

**INVESTIGATING THE ROLE OF DSTATCOM IN DISTRIBUTION NETWORK
WITH NON-LINEAR LOAD AND ACTIVE LOAD**

Thesis

submitted in partial fulfillment of the requirements for the award of degree of

**MASTER OF ENGINEERING
IN
POWER SYSTEMS**

Submitted By:

SAVREET KAUR

Regn. No.: 801241021

Supervised By:

Mr. PARAG NIJHAWAN

Assistant Professor, EIED



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ELECTRICAL & INSTRUMENTATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY, PATIALA-147004


CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled “**Investigating the role of DSTATCOM in Distribution Network with Non-linear Load and Active Load**” in partial fulfillment of the requirement for the award degree of Master of Engineering in *Power Systems* submitted in Electrical and Instrumentation Engineering department, Thapar University, Patiala is an authentic record of my own work carried out under the guidance of Mr. Parag Nijhawan, Assistant Professor, EIED, Thapar University.


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



(SAVREET KAUR)

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


(PARAG NIJHAWAN)
Assistant Professor
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

Countersigned By:


(Dr. RAVINDER AGARWAL)
Professor & Head
Electrical & Instrumentation Engineering Department
Thapar University, Patiala


(Dr. S.K. MOHAPATRA)
Sr. Professor & Dean
Academics Affairs
Thapar University, Patiala

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Savreet Kaur
18/07/14

(Savreet Kaur)

Regn. No.: 801241021

ABSTRACT

The effectiveness of DSTATCOM in a distribution network with Field Oriented Control (FOC) induction motor drive as non-linear load and wind turbine coupled with asynchronous generator is examined. The above-mentioned FOC induction motor drive being non-linear in nature, introduces harmonics into the distribution network. Simulation of DSTATCOM based upon dqo transformation technique using PI controller has been performed in MATLAB/SIMULINK. The performance of DSTATCOM for both non-linear load and active load is analysed. DSTATCOM being connected in shunt with the distribution network injects compensating current into the network so as to provide compensation for the harmonics present in the source current.

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LIST OF ABBREVIATIONS

ASD	Adjustable Speed Drive
BESS	Battery Energy Storage System
CBEMA	Computer Business Equipment Manufacturers Association
CPD	Custom Power Device
DSTATCOM	Distribution Static Compensator
DTC	Direct Torque Control
DVR	Dynamic Voltage Restorer
EMTDC	Electromagnetic Transients Including DC
ESS	Energy Storage System
EPQ	Electric Power Quality
FACTS	Flexible AC Transmission System
FFT	Fast Fourier Transform
FLC	Fuzzy Logic Controller
FOC	Field Oriented Control
GTO	Gate Turn-Off Thyristor
HVDVR	High Voltage Dynamic Voltage Restorer
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IGCT	Insulated Gate Commutated Thyristor
IPFC	Interline Power Flow Conditioner
IPM	Intelligent Power Module
IRPT	Instantaneous Reactive Power Theory

MOSFET	Metal-Oxide Semi-conductor Field effect Transistor
PI	Proportional Integral
PLC	Programmable Logic Controller
PLL	Phase Locked Loop
PQ	Power Quality
PSCAD	Power System Computer Aided System
PWM	Pulse Width Modulation
SA	Surge Arrester
SMESS	Super Magnetic Energy Storage System
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
SVPWM	Space Vector Pulse Width Modulation
TCSC	Thyristor Controlled Series Compensator
THD	Total Harmonic Distortion
UPFC	Unified Power Flow Conditioner
UPQC	Unified Power Quality Conditioner
VSC	Voltage Source Converter

OVERVIEW

1.1 INTRODUCTION

The electric power system consists of three major functional blocks:-generation, transmission and distribution. As per reliability consideration in power system, generation unit must generate adequate amount of power, transmission unit should supply maximum power over long distances without overloading and distribution system must deliver electric power to each consumer's premises from bulk power systems. Distribution system is located at the end of electric power system and is directly to the consumer, so the power quality depends upon the state of distribution system. The reason for this is that failure in the electric distribution network accounts for about 91% of the average consumer's interruptions. Earlier, power system reliability focussed on generation and transmission system due to capital investment in these. But today, distribution system is receiving more attention as reliability is concerned.

The main cause of terminal voltage fluctuation, transients and waveform distortions on the distribution system are the utility and customer-side disturbances. Now days, power quality engineers are progressively more worried about the quality of electrical power. In modern industries, electronic controllers are used by load equipment, as they are sensitive to poor voltage quality and if supply voltage is depressed they will shut down and may mal-operate, if harmonic distortion of the supply voltage is excessive [1]. Electronic switching devices used by new load equipments, can supply poor network voltage quality.

Power quality issues are achieving a major concern due to the increase in number of sensitive loads. Also the extensive use of electronic equipment, such as information technology equipment, adjustable speed drives (ASD), arc furnaces, electronic fluorescent lamp ballasts and programmable logic controllers (PLC) have entirely altered the electric loads nature [2]. These loads are the foremost sufferers of power quality problems. the non-linearity of these loads cause disturbances in the voltage waveform. a utility will likely to deliver a low distortion balanced voltage to its customers, particularly those with sensitive loads.

For the improvement of power quality and reliability of system, the FACTS devices and custom power devices are introduced into the power system. DSTATCOM/STATCOM, DVR, SSSC, UPFC, UPQC etc. are some of the major devices used for the improvement of

voltage sag and swells. With the help of these FACTS devices [3], we are capable of reducing the problems related to power quality.

In this thesis work, DSTATCOM has been modelled to provide current compensation with active and dynamic type non linear loads.

STATCOM when connected to the distribution network is known as Distribution STATCOM. It consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. DSTATCOM when connected with a particular load injects compensating current, so that total demand meets the specifications for utility connections. Capacitive and inductive reactive power is produced internally by DSTATCOM [18]. Its control is very fast and provides sufficient reactive compensation to the system. DSTATCOM can be successfully employed to regulate voltage for a series of small induction motors loads, which draw large starting currents (5-6 times) of full rated current and may influence the working of other sensitive loads, linked to the system.

1.2 Literature Survey

Power quality is one of today's most concerned areas of power system. Modern load consists of electronic controllers which contribute to poor network voltage quality. Several research papers have addressed the enhancement of current & voltage quality by use of custom power devices. A brief literature review related to power quality improvement using DSTATCOM is presented here:

The electric utilities are getting a large number of customer complaints due to these types of problems. A systematic plan is required to detect power quality problems [1] in industrial, commercial or residential facilities. This paper clarify about on site field measurements and routine checks on the system, that can help to find these problems most of the time. The data gathered from the measurements can help in recognizing the nature of the existing problem and also help to associate the events to the problems.

Non-linear loads, load switching, system faults, motor starting, load variations, intermittent loads and arc furnaces usually cause [2] power quality disturbances. These cause many electrical disturbances like voltage surge, voltage dip, harmonic distortions, interruptions and flicker. This paper presents analysis of the real time industrial electrical disturbances, power disturbance log and some proposals to minimize or prevent problems caused by power disturbances.

The operation, performance, characteristics, applications for FACTS devices [3] such as TCSC, SVC, STATCOM, UPFC etc are described. Basic terms used in FACTS transmission system are presented. Various control strategies are discussed which act as the performance index for the FACTS devices. The main Power Quality (PQ) problems [4] are explained with their associated causes and consequences. The economic impacts associated with PQ are characterized and some solutions to mitigate the PQ problems are presented.

A detailed comparison between the two control techniques [5] i.e. field oriented control and direct torque control of induction motor drives is presented in this paper. The performance of these two control schemes is calculated in terms of torque and current ripple. This paper also explained the advantages and disadvantages of induction motor drives. The configurations, working and important functions of custom power devices are explained in this paper.

Voltage flicker [6], a phenomenon of infuriating light intensity fluctuation, is caused by fast industrial load variations and is the main problem for both customers and power companies in the area of power quality. The quick response of the DSTATCOM makes it capable for improving power quality in distribution systems. Voltage flicker mitigation studies with a current controlled PWM-based DSTATCOM are also executed and discussed. The voltage flicker problem in a 69/13.8 kV distribution system is examined.

A VSC with pulse width modulation provides a rapid control for flicker easing purpose. The voltage regulation in the distribution feeder is improved very effectively by installing a shunt compensator. DSTATCOM is modelled and simulated to confirm the power factor correction and voltage regulation along with neutral current compensation, harmonic elimination and load balancing with linear loads and non-linear loads. The three-phase, three-wire DSTATCOM is employed for power quality improvement [7].

DSTATCOM [8] is employed for load balancing, power factor correction, neutral current elimination and voltage regulation in three-phase, four-wire distribution system feeding commercial and domestic consumers. A four leg voltage source inverter (VSI) configuration with a dc bus capacitor is employed as DSTATCOM. The modified instantaneous reactive power theory (IRPT) is used in the control of DSTATCOM, in this paper. The compensator is designed such that it not only cleans the distortion created by the load, but also improves the voltage quality at the point of common coupling (PCC). The other feature of the proposal is a linear quadratic regulator (LQR) based switching controller scheme that tracks reference using the proposed compensator filter structure. It proposes a new switching control scheme and demonstrates its suitability for this problem and also

suggests a scheme in which the fundamental sequence components of a three-phase signal can be computed from its illustrations. The problem for correction of load unbalance and distortion at a weak ac bus using DSTATCOM is discussed [9].

The dynamic performance of a DSTATCOM coupled with energy source system (ESS) for recovering the power quality of distribution systems is examined. The three modes of operation [10] are considered, i.e. voltage control, power factor correction and active power control. The multi-level control technique is suggested, which is based on the instantaneous power theory on the synchronous rotating dq reference frame.

The application [11] of a DSTATCOM to an existing industrial facility for voltage flicker mitigation during the starting of a large motor is discussed. The DSTATCOM performs well, should have satisfactory reliability and is cost competitive with other solutions. Since the cost of a DSTATCOM is expected to be comparable to the addition of onsite generation, it is the only solution that meets all of the requirements.

DSTATCOM is a compensating device which is employed to limit the flow of reactive power in the distribution systems. The decoupled theory employing the PI controller is utilized to control the DSTATCOM. The different types of control strategies [12] used for the control of DSTATCOM are discussed. To maintain power balance at the PCC to adjust the dc capacitor voltages a control scheme is used. Many simulations are performed to gain insight into the effect of capacitor size on DSTATCOM harmonic generation, speed of response of the PWM control and transient overshooting. Though DSTATCOM is similar to a STATCOM at the transmission level but its control scheme should be able to complete reactive power compensation, power factor improvement and voltage regulation and for achieve better power quality levels at the distribution end.

The modelling & control of DSTATCOM and BESS using SIMULINK in MATLAB environment is done. A control system based on dqo technique [13] is proposed. The results are presented for a test system with/without DSTATCOM for a wide variety of system disturbances. The modelled DSTATCOM is also tested for load compensation of linear and non-linear loads in both steady state and dynamic conditions.

A feed forward based dqo transformation [14] compensation scheme for the control of DSTATCOM in faulty conditions is used. Compensation technique of the DSTATCOM is derived with symmetrical component method and a current regulated PWM inverter is proposed to create required compensation current. The results are presented for a test system with/without DSTATCOM for a wide variety of system disturbances.

The load and the compensator are assumed as a whole comprehensive load, and the control object is that the line side only give positive sequence active currents. The control scheme suggested is consists of DC voltage controller and current controller. Dc voltage controller mainly sustains the voltage of DC capacitor at a required value whereas DC current controller detects source current, which consists of a close-loop structure presented in ‘dq’ reference frame [15]. In the current controller, the reference of d-axis is provided by DC voltage controller and the reference current of q-axis is zero. Compared to double ‘dq’ decoupled control method usually used for DSTATCOM under unbalanced conditions, the control scheme has a simple structure, less calculation and is easy to understand. Simulation results showed that DSTATCOM using recommended control method can get a good performance under unbalanced conditions.

Field oriented control (FOC) [16] of induction motor (IM) is employed in various variable speed drives. The various types of motor parameters are required for its operation. These parameters are influenced by the saturation of the machine. So to achieve good drive operation these parameters should be properly estimated.

The one of the commonly used wind turbine is asynchronous wind turbine [17]. The wind speed as a input to the wind turbine is used to generate the torque which further is used to control the output power of the asynchronous generator.

DSTATCOM is realized using a three leg IGBT static and dynamic performance. In this paper, a hysteresis rule based carrier-less PWM current controller is used to derive gating pulses for the IGBT switches. It is observed that DSTATCOM effectively improves power quality [18] in electric distribution systems. It is effective in compensating reactive power and improving the power factor of the distribution system.

A comparative analysis between a SVC and a DSTATCOM for improvement of induction generator stability is done. This study is based on transient stability simulations. The dynamic performance of a distribution network with an induction generator and a SVC or a DSTATCOM during balance and unbalance faults is analysed. Simulation results showed that a DSTATCOM with the same power capability of a SVC allows the critical power injection from an induction generator to assume higher values [19].

An effective control technique for DSTATCOM is discussed. As a custom power conditioner DSTATCOM mitigates the current fluctuation and voltage flicker in industrial distribution systems. The proposed control depends on a current vector control technique for generating the required reactive power and is newly utilized for a single-phase DSTATCOM. It is known that the current vector control is commonly implemented on a three-phase system

to operate the three-phase DSTATCOM. The novelty in this paper is articulated in the implementation of the current vector control on a single-phase circuit to operate a single-phase DSTATCOM [20].

In today's era industrial drives are the major causers and the major victims of power quality problems. There are different types of industrial drives such as Field Orientation Control (FOC) induction motor drives and Direct Torque Control (DTC) induction motor drives [21]. Induction machines have been widely used in industry because of their advantages like- simple in construction, ruggedness, reliability, low cost, less maintenance. But due to their highly coupled non-linear structure high performance of these machines is quite challenging.

Several control strategies have been developed for induction machine drives. These are FOC, DTC. The performance of two control strategies namely, Direct Field Orientation Control (DFOC) and DTC has been evaluated and compared. Simulation results have shown that both the methods give very good performance with faster dynamics. It has been shown that DTC is less sensitive to machine parameters and FOC has been demonstrated superior under steady state but DTC has higher current and torque ripple [22].

The ABC-DQ current transformations vector based PWM inverter controller is used to control brushless synchronous motor drive. Among the major peripheral devices in the drive system are the A/D and D/A converters, analog or digital filters and position encoder. These devices deal with signals and other quantities which have to undergo digitization and quantization. All the above processes and the devices introduce non-linearities and errors in the drive system [23].

The static and dynamic characteristics of buck-type three-phase PWM rectifier which are fully based on the dc and ac circuit models are developed by the circuit DQ transformation. Various static converter characteristics such as gain, real and reactive power, power factor and unity power factor conditions are completely examined [24].

A control method is suggested that enables DSTATCOM to mitigate all types of fault, intelligently (such as single line to ground fault, double phase to ground fault and three-phase fault). A 12-pulse DSTATCOM configuration with IGBT is designed and the graphic based models of the DSTATCOM are developed using the PSCAD/EMTDC. It validates the operation of a DSTATCOM system for improving distribution system performance under all types of fault. The reliability and robustness of the control scheme in the system response to the voltage sags caused by single line to ground, double line to ground and three-phase faults is proved in the simulation results [25].

