based DSTATCOM. As per waveforms shown above it is depicted that source current waveforms are more sinusoidal and balanced in ZSI based DSTATCOM compensated distribution system as compared to that observed in VSI based DSTATCOM compensated distribution system.

6.2 Future scope of work:

- To develop better control techniques for ZSI.
- To show ZSI based DSTATCOM performance in distribution system for power quality improvement.
- To compare the performance of ZSI based custom devices with VSI based custom devices in distribution system.

REFERENCES

- [1] Alka Singh, Suman Bhowmick and Kapil Shukla, "Load Compensation with DSTATCOM and BESS", *IEEE 5th International Conference on Power Electronics*, December 2012.
- [2] Wei- Neng Chang and Kuan- Dih Yeh, "Design and Implementation of DSTATCOM for Fast Load Compensation of Unbalanced Loads", *Journal of Marine Science and Technology*, Vol. 17, Issue No. 4, pp. 257-263, 2009.
- [3] D.Masand, S.Jain and G.Agnihotri, "DSTATCOM Performance Under Linear and Nonlinear Current Regulation Methods", *J.Electrical Systems*, pp. 91-105, 2008.
- [4] M.G.Molina, "Dynamic Modeling and Control Design of DSTATCOM with Ultra-Capacitor Energy Storage for Power Quality Improvements", *IEEE Conference on Transmission and Distribution: Latin America*, pp. 1-8, August 2008.
- [5] Arvind Dhingra and Ashwani Kumar Sharma, "Power Quality Issues: Monitoring & Measurement", *International Journal of Electronic and Electrical Engineering*, Vol. 7, Issue No. 10, pp. 1049-1056, 2014.
- [6] Sandeep G J S M and SK Rasoolahemmed, "Importance of Active Filters for Improvement of Power Quality", *International Journal of Engineering Trends and Technology*, Vol. 4, Issue 4, pp. 1164-1171, April 2013.
- [7] P.Prasad, Khaja Jainuddin, Y.Rambabu and V.K.R. Mohan Rao, "Unified Power Quality Conditioner (UPQC) with Storage Device for Power Quality Problems", *International Journal Of Engineering and Science*, Vol.3, Issue No. 8, pp. 19-26, September 2013.
- [8] Jose M.R Baptista, Manuel R. Cordeiro and A. Machado e Moura, "Voltage Wave Quality in Low Voltage Power System", *International Conference on Renewable Energies And Power Quality*.
- [9] Shalini Bajpai, "Power Quality Improvement using AC to AC PWM Converter for Distribution Line", *International Journal of Engineering Inventions*, Vol. 2, Issue No. 11, pp. 60-66, July 2013.
- [10] Prafull A. Desale, Vishvadeep J. Dhawale and Ranjeet M. Bandgar, "Brief Review Paper on the Custom Power Devices for Power Quality Improvement", *International Journal of Electrical Engineering*, Vol. 7, Issue No. 7, pp. 723-733, 2014.
- [11] Vijayakumar. R and Thangaraj. R, "Distribution System Voltage Regulation using Multifunctional DVR Implementation for Emergency Control and Protect Consumers System", *International Science And Research Journals*, Vol. 2, Issue No. 2, pp. 59-67, April 2014.

- [12] M. Anuj Gargeya, "A New Proposal for Mitigation of Power Quality Problems using DSTATCOM", *International Journal of Scientific Engineering and Technology*, Vol. 2, Issue No. 5, pp. 317-321, May 2013.
- [13] T. Devaraju, V.C. Veera Reddy and M. Vijaya Kumar, "Role of Custom Power Devices in Power Quality Enhancement: A Review", *International Journal of Engineering Science and Technology*, Vol. 2, Issue No. 8, pp. 3628-3634, 2010.
- [14] M. P. Bahrman, J. G. Johansson, and B. A. Nilsson, "Voltage Source Converter Transmission Technologies – The right fit for the application", *IEEE Power Engineering society General Meeting*, Vol. 3, pp.1840–1847, 2003.
- [15] Mirjana Milosevic, "Hysteresis Current Control in Three Phase Voltage Source Inverter", *Technical Report, Zurich*, 2003.
- [16] Parag Nijhawan, Ravinder Singh Bhatia and Dinesh Kumar jain, "Application of PI Controller Based DSTATCOM for Improving the Power Quality in a Power System Network with Induction Furnace Load", *Songklanakarinn Journal of Science and technology*, Vol. 2, Issue No. 34, pp. 195-201, March-April 2012.
- [17] P. Bapaiah, "Power Quality Improvement by Using DSTATCOM", *International Journal of Emerging Trends In Electrical And Electronics*, Vol. 2, Issue No. 4, pp. 1-12, April 2013.
- [18] P. Venkata Kishore, S. Rama Reddy and P.V. Kishore, "Modeling and Simulation of Thirty Bus System with DSTATCOM for Power Quality Improvement", *International Journal of Scientific and Technology Research*, Vol. 2, Issue No. 9, pp. 4560-4569, 2010.
- [19] Paulmathew and Venkatesh. A, "Analysis of DClink Z-Source Control Based Hybrid Active Power Filter", *International Journal of Scientific and Technology Research*, Vol. 3, Issue No. 4, April 2014.
- [20] B.Anvari, M. Shirinabadi and E. Afjei, "Design and Simulation of Z-Source Inverter for Brushless DC Motor Drive", *International Research Journal of Applied and Basic Sciences*, Vol. 7, Issue No. 7, pp. 417-421, 2013.
- [21] F.Z. Peng, Miaosen Shen and Zhaoming Qian, "Maximum Boost Control of the Z-Source Inverter", *IEEE Transaction on Power Electronics*, Vol. 20, Issue No. 4, pp. 833-838, July 2005.

[22] Miaosen Shen, Jin Wang, Alan Joseph, Fang Z. Peng, Leon M. Tolbert and Donald J. Adams, "Maximum Constant Boost Control of Z- Source Inverter", *IEEE/IAS, Seattle*, pp. 142-147, 2004

[23] Parag Nijhawan, R.S.Bhatia, D.K. Jain, "Performance Analysis of Different Control methods of Z- Source Inverter feeding Induction Furnance Load", *International Review of Automatic Control*, Vol. 7, Issue no. 2, pp. 166-175, March 2014

[24] Bhim Singh, P. Jayaprakash and D.P. Kothari, "New Control Approach For Capacitor Supported DSTATCOM In Three Phase Four Wire Distribution System Under Non-Ideal Supply Voltage Conditions Based On Synchronous Reference Frame Theory", *Electrical Power and Energy Systems*, pp. 1109-1117, 2011.