The impact of induction and synchronous machines on the dynamic behaviour of distribution networks is examined. The working of a DSTATCOM as a voltage controller or a power factor controller is investigated. The influence of these controllers on the stability and protection system of distribution networks with distributed generators is discussed. The Computer simulation result shows that a DSTATCOM voltage controller can extensively improve the stability operation of induction generators. The stable operation of synchronous generators is badly disturbed by the DSTATCOM power factor controller [26].

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment. As appropriate as this description might seem, the limitation of power quality to sensitive electronic equipment might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems [27].

The various power quality problems are discussed and a PI controller based technique for correcting the voltage sag, swell and interruption in a distributed system is described. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices. Both DSTARCOM and DVR are based on the VSC principle. A DVR injects a voltage in series with the AC system voltage and a DSTATCOM injects a current into the AC system to correct the voltage sag, swell and interruption [28].

The application of DSTATCOM in a distribution network with induction furnace load is investigated. The common type of load used in various industries is induction furnace. The design and operation of the induction furnace causes harmonic distortion in the system. The harmonic distortion is the major problem associated with induction furnace. Harmonic distortion affects the performance of other loads connected in the system. DSTATCOM is a shunt connected custom power device which improves the power quality by injecting a compensating current into the power system network [29].

The DSTATCOM is used to improve power quality of distribution network under normal operating and fault conditions. Comparison of THD analysis for FOC induction motor drive load under normal and various faults conditions with or without DSTATCOM is also

discussed. DSTATCOM is realized using IGBT, and dqo transformation based PWM current controller is used to generate gating pulses for the IGBT switch. It is observed that DSTATCOM is effective in compensating load current harmonics, reactive power compensation and improving the power quality of the distribution system [30].

1.3 Scope of Work

From the literature review, it is observed that power quality is major area of concern for power engineers now days. Reliability of supply is of utmost importance for the utilities to achieve global benefits. Different types of custom power devices are proposed and analysed to improve the power quality. As the major interruptions to customers are caused by failure in distribution system, so, more attention is given on the removal of voltage sags, swells and harmonics at the distribution end. In order to improve the quality of power, a custom power device called DSTATCOM is used and the results are obtained by using MATLAB/ SIMULINK. The effectiveness of DSTATCOM can be established for distribution networks with non-linear loads and with active loads like PV cell and wind turbine system.

1.4 Objective of Thesis

This work proposes the MATLAB SIMULINK model of DSTATCOM which is used for the improvement of power quality at distribution level. The major objectives of this work are summarized as follows:

- To study the model of DSTATCOM along with its controller.
- To investigate the performance of DSTATCOM using dqo transformation control scheme for different loads like active load (wind turbine coupled with asynchronous generator which acts as both source and load) and non-linear load (FOC induction motor drive load).

1.5 Organization of Thesis

The work carried out in the thesis has been compiled in five chapters as per the details given below:

- Chapter-1 highlights the overview, literature review and scope of work. It also contains the organization of thesis. The outline of the thesis is also given in this chapter.

- Chapter-2 explains the power quality, various power quality problems and their causes.
- Chapter-3 describes the DSTATCOM in detail and outlines the control scheme used for simulation of it.
- Chapter-4 presents parameter of the test system. Simulink models of the test system with active loads, non-linear loads and FOC induction motor drive load and their results are also discussed in this chapter.
- Chapter-5 contains the conclusions and future scope of work.

POWER QUALITY PROBLEMS

2.1 Power Quality

Electricity consumers face power quality problem at all stages of usage. Actually, Power quality defines the assets of power supply distributed to the users in normal operating conditions. New electronic equipments and devices are more prone to power quality problems. Reduced PQ has become a major problem for both power suppliers and customers. Poor PQ means there is enough variation in the power supply to affect equipments and may lead to their mis-operation or failure. It is unfeasible to completely control disturbances on the supply system but efforts and investments are made by utilities to avoid interruptions. Normal operations such as switching loads and capacitors or faults and opening of circuit breakers to clear faults mainly cause disturbances. Faults are commonly caused by incidents such as lightning, birds flying close to power lines and getting electrocuted, and accidental acts such as trees or equipment contacting power lines.

Institute of Electrical and Electronic Engineers (IEEE) standard IEEE 1100 defines power quality [2] as “the concept of powering and grounding discerning electronic equipment in a way suitable for the equipment”.

2.2 Power Quality Problems

From above discussion it can be said that Power Quality problem means power supply that causes inconvenience or production loss; deviation in voltage, current, frequency that results in failure or maloperation of consumer equipment; unsatisfactory consumer service.

Table 2.1: A Summary of PQ Problems: Nature and Solutions [28]

PQ Problems	Characteristics	Solutions
Impulsive Transients	Sudden change in voltage and current signals in steady state.	Filters, Isolation Transformers, and Surge Arresters
Oscillatory Transients	Sudden change in voltage and current signals at (< 5 to > 500 kHz).	Filters, Isolation Transformers, and Surge Arresters

Voltage Sags	0.1–0.9 Decrease in Per unit RMS Value at 0.5 cycles to 1 min.	DSTATCOMs, Ferroresonant Transformers, UPS and Backup Generators.
Voltage Swells	1.1–1.8 Increase in Per unit RMS Value at 0.5 cycles to 1 min.	DSTATCOMs, Ferroresonant Transformers, UPS and Backup Generators.
Over/Undervoltages	> 110% Increase and < 90% Decrease in RMS voltage for > 1 min.	Voltage regulators And Ferroresonant Transformers
Harmonic Distortion	Refer to IEEE Std 519–1992 for allowed THD ($\pm 5\%$) and TDD ($\pm 10\%$).	DSTATCOM as an Active Filter, Passive Filters and Ferroresonant Transformers.
Voltage Flicker	Variation in Magnitude with frequency.	DSTATCOMs and SVCs.

2.2.1 Voltage Sag (Or Dip)

Voltage sag [1] is defined as a drop in the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0.5 cycle to 1 minute. It is clear from Figure-2.1 that voltage sag reduces the magnitude of voltage. Connection of heavy loads, start-up of large motors and faults in consumer's installation are the main reasons for voltage sag. Starting of large induction motors can result in voltage dip as the motor draws a current up to 10 times the full load current during the starting. The Consequences of voltage sag are disconnection and loss of efficiency in electric rotating machines, tripping of electro-magnetic relays and malfunction of information technology equipment namely micro-processor based control systems.

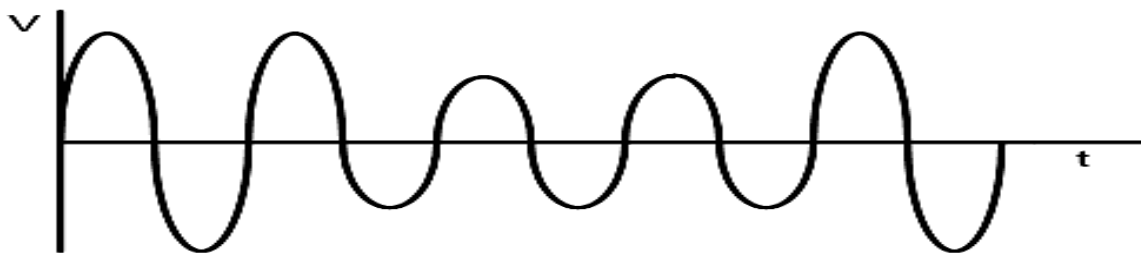


Figure-2.1: Voltage Sag

2.2.2 Voltage Swell

Voltage swell is defined as momentary increase of the voltage at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds. Figure-2.2 shows the rise in voltage magnitude due to voltage swell [28]. Voltage swell is caused due to line faults, badly dimensioned power sources and incorrect tap settings in tap changers in substations. A SLG (single line to ground) fault can result in a voltage swell in the healthy phases. Swell can also result from energizing a large capacitor bank. The consequences of voltage swell are flickering of lighting and screens, data loss and stoppage or damage of sensitive equipment.

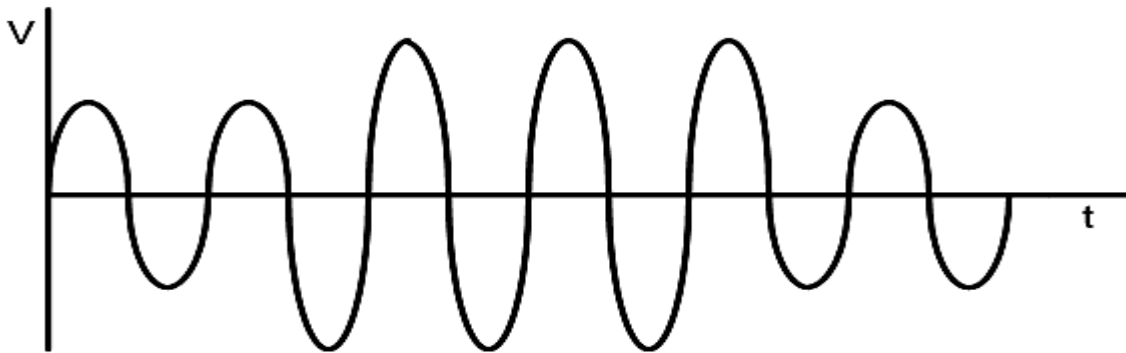


Figure- 2.2: Voltage Swell

2.2.3 Interruption

A very short but complete loss of supply is called an interruption. An interruption occurs when the supply voltage reduces less than 10% from its original value up to a period of time not exceeding one minute. The number of interruptions of the supply also increases voltage sag which needs a proper mitigation [27].

2.2.3.1 Very Short Interruption

Very short interruption [2] is defined as complete interruption of electrical supply for duration from few milliseconds to one or two seconds. It is caused due to insulation failure, lightning, system faults, equipment failures and insulator flashover. The consequences of very short interruption are loss of information and malfunction of data processing equipment, tripping of protection devices and stoppage of sensitive equipment.

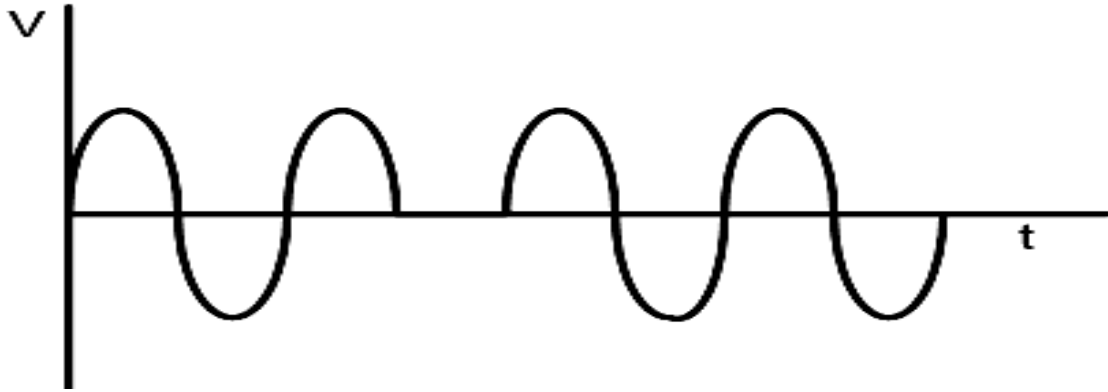


Figure-2.3: Very Short Interruptions

2.2.3.2 Long Interruptions:

Long interruptions are defined as loss of utility power lasting more than 2 minutes due to major local area or regional electrical incidents [2]. These are caused by equipment failure in the power system network, storms and objects striking lines or poles, power system faults and control malfunctioning causes long interruptions. Long interruptions result in stoppage of all equipment.

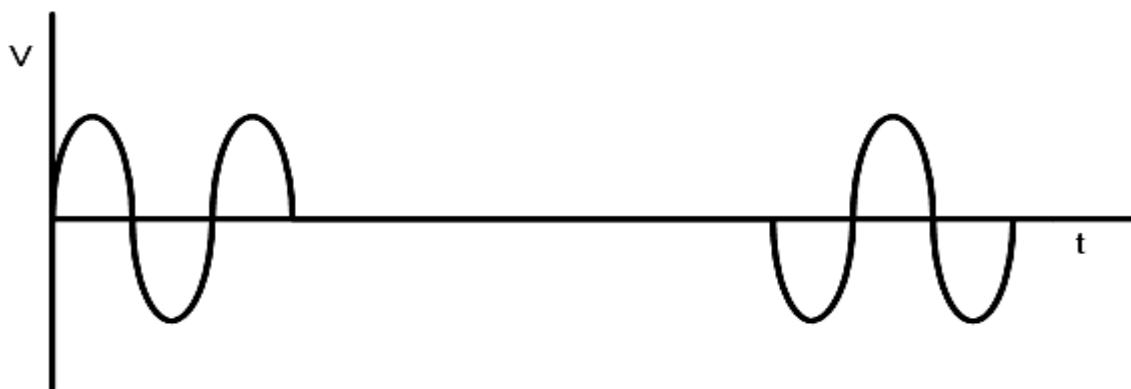


Figure-2.4: Long Interruptions

2.2.4 Transients

Transients are rapid deviations of the voltage values for durations from a several microseconds to few milliseconds [1]. These variations may reach thousands of volts, even in low voltage. Transients are of two types which are given below:

2.2.4.1 Impulsive Transients

An impulsive transient is a short unidirectional change in voltage, current, or both on a power line as shown in Figure-2.5. The main causes of impulsive transients are lightning, switching of inductive loads and disconnection of heavy loads [4]. The impulsive transients effects electronic components, insulation materials, and produce data processing errors and electromagnetic interference.



Figure-2.5: Impulsive Transients

2.2.4.2 Oscillatory Transients

An oscillatory transient is a small bidirectional change in voltage, current, or both on a power line. Reasons behind these transients are power factor correction capacitors, switching of inductive loads and transformer ferro-resonance. The effects of oscillatory transients are failure of insulation materials, overheating of all cables, equipment and electromagnetic interference.

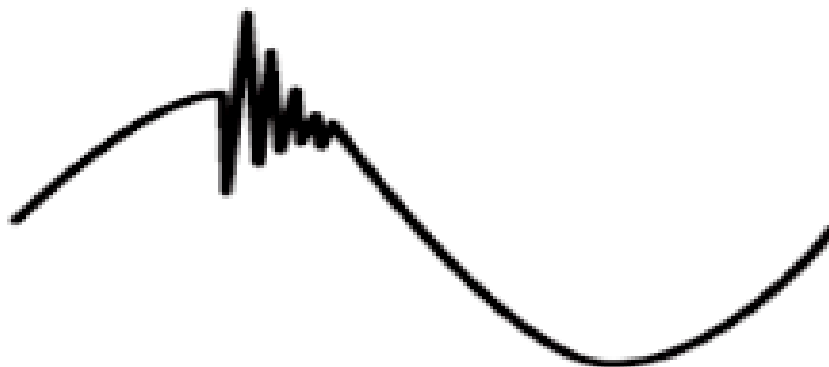


Figure-2.6: Oscillatory Transients

2.2.5 Harmonic Distortion

Harmonic distortion is the change in the waveform of the supply voltage from the ideal sinusoidal waveform. It is caused by the interaction of distorting customer loads with the impedance of the supply network. Its major adverse effects are the heating of induction motors, transformers and capacitors and the overloading of neutrals. Power factor correction capacitors can amplify harmonics to unacceptable values in the presence of harmonic distortion. Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angle of 6 each harmonic component [27].

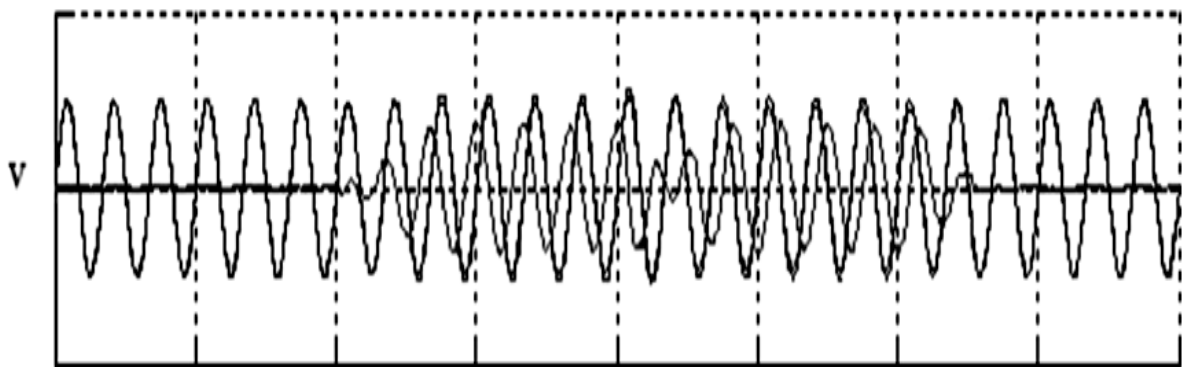


Figure-2.7: Harmonic Distortion

Harmonic distortion levels can be described by calculating total harmonic distortion (THD) which measures the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. THD is represented as the square-root of sum of the squares of each individual harmonic component. Voltage THD is given by

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

Where V_1 is the rms magnitude of the fundamental component and V_n is the rms magnitude of component n , where $n=2, \dots, \infty$.

The problem with this approach is that THD become infinity if no fundamental component is present. A way to avoid this ambiguity is to use an alternate definition that represents the harmonic distortion. This is called the distortion index (DIN) and is defined as

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

THD and DIN are interrelated by the following equations

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

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

2.2.6 Voltage Fluctuation

Voltage fluctuations can be described as repetitive or random variations of the voltage envelope due to sudden changes in the real and reactive power drawn by a load. The characteristics of voltage fluctuations depend on the load type and size and the power system capacity. Voltage fluctuations [4] may also cause spurious tripping of relays; interfere with communication equipment; and trip out electronic equipment. Voltage fluctuations are caused when loads draw currents having significant sudden or periodic variations. The fluctuating current that is drawn from the supply causes additional voltage drops in the power system leading to fluctuations in the supply voltage

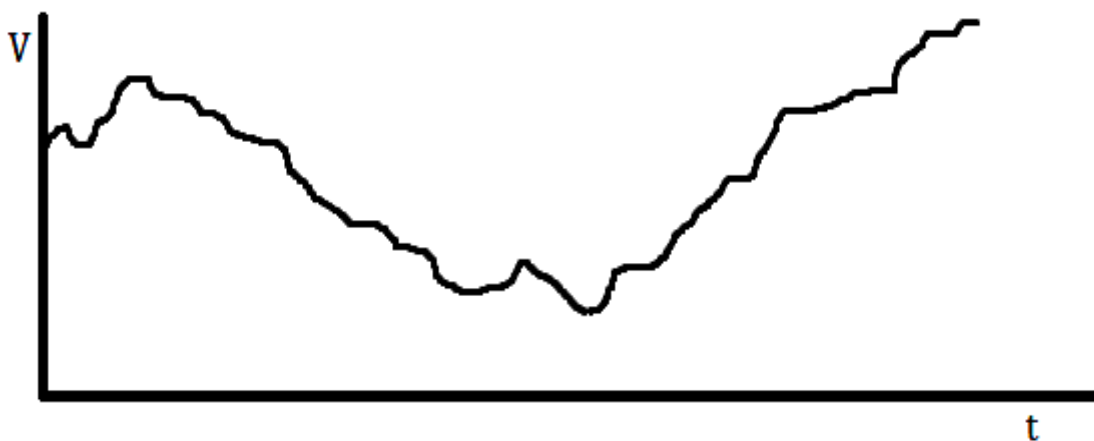


Figure-2.8: Voltage Fluctuation

2.2.7 Noise

Superimposing of high frequency signals on the waveform of the power system frequency. Noise is a disturbance with a broad frequency distribution upto about 200,000 Hz. It is caused due to radiation due to welding machines, electromagnetic interferences generated by hertzian waves such as microwaves, arc furnaces and electronic equipment and improper grounding. electrical noise may generate interference signals which increases the probability of transmission error rates [27]. Noise produces disturbances in sensitive electronic equipments and data processing errors.

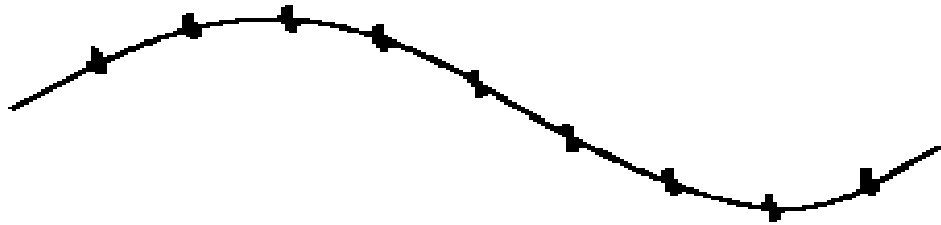


Figure-2.9: Noise

2.2.8 Voltage Unbalance

Voltage unbalance is referred as any difference in the magnitude or phase angle of the three-phase system voltage [4]. It is shown in Figure-2.10. The major causes of voltage unbalance include large single-phase loads (induction furnaces, traction loads) and incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault). The effects of voltage unbalance are unbalanced systems imply the existence of a negative sequence that is harmful to all three phase loads. Three-phase induction machines are affected adversely.

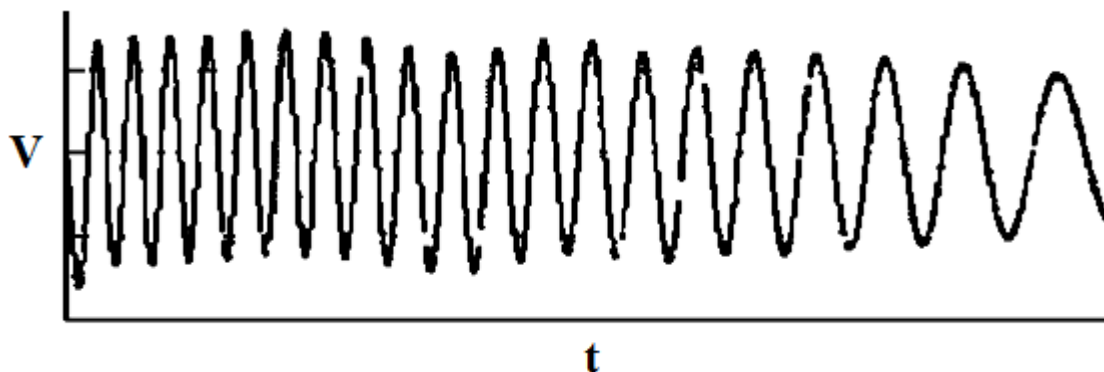


Figure-2.10: Voltage Unbalance

2.3 Solutions to PQ problems

The solution to the power quality can be done from customer side or from utility side.

Approaches that are used to improve the power quality are as follows:

- **Load conditioning:** It make certain that the equipment is less responsive to power disturbances, allowing the operation even under large voltage distortion.
- **Line conditioning systems:** They overcome or redress the power system disruptions. To achieve improve power quality is to use passive filters connected at the sensitive load terminals. The objection is to administer the sensitive load terminal voltage so that its magnitude remains same and any harmonic distortion is reduced to an adequate level.

DISTRIBUTION STATCOM

3.1 Introduction

DSTATCOM is basically a shunt connected solid state device which is installed at the Distribution level so as to control the load side disturbances. The first DSTATCOM, a SVC with Voltage Source Converter was employed in 1999. It has overcome the synchronous condenser because of its lower investment cost, better dynamics, no inertia, lower operating and maintenance cost. A power VSC based on high power electronic technologies is the heart of DSTATCOM [7]. DSTATCOM provides reactive power compensation in ac networks. The voltage source converter controls the exchange of reactive power between the Dc voltage storage device and the AC system through the leakage reactance of a transformer. DSTATCOM constantly verifies the line waveform with respect to the reference ac signal so as to provide the sufficient quantity of leading or lagging reactive current compensation to decrease the voltage fluctuations. A DSTATCOM is similar to STATCOM with the difference that STATCOM is used at the transmission level to control fundamental reactive power and to offer voltage support whereas a DSTATCOM is used at the distribution level for voltage regulation and correcting the power factor. DSTATCOM can also be employed to eliminate the total harmonic distortions, voltage sags and swells [9]. Moreover, a DSTATCOM can act as a shunt active filter, to reduce unbalance or distortions in the source current or the supply voltage.

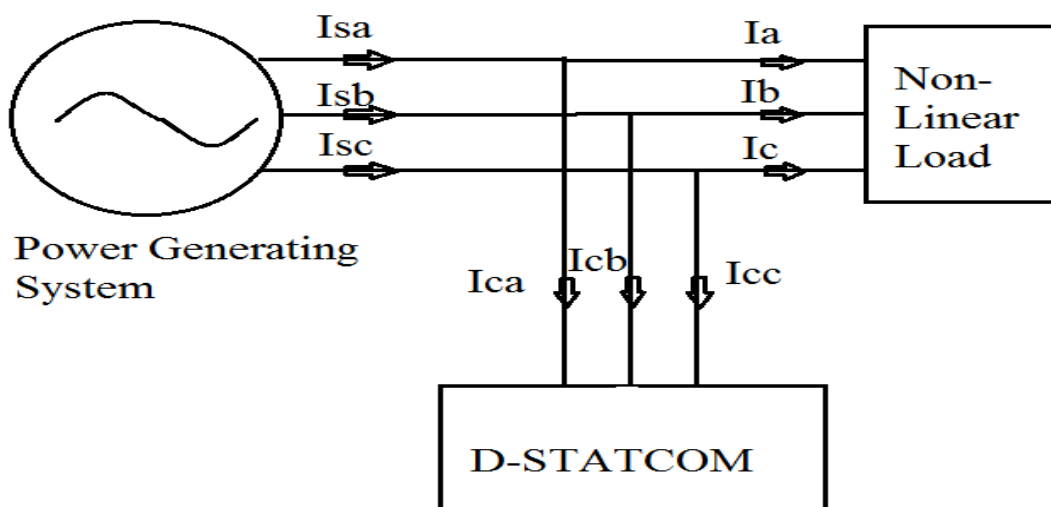


Figure-3.1: Basic Structure of the DSTATCOM [7]

3.2 Basic Configuration of DSTATCOM

The main components of DSTATCOM are:

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

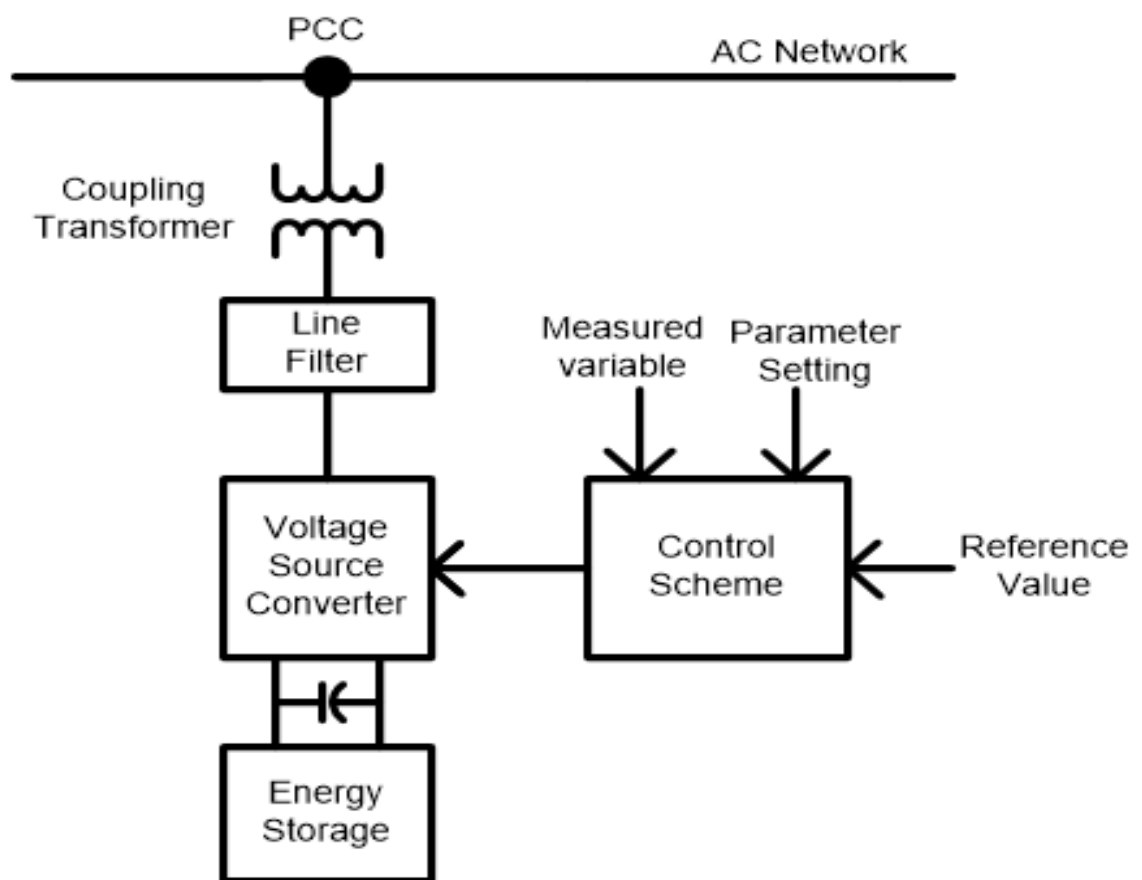


Figure-3.2: Schematic Representation of the DSTATCOM [10]

3.2.1 Voltage Source Converter

A VSC converts the DC voltage across storage device into a three phase AC output voltage wave. This output voltage is controlled in magnitude and phase angle to generate required leading or lagging reactive power for compensation. A VSC [8] can be a 3-phase, 3-wire or 3-phase, 4-wire. It can be a two level converter or a three level converter. In this work, a two level VSC is utilized.

3.2.2 Energy Storage Device

DC source is connected in shunt with the DC capacitor. It is the major element that stores the reactive energy and carries the input ripple current. This storage device is charged by a battery source or can be recharged by a converter itself. Its main function is to supply energy to VSC through a dc link to generate the injected voltage.

3.2.3 L-C Passive Filter

The selection of LC filter is based on the type of system and the presence of harmonics at the inverter output. To eliminate the harmonics and to match the output impedance of inverter, LC filter is utilized.

3.2.4 Coupling Transformer

The output voltage of voltage source converter is linked with the AC system via coupling transformer. These voltages are coupled with AC system through the reactance of coupling transformer.

3.2.5 Control Block

The main functions of Control block are the detection of fault, voltage sag and voltage swell in the system, computation of voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter and closing the trigger pulses when the event has passed. External devices such as mechanically switched capacitor banks are also controlled by the control blocks. These control blocks are designed on the basis of various control theories and algorithms like instantaneous DQO theory, synchronous frame theory etc.

3.3 Location of DSTATCOM

The DSTATCOM is connected in shunt with distribution system as shown in Figure-3.3. Here in this figure three distribution feeders are considered. These feeders are feeding different sensitive loads. DSTATCOM is connected at the point of common coupling to inject current into the system when any non-linearity occurs due to these loads.

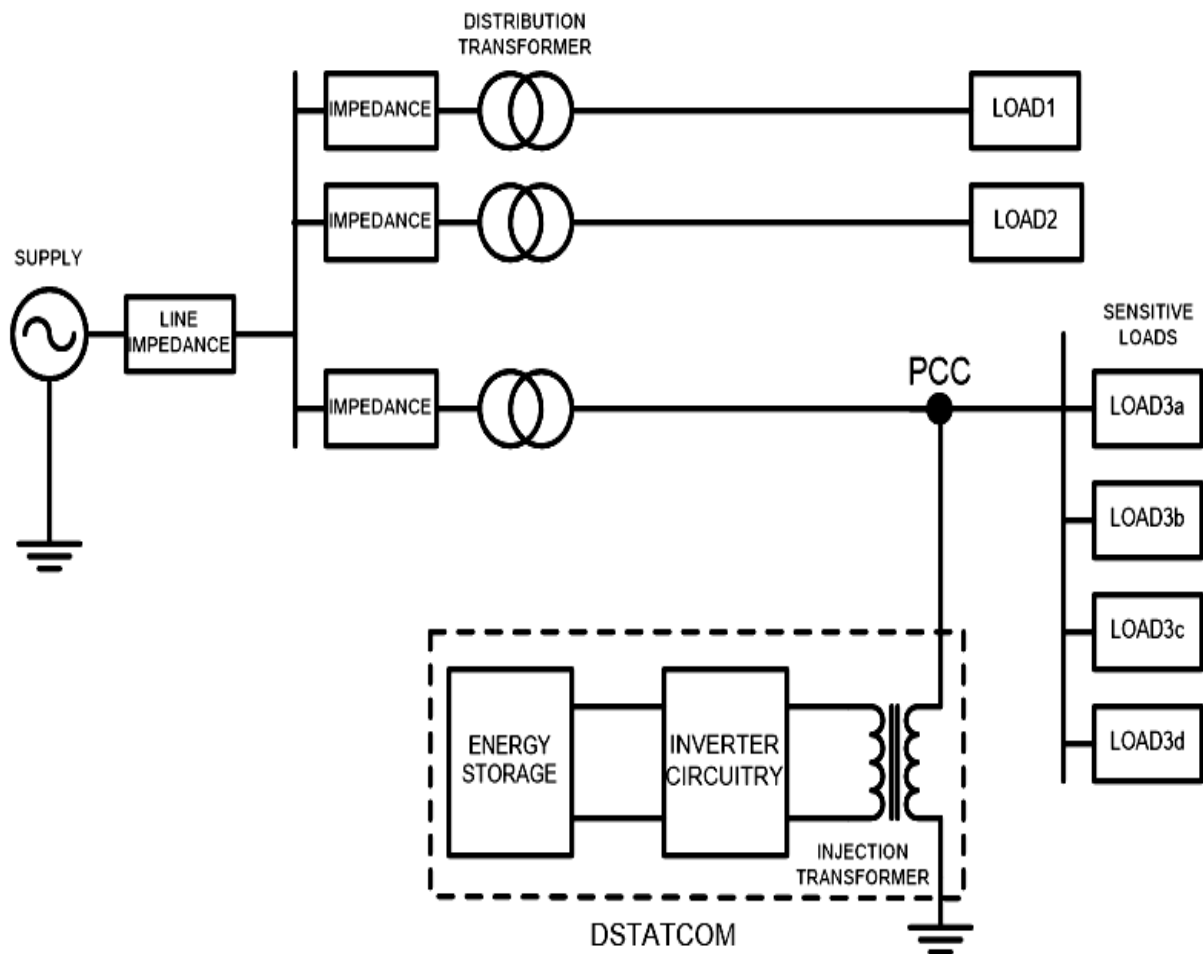


Figure-3.3: Typical Location of DSTATCOM in Distribution System [10]

3.4 Principle of DSTATCOM

A DSTATCOM is a solid state power electronic switching device which includes either GTO or IGBT, an energy storage device, a coupling transformer and a controller. The fundamental principle of a DSATCOM is same as that of synchronous machine. The synchronous machine supplies lagging current when under excited and leading current when over excited. Similarly, DSTATCOM can produce and absorb reactive power depending upon the compensation required [10,11]. The DSTATCOM is linked to the power networks at a PCC, where the voltage-quality problem occurs. All the necessary voltages and currents are calculated and are compared with the commands by the controller. The controller then executes feedback control and generates a set of switching pulses to drive the power converter. Figure-3.4 shows a single line diagram of a DSTATCOM.

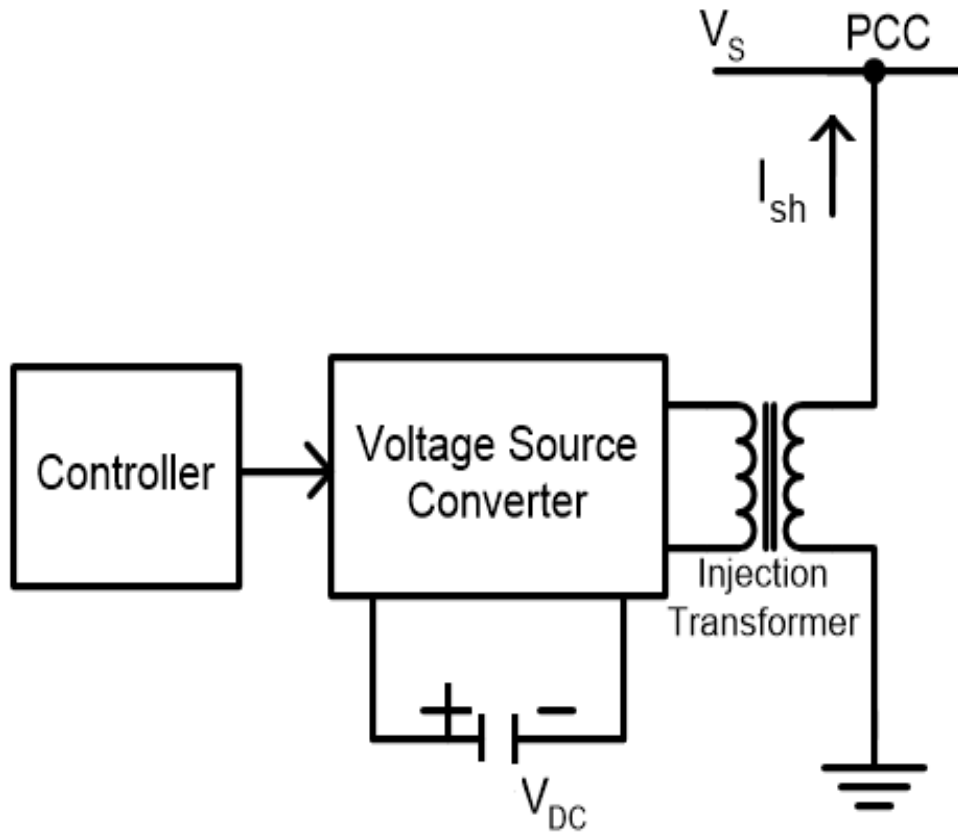


Figure-3.4: Single Line diagram of DSTATCOM [25]

The IGBT based VSC changes the DC voltage into a set of three-phase ac output voltages. These voltages are in phase and linked with the AC system through the reactance of the coupling transformer. To efficiently control the active and reactive power exchange between the DSTATCOM and the ac system, appropriate alteration of phase and magnitude of DSTATCOM output voltages is done.

3.4.1 Exchange of Reactive Power

Variable amplitude 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-

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

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.

Reactive power exchange between DSTATCOM and AC system is explained through following cases:

Case I: If the amplitudes of the DSTATCOM output voltage which is V_i and the AC system voltage which is V_s are equal, the reactive current is zero and the DSTATCOM does not generate/absorb reactive power. It is shown in Figure-3.5.

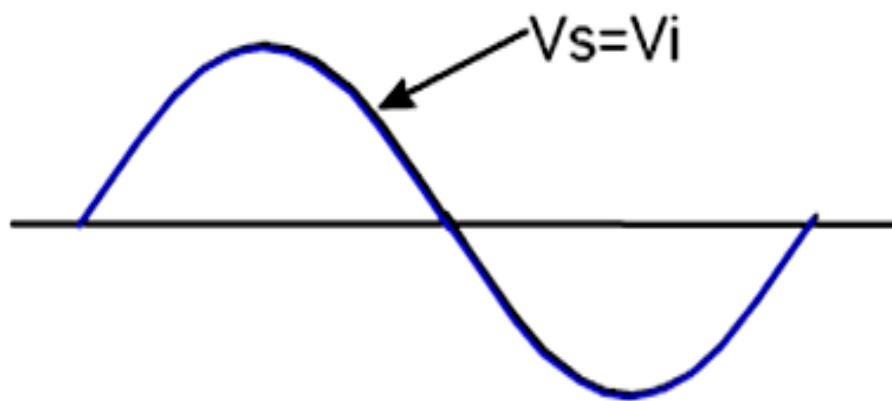


Figure-3.5: No Load Operation [10]

Case II: If the amplitude of the DSTATCOM output voltage is increased above the amplitude of the AC system voltage, the lagging current flows through the transformer reactance from the DSTATCOM to the AC system, resulting in the device generating capacitive reactive power. It is shown in Figure-3.6.

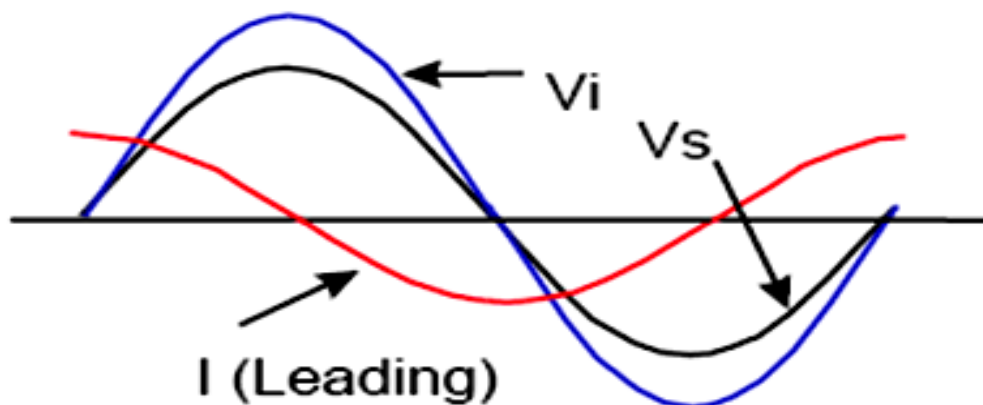


Figure-3.6: Capacitive Operation [10]

Case III: If the amplitude of the DSTATCOM output voltage is decreased to a level below that of the AC system, then the leading current flows from the AC system to the DSTATCOM and the device produce inductive reactive power. It is shown in Figure-3.7.

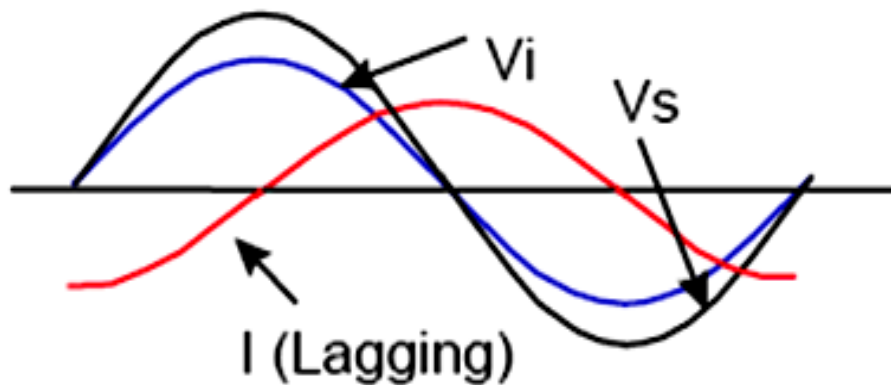


Figure-3.7: Inductive Operation [10]

3.4.2 Exchange of Active Power

The DC capacitor is required to supply real power to the switches because greater switching devices are employed. To make the capacitor voltage constant, real power exchange is required in the case of direct voltage control. Figure-3.8 shows the V-I characteristic of the DSTATCOM. The voltage from V_1 to V_2 is smoothly and continuously controlled by the DSTATCOM.

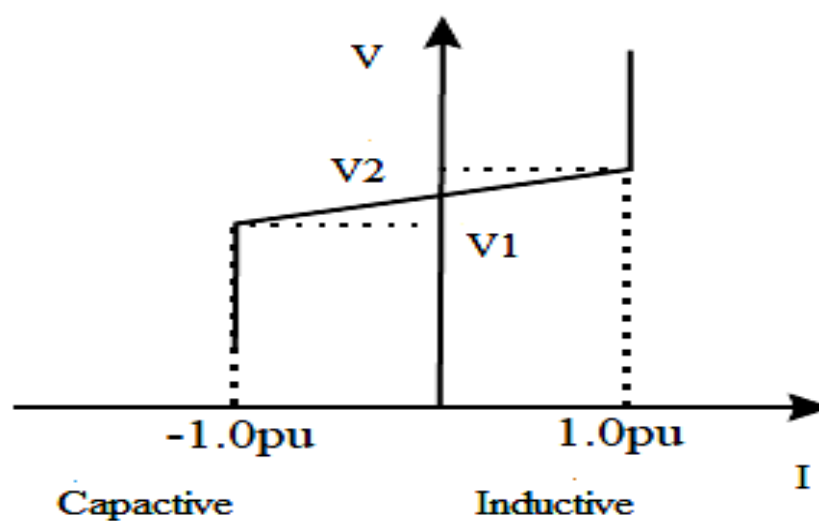


Figure-3.8: V-I Characteristic of a DSTATCOM [10]

In case of very low voltage in the distribution system or in case of faults, there is a real power exchange with the AC system if DSTATCOM is provided with an external DC source to regulate the voltage. If the VSC output voltage leads the system voltage then the real power from the capacitor or the DC source will be supplied to the AC system to regulate the system voltage equal to 1p.u or to make the capacitor voltage constant.

3.5 Load Compensation using DSTATCOM

The schematic diagram shown in Figure-3.9 describes a distribution system compensated by DSTATCOM. Suppose, the DSTATCOM is working in current control mode and Load-1 is non-linear, reactive and unbalanced. Initially without compensator, the unbalanced and distorted current I_s is flowing through the feeder, which results in unbalanced voltage of bus-1.

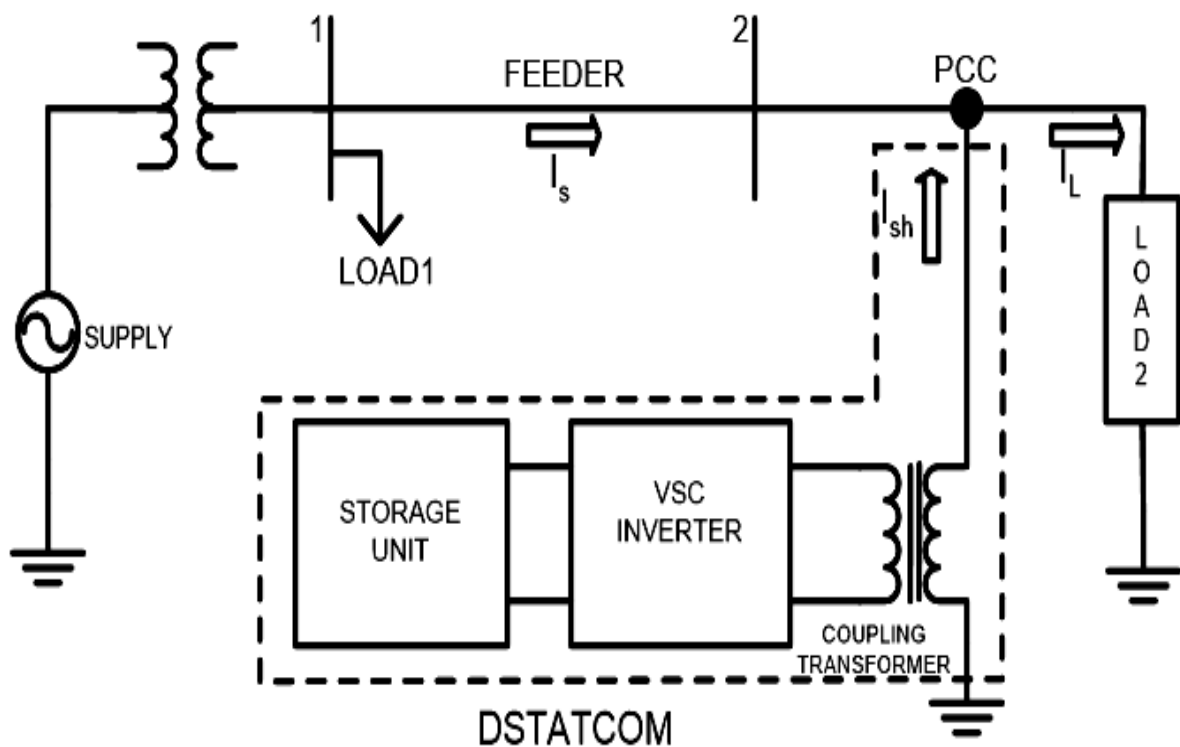


Figure-3.9: Schematic Diagram of Ideal Load Compensation [11]

To eliminate this problem, DSTATCOM injects I_{sh} current so as to make current I_s fundamental and positive sequence and compel I_s to be in phase with the bus-1 voltage. The method of operating the DSTATCOM to compensate the load current is known as load compensation. The compensated load will obtain a unity power factor and a fundamental

positive sequence current. The utility customer point of common coupling (PCC) is the point at which the compensator is linked with the system. Representing the load current by I_L , the KCL at the PCC yields:

$$I_s + I_{sh} = I_L \quad (1)$$

So, from above equation I_{sh} is written as:

$$I_{sh} = I_L - I_f \quad (2)$$

The main function of the compensator is that it produces a current I_{sh} that cancels the reactive component, harmonic component and unbalance of the load current.

3.6 Principle of Voltage Regulation

(A) Voltage Regulation without DSTATCOM [10]

Figure-3.10 represents a simple circuit which consists of a source Voltage E , voltage at a PCC V and a load current I_L . In the absence of a voltage compensator, the PCC voltage drop produced by the load current I_L , is shown in Figure-3.10. ΔV is given by equation (1):

$$\Delta V = E - V = Z_s * I_L \quad (1)$$

Also

$$S = VI_L^*$$

$$\text{So, } S^* = V^* I_L \quad (2)$$

From equation (2)

$$I_L = \frac{P_L - jQ_L}{V} \quad (3)$$

Put the value of I_L from equation (3) into equation (1)

$$\begin{aligned} \Delta V &= (R_s + jX_s) \left(\frac{P_L - jQ_L}{V} \right) \\ &= \frac{(R_s P_L - X_s Q_L)}{V} + j \frac{(X_s P_L + R_s Q_L)}{V} \\ &= \Delta V_r + \Delta V_s \end{aligned} \quad (4)$$

The voltage change has a component ΔV_r in phase with V and component ΔV_s , which are illustrated in Figure-3.11. The magnitude and the phase of V , relative to the supply voltage E , are functions of the magnitude and phase of the load current. In other words the voltage drop depends on both the real and reactive power of the load. The component ΔV is rewritten as

$$\Delta V = I_s R_s + j I_s X_s \quad (5)$$

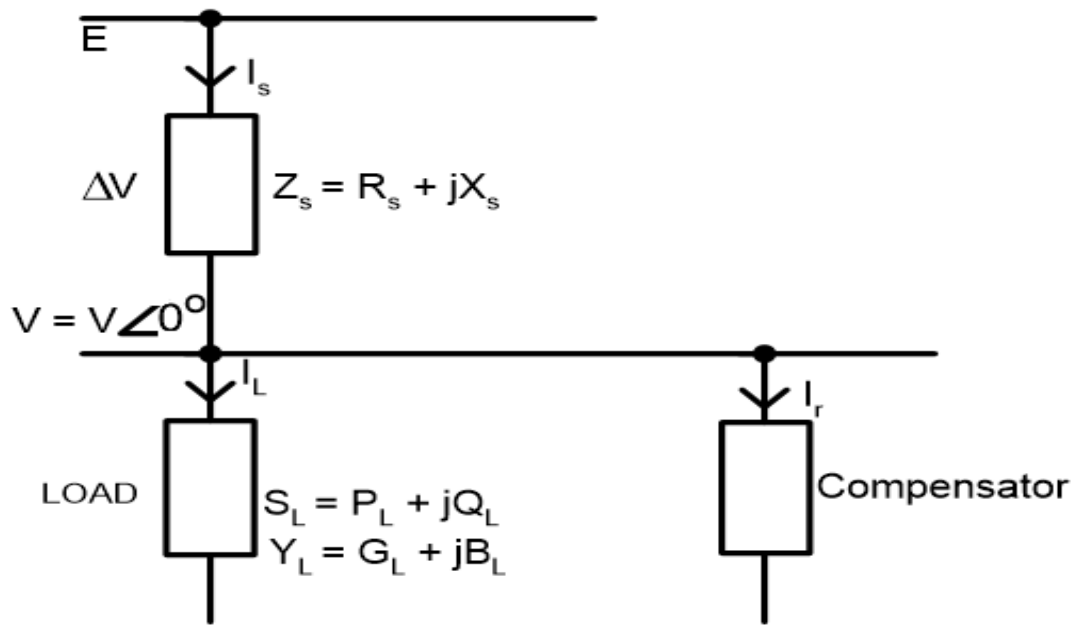


Figure-3.10: Circuit for Demonstrating the Voltage Regulation Principle

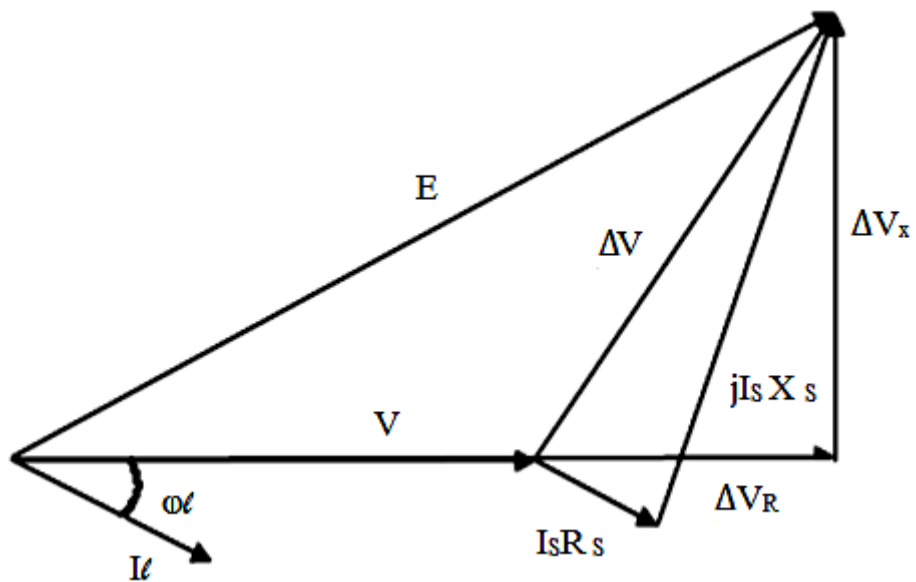


Figure-3.11: Phasor Diagram for Voltage Regulation without DSTATCOM

(B) Voltage Regulation with DSTATCOM

A compensator is coupled with the system load. Figure-3.12 describes the vector diagram for voltage compensation. By employing a compensator in parallel with the load, it is possible to make $E=V$ by controlling the current of the compensator.

$$I_s = I_r + I_L$$

Where I_r is the compensating current.

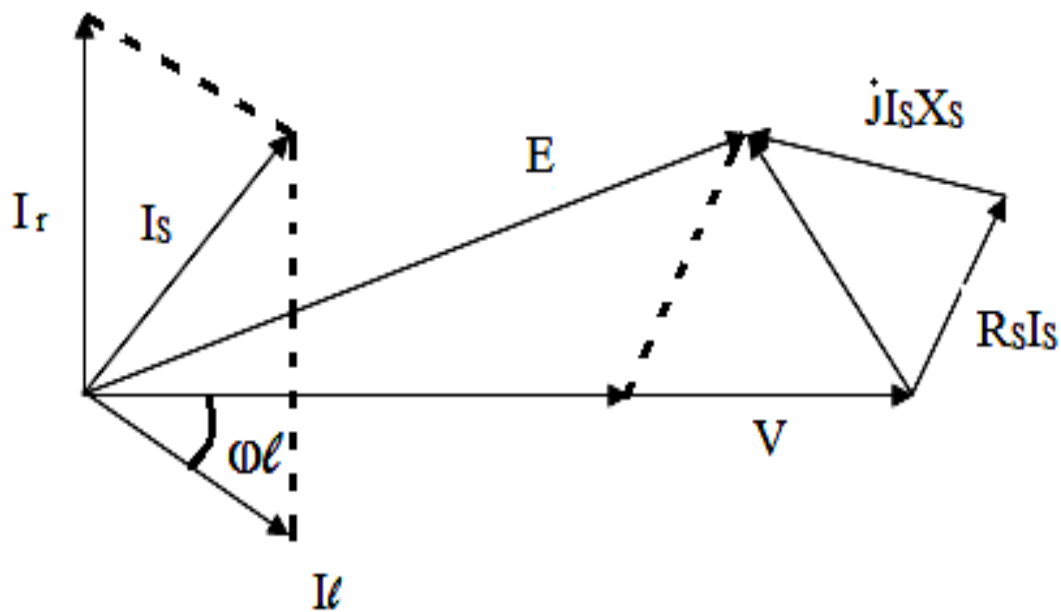


Figure-3.12: Phasor Diagram for Voltage Regulation with DSTATCOM

3.7 Advantages of DSTATCOM

The major benefits of using DSTATCOM are as follows:

- Better dynamics, no inertia, lower operating, lower investment cost and maintenance cost than synchronous condenser.
- Continuous and dynamic voltage control.
- Allows full grid control.
- High dynamic and fast step response of 8 ms to 30 ms.
- Helps in system stability control as active power control is possible with a DSTATCOM.
- Maximum reactive current over extended voltage range.
- High efficiency.

- Single phase control for unbalanced loads.
- No potential for making a resonance point. This is because no capacitor banks or reactors are essential to produce the reactive power for a DSTATCOM.

3.8 Applications of DSTATCOM

A DSTATCOM is similar to STATCOM with the difference that STATCOM is used at the transmission level to control fundamental reactive power and to offer voltage support whereas a DSTATCOM is used at the distribution level for voltage regulation and correcting the power factor. Various applications of DSTATCOM are as follow:

- The DSTATCOM provides high speed control over reactive power to compensate voltage.
- DSTATCOM defend the utility distribution system from voltage sags and flicker caused due to varying reactive current demand.
- A DSTATCOM supply leading or lagging reactive power to attain system stability during transient conditions.
- The DSTATCOM can also be utilized for industrial facilities to compensate voltage sag and flicker that are caused by non-linear dynamic loads.
- The DSTATCOM provides instant reactive power exchange across the distribution system without using bulky capacitors or reactors.
- In many applications, a DSTATCOM can utilize its very important short-term transient overload capability to decrease the size of the compensation system required to handle transient incidents. The short-term overload capability is up to 325% for periods of 1 to 3 seconds. The DSTATCOM controls mechanically switched capacitors to produce the possible compensation on a both a transient and steady state basis.
- DSTATCOM can also be employed for the utilities having weak grid knots or fluctuating reactive loads.
- It can be used for delivering unbalanced loads (like arc furnace load, wood chippers, welding operations, car crushers & shredders etc.).
- DSTATCOM finds various applications in wind farms and industrial mill for the improvement of power quality.

3.9 DQO Transformation

The dqo transformation or Park's transformation [12,14] is used to control of DSTATCOM. The benefit of using dqo method is that it gives information about current unbalance, phase faults and phase shift with start and end times. The quantities are expressed as the instantaneous space vectors. The load currents which are in a-b-c frame are first transformed into α - β frame using Clark's transformation as shown in equation (1). Then this α - β frame is converted to dqo frame given by equation (2). This is also called as Park's transformation.

$$\begin{pmatrix} i_\alpha \\ i_\beta \\ i_0 \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \quad (1)$$

If θ is the transformation angle, then the currents transformation from α - β to d-q is defined as:

$$\begin{pmatrix} i_d \\ i_q \\ i_0 \end{pmatrix} = \begin{pmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \\ i_0 \end{pmatrix} \quad (2)$$

Inverse Park's transformation can now applied to obtain three phase reference currents in a-b-c coordinates from the i_d , i_q dc components given by equation (3).

$$\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos \theta & -\sin \theta & \frac{1}{\sqrt{2}} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & \frac{1}{\sqrt{2}} \\ \cos(\theta - \frac{4\pi}{3}) & -\sin(\theta - \frac{4\pi}{3}) & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} i_d \\ i_q \\ i_0 \end{pmatrix} \quad (3)$$

The flow chart of the feed forward dqo transformation is shown in figure-3.13.

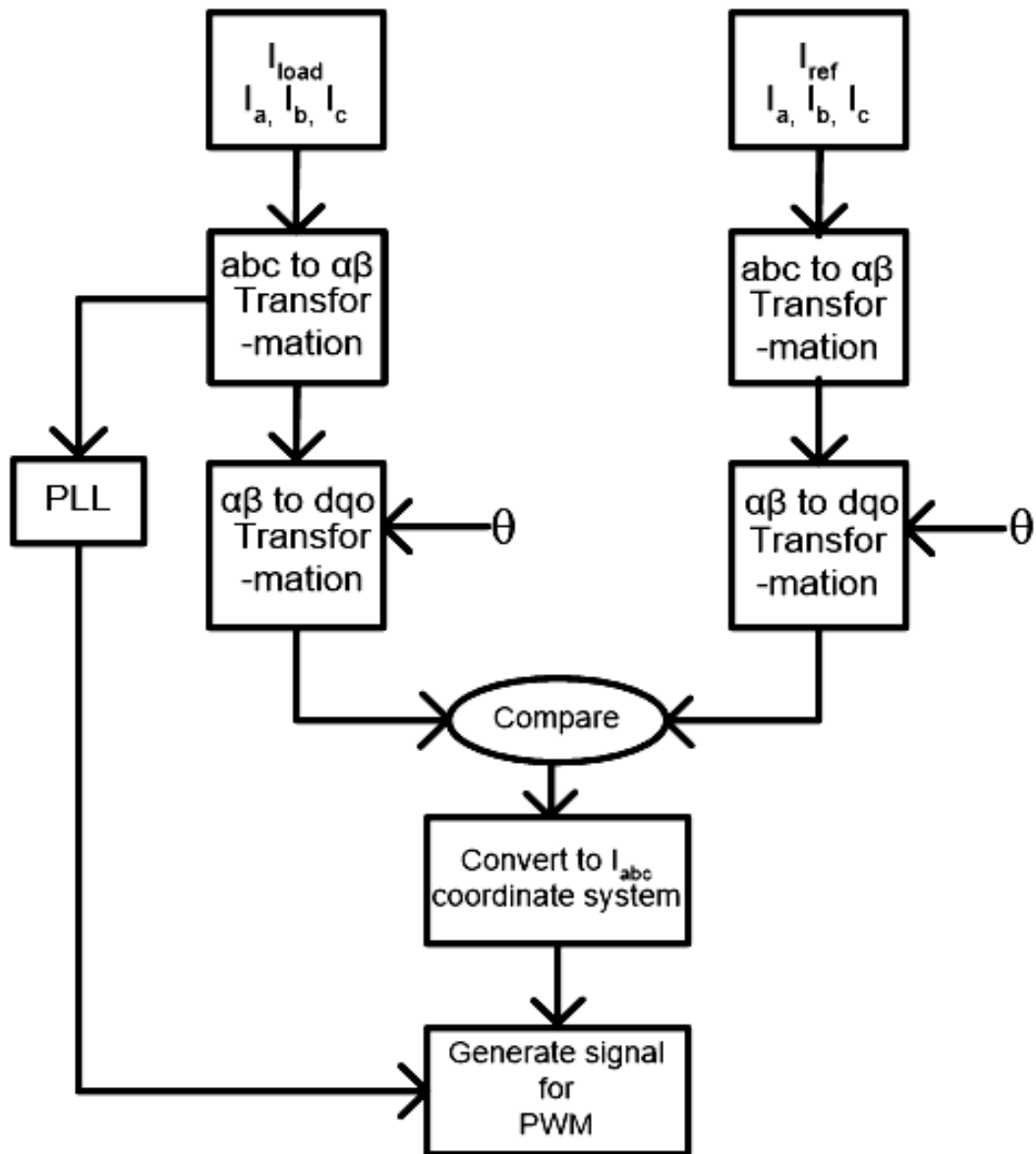


Figure-3.13: Flow Chart of DQO Transformation [12]

3.10 Control Scheme

The main functions of controller are the detection of fault, voltage sag and voltage swell in the system, computation of voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter and closing the trigger pulses when the event has passed. DSTATCOM reacts rapidly on the detection of fault and inject an ac current to the grid. It can be applied using a feedback control technique on the basis of reference current and load current. Figure-3.14 represents the basic control scheme.

The load current is sent to a transformer block that converts stationary a-b-c frame to rotating α - β frame. Transformation block's output is given to a phase lock loop(PLL) and another transformation block. The second transformation block converts $\alpha\beta$ frame to dqo, and also detects fault in load current [13,14]. Whenever fault occurs, the fault detection block produces the reference supply current. The difference between the reference current and the load current produces the injection current. Using Inverse Park's transformation, DC components i_d and i_q are converted into three phase reference currents in a-b-c coordinates and with the help of pulse width modulation(PWM), these reference currents are transferred to converter to generate the required current.

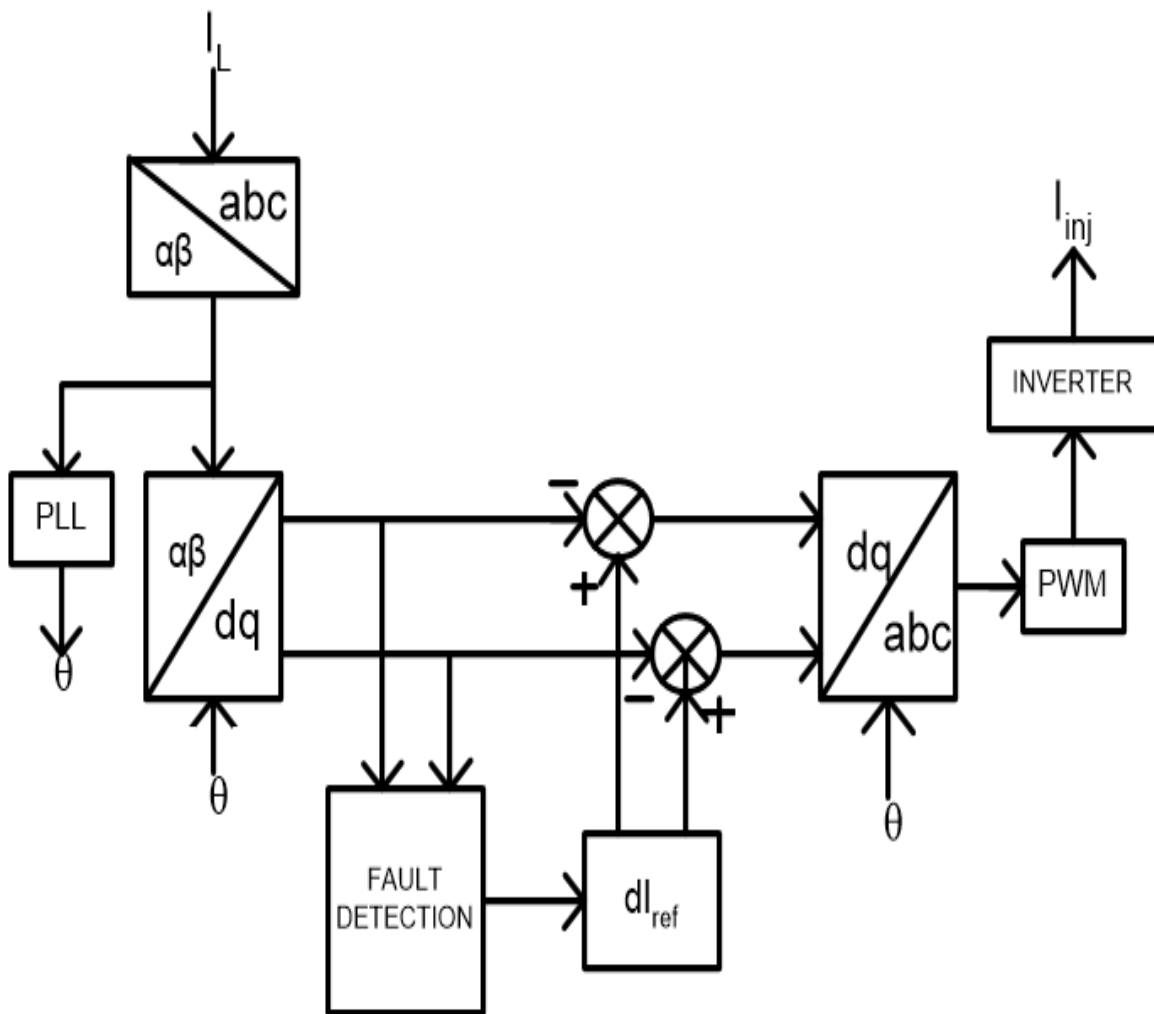


Figure-3.14: Control Scheme [14]

3.11 PI CONTROLLER

3.11.1 Introduction

A PI-Lead controller is a proportional gain in parallel with an integrator; both in series with a lead controller. The proportional gain provides fast error response. The integrator drives the system to a 0 steady-state error. PI controller is one of the most widely sought after controller in industry as it is the simplest to design. The overview of PI controller is given below:

Proportional (Gain)

‘P’ is Proportional control in which the output varies based on how far you are from your target. The error is multiplied by a negative (for reverse action) proportional constant P, and added to the current output. P represents the band over which a controller's output is proportional to the error of the system. E.g. for a heater, a controller with a proportional band of 10 deg C and a set point of 100 deg C would have an output of 100% up to 90 deg C, 50% at 95 Deg C and 10% at 99 deg C. If the temperature overshoots the set point value, the heating power would be cut back further. Proportional only control can provide a stable process temperature but there will always be an error between the required set point and the actual process temperature.

Integral (Reset)

‘I’ is an Integral control in which the output varies based on how long it’s taking you to get to your target. The error is integrated (averaged) over a period of time, and then multiplied by a constant ‘I’, and added to the current control output. ‘I’ represent the steady state error of the system and will remove set point/measured value errors. For many applications Proportional + Integral control will be satisfactory with good stability and at the desired set point.

3.11.2 Advantages and Disadvantages

- Advantages (Combined benefits)
 - Fast action
 - Eliminate the offset
- Disadvantage
 - Oscillatory or unstable with integral control
 - One more parameter to tune

TEST SYSTEM AND RESULTS

4.1 Introduction

As conventional equipment cannot be used to solve the power quality problems like voltage sags, voltage swells, flicker, harmonic distortion and interruption of power supply, PWM converter-based parallel connected power conditioner named DSTATCOM has been introduced. DSTATCOM consists of PWM voltage source inverter circuit and a DC capacitor connected at one end. The integrated gate bipolar transistor (IGBT), because of its lower switching losses and small size, is used for the distribution voltage level. As a result, the pulse width modulation (PWM) switching method is used to limit the output voltage. Addition of Energy storage system to the power conditioner makes the system operation more flexible and also it provides easy planning for utilities and industry. In this thesis, MATLAB/SIMULINK (version 11) software has been used to design and develop DSTATCOM based upon dqo transformation. This test system is analysed under normal and load perturbation conditions. The DSTATCOM is connected to the common feeder supplying the unlike loads. The control technique employs a dqo transformation which starts when the difference between the load current and reference current is observed. Consequently, the reference voltage for the inverter (modulating reference signal) is produced.

In this work, simulation to check the effectiveness of DSTATCOM to compensate the load current harmonics under various operating conditions of the distribution network is carried out for different loads which are as follows:

- Active load (wind turbine using asynchronous generator)
- Non-linear load (FOC induction motor drive load)

4.2 Parameters of the Test System

The modelled system has been tested on different loads i.e.. active load and FOC induction motor drive load. The system is employed with three phase programmable voltage source with configuration of 11KV, 50 Hz. The source is feeding a distribution line. System test parameters are listed below in Table 4.1.

Table 4.1: SYSTEM PARAMETERS

Serial No.	System Quantities	Parameters
1.	Source	3-phase, 338 V _{rms} (phase-phase), 50Hz, 500MVA, Short circuit level(VA), 11kV Base voltage
2.	Convertor	IGBT based, 3-arms, 6-pulse, $R_{on} = 1m\Omega$.
3.	FOC Induction Motor Drive	Nominal Power 2238 VA, 11 KV, 50 Hz Stator Resistance $R_s = 0.435 \Omega$ Stator Leakage Reactance $X_s = .002 \Omega$ Rotor Resistance $R_r = 0.816 \Omega$ Rotor Leakage Reactance $X_r = .002 \Omega$ Mutual Inductance = 69.3 mH
4.	Wind Turbine	Nominal mechanical output power (360KW) Base wind speed (12 m/s)
5.	Asynchronous Generator	Rotor type = squirrel cage Voltage = 480 V _{rms} (line-line), 50 Hz, Stator resistance = 0.016 Ω Stator inductance = 0.06 H Rotor resistance = 0.015 Ω Rotor inductance = 0.06 H Mutual inductance = 3.5 H

4.3 Block Diagram of Test System for Current Harmonic Compensation

In this case, it is observed that the total harmonic distortion (THD) level of the load current is 5.31% which is due to the presence of the non-linear load i.e. FOC induction motor drive. However, due to the coupling of DSTATCOM in the network, the supply current remains unaffected i.e. the THD level of the supply current is observed to be 0%. This means the proposed DSTATCOM effectively compensates the harmonics present in the load current and as a result these are not present in the source current. Block diagram of SIMULINK model of the test system is given in Figure-4.1.

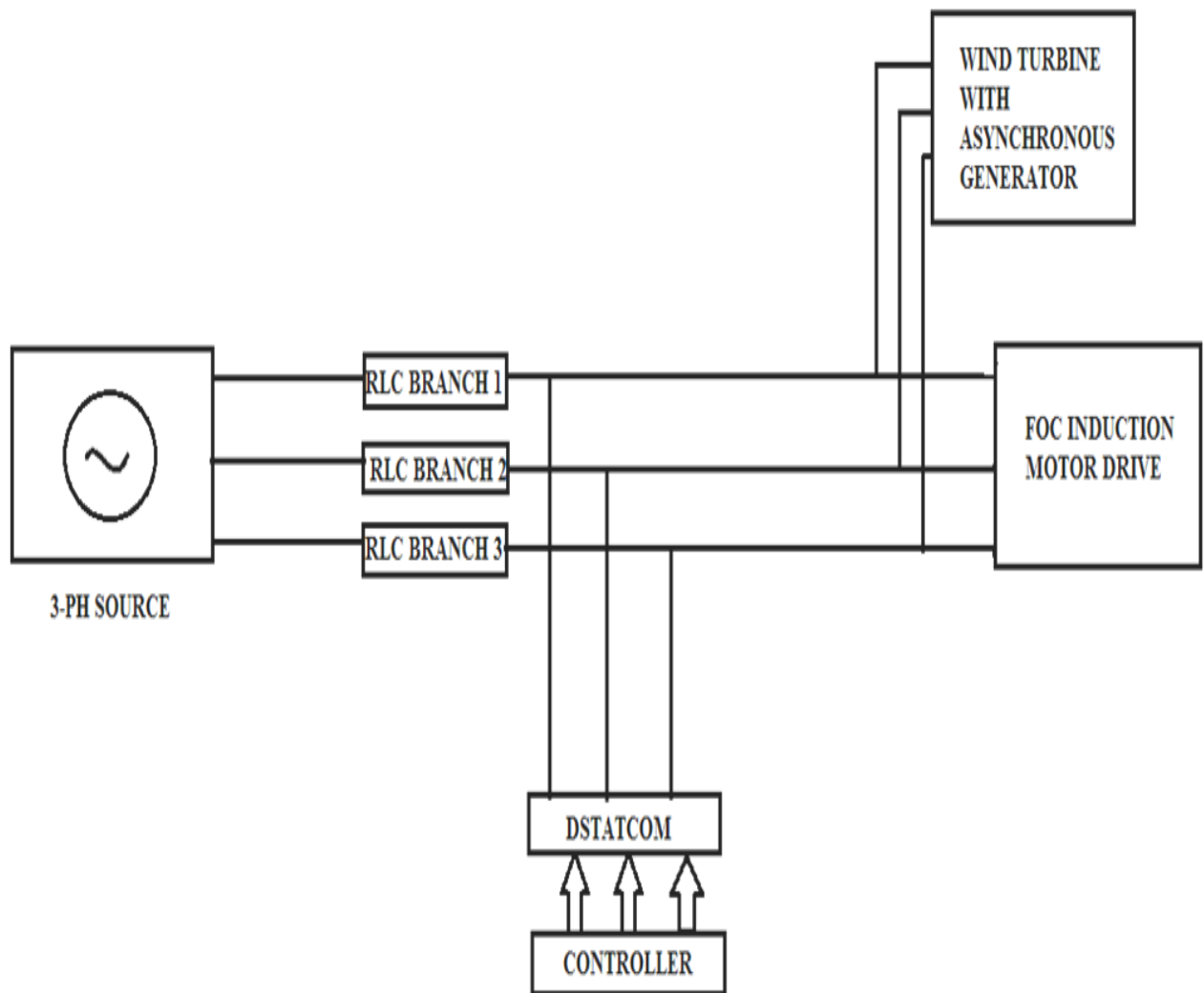


Figure-4.1: Block Diagram of SIMULINK Model for Current Harmonic Compensation

The output waveforms of supply voltage, supply current, load voltage and load current along with their frequency spectrums graphs are shown below. The THD level in every case is observed.

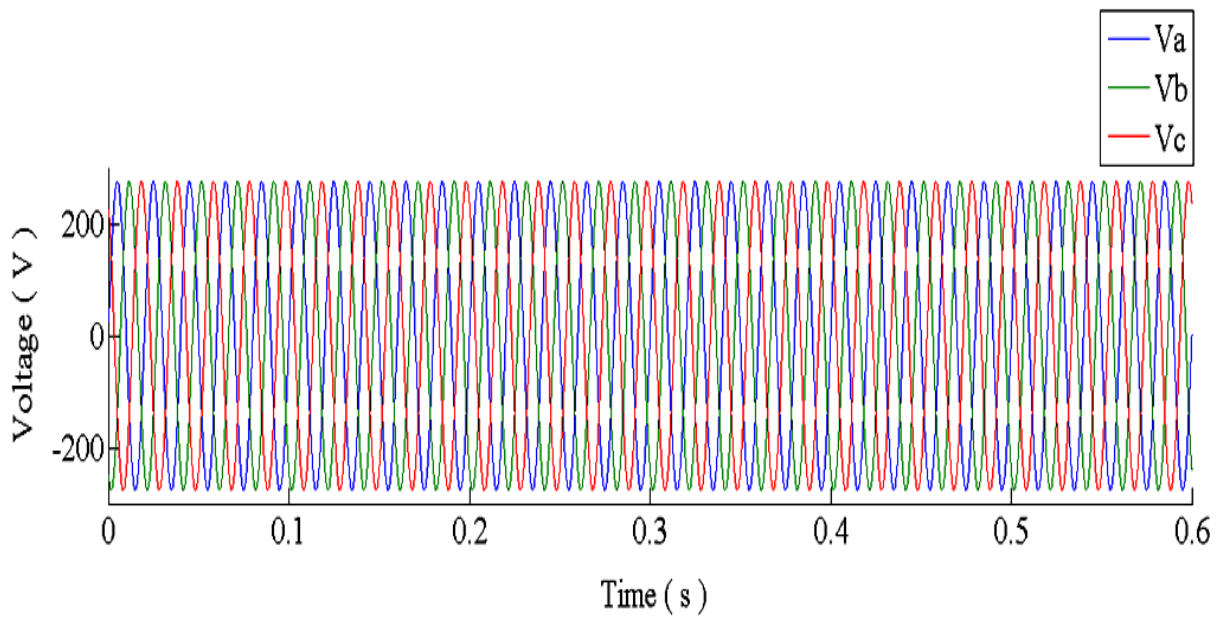


Figure-4.2: Output Waveform of Supply Voltage

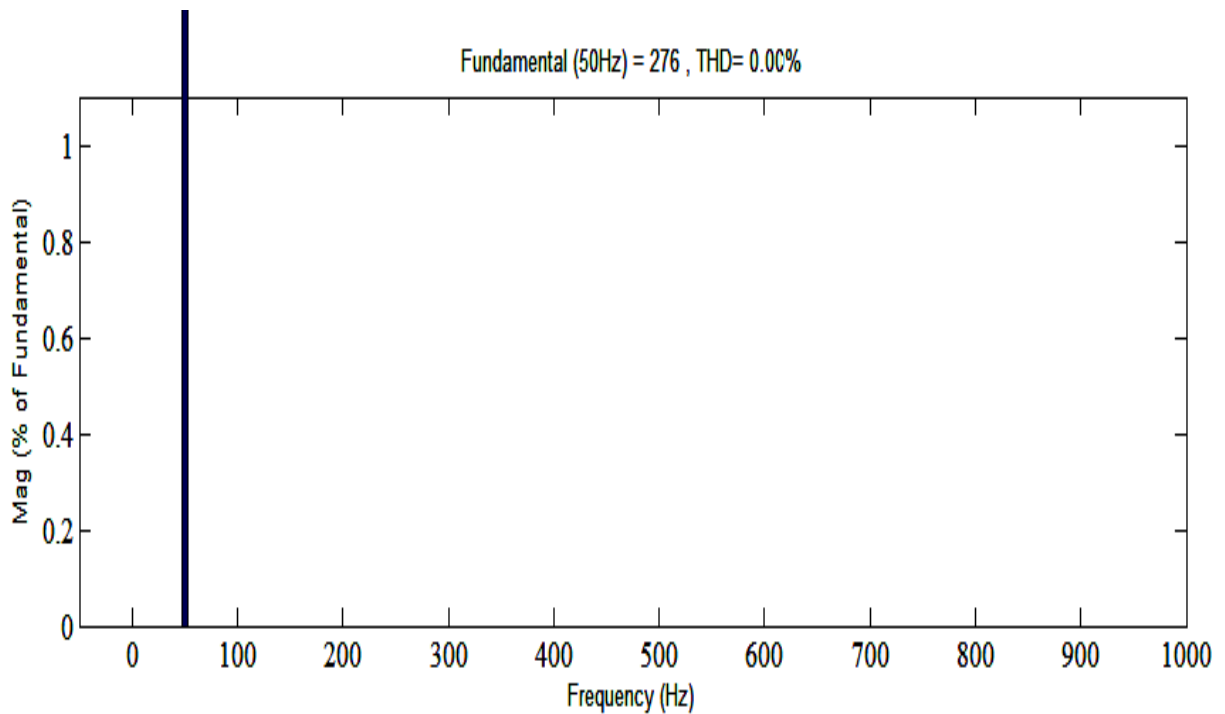


Figure-4.3: Frequency Spectrum of Supply Voltage

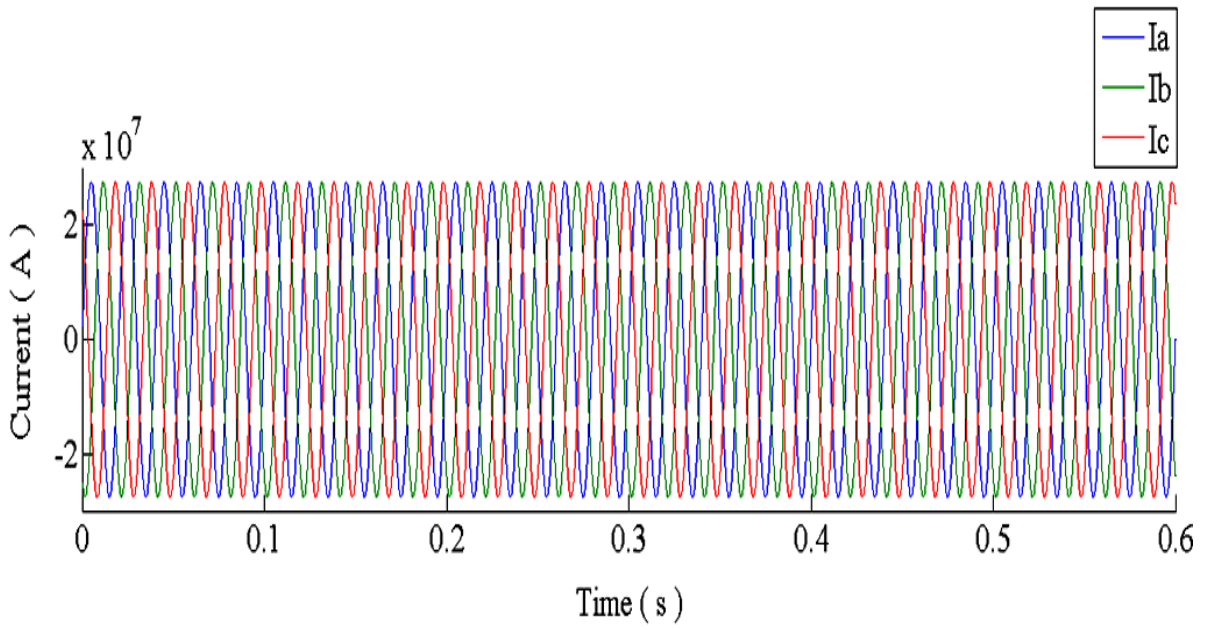


Figure-4.4: Output Waveform of Supply Current

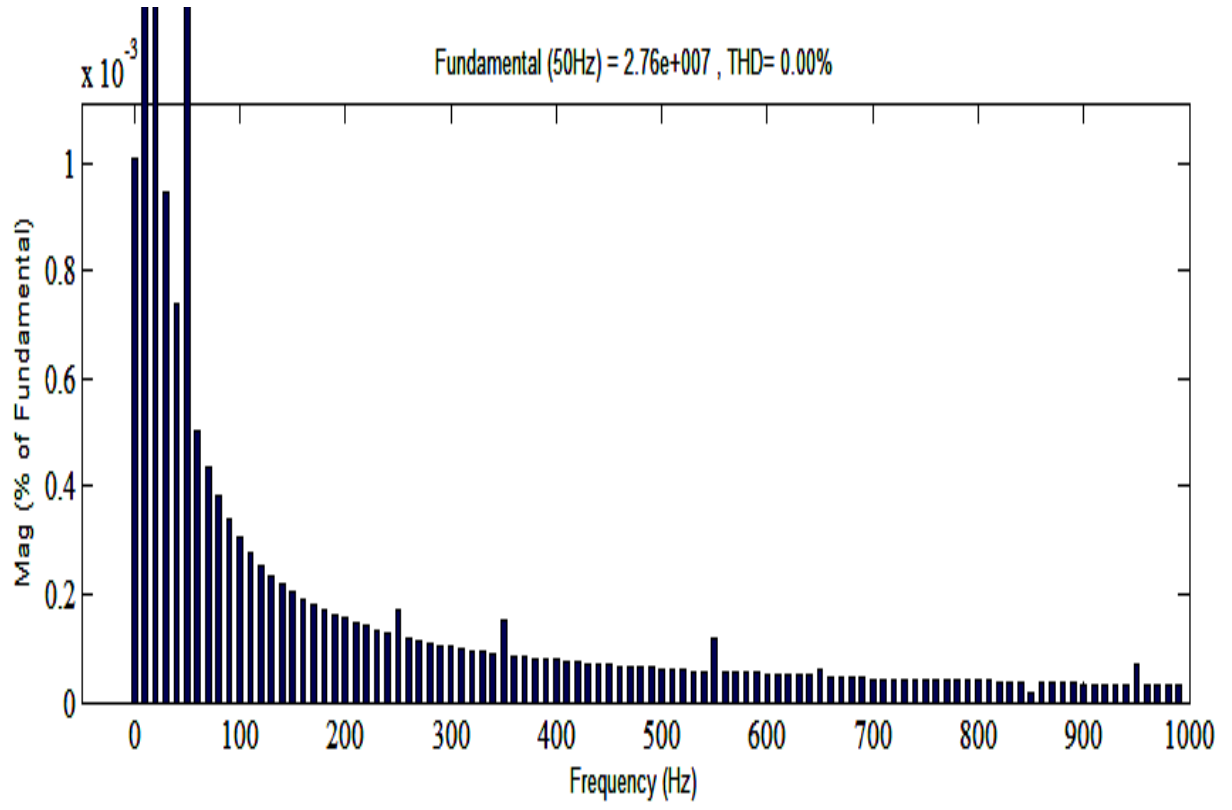


Figure-4.5: Frequency Spectrum of Supply Current

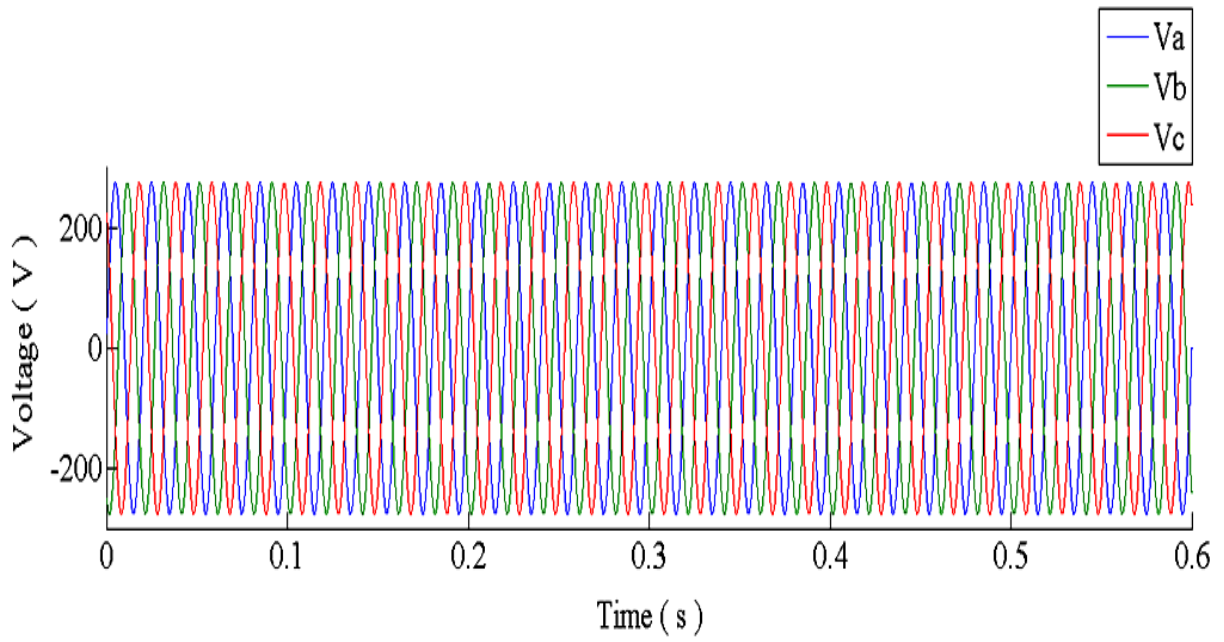


Figure-4.6: Output Waveform of Load Voltage

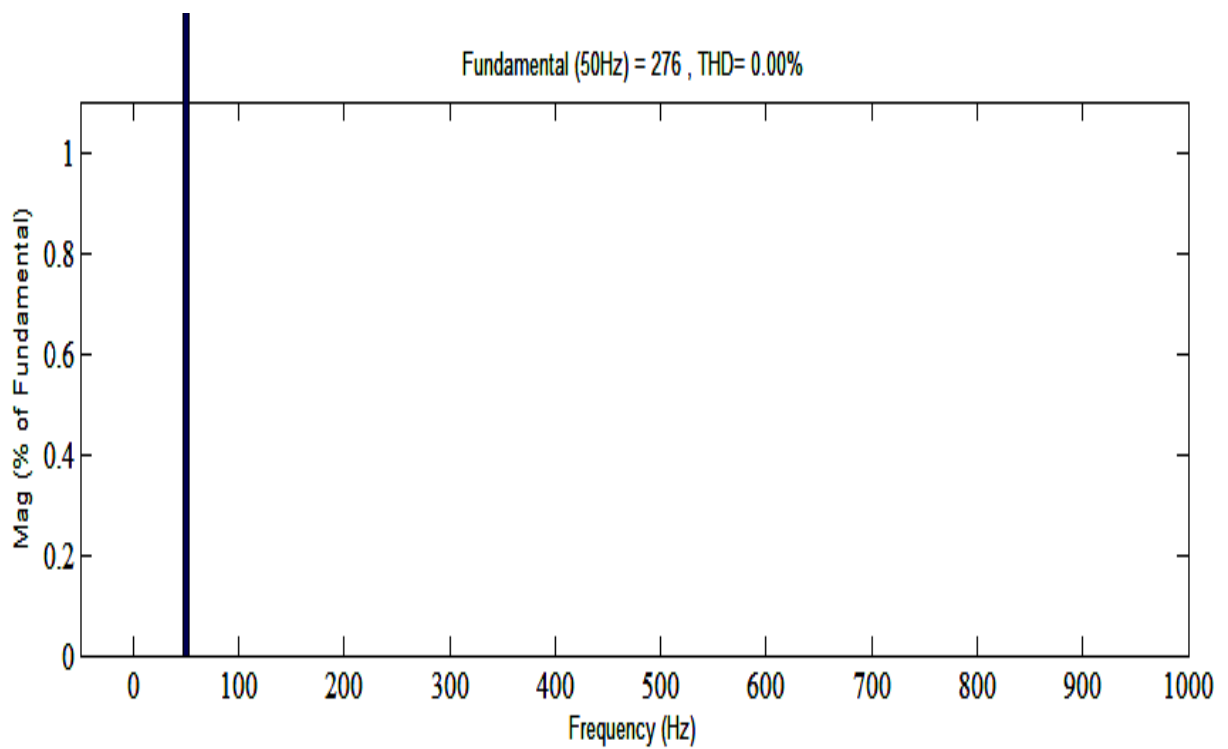


Figure-4.7: Frequency Spectrum of Load Voltage

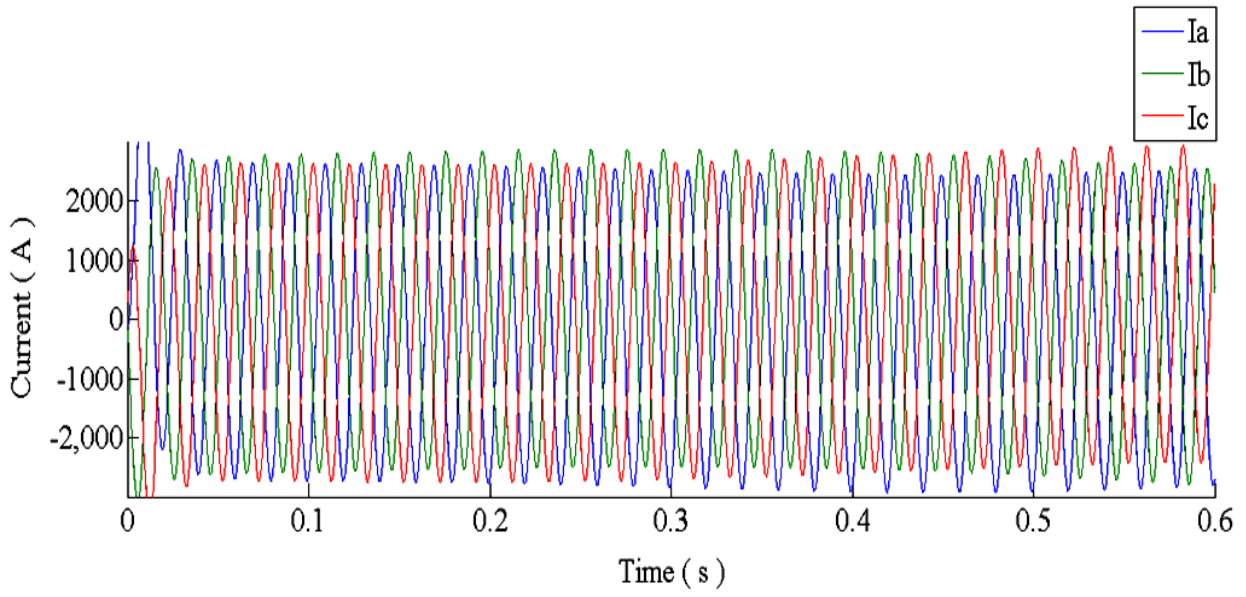


Figure-4.8: Output Waveform of Load Current

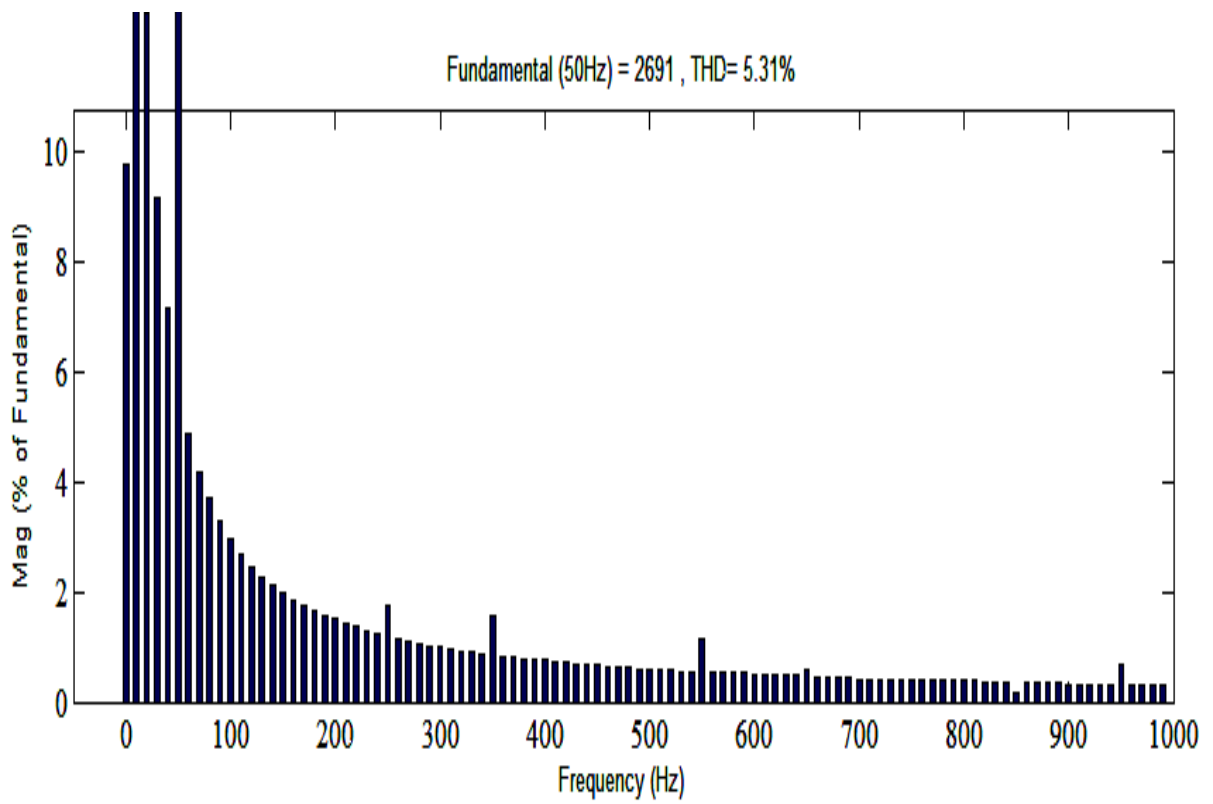


Figure-4.9: Frequency Spectrum of Load Current

4.4 Block Diagram of SIMULINK Model of Test System for Load Perturbation Condition

In this case, circuit breakers are employed in three-phases and are operated at different instants of time. At time = 0 seconds, a FOC induction motor drive is connected to the three phase supply. Effect of load perturbation is first observed at time = 0.2 seconds, at which the three phase load is converted into two phase. At time= 0.25 seconds, two phase load is further converted into single phase. Finally, at time = 0.3 seconds, no supply is provided to the load. Now the wind turbine will act as source and provide supply to the load. However, at time = 0.35 seconds, single phase supply to the load is restored. At time=0.4 seconds, two phase supply of the load is restored. At time=0.45 seconds, three phase supply of the load is restored. Now, the wind turbine will act as a load.

The block diagram of SIMULINK model of test system is shown in Figure-4.10. The output waveforms of supply voltage, supply current, load voltage, load current are obtained and are shown below.

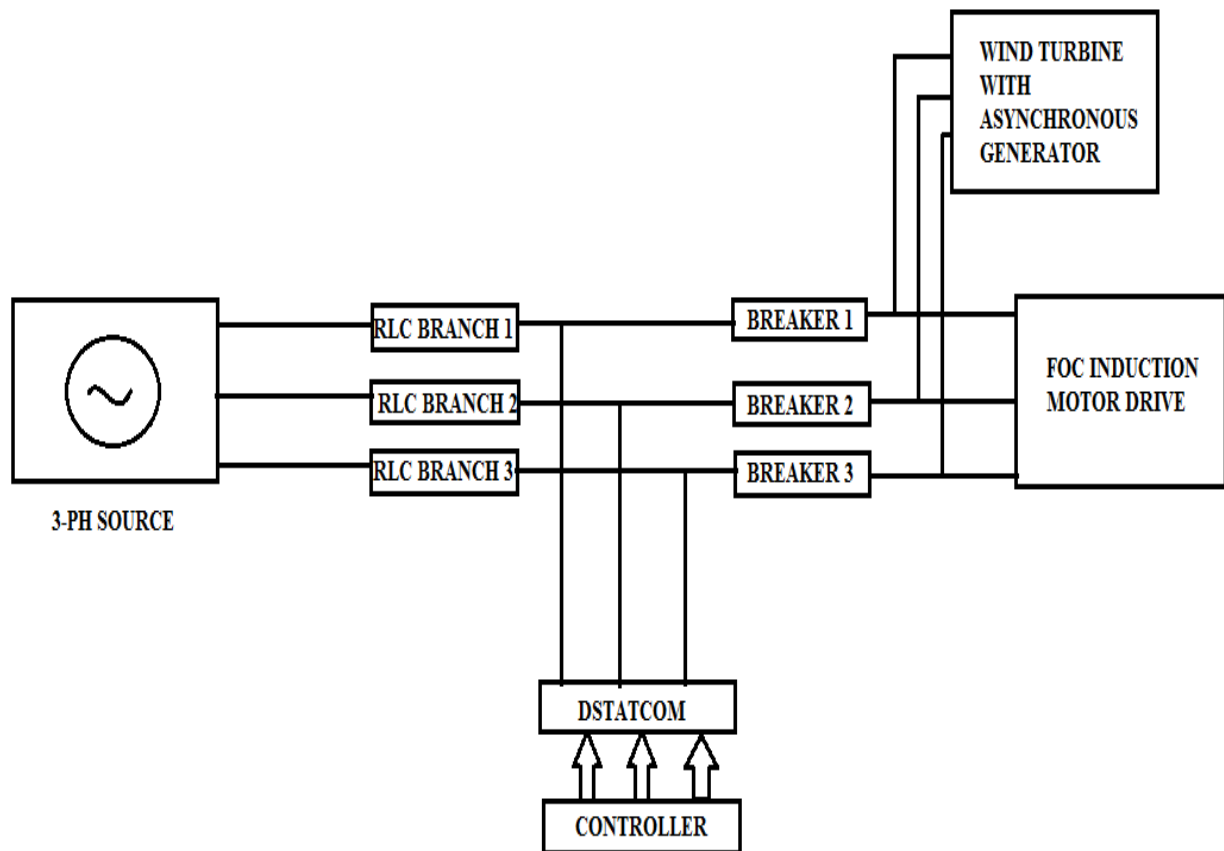


Figure-4.10. Block Diagram of SIMULINK Model of Test System under Load Perturbation

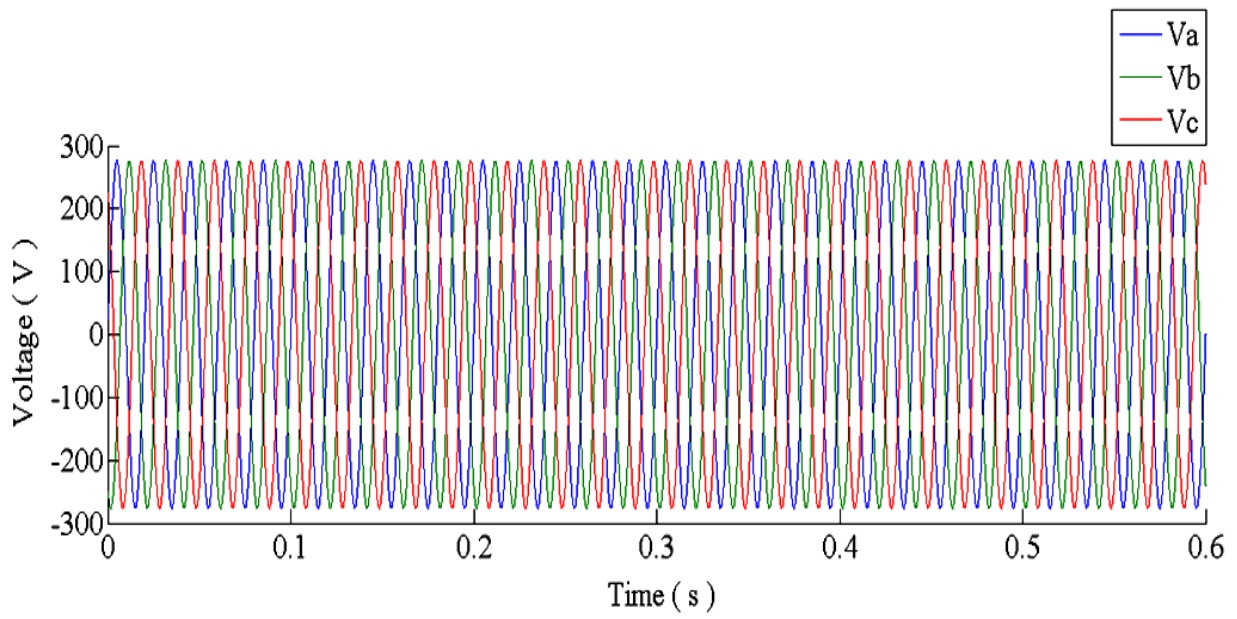


Figure-4.11: Waveform of Supply Voltage under Load Perturbation Condition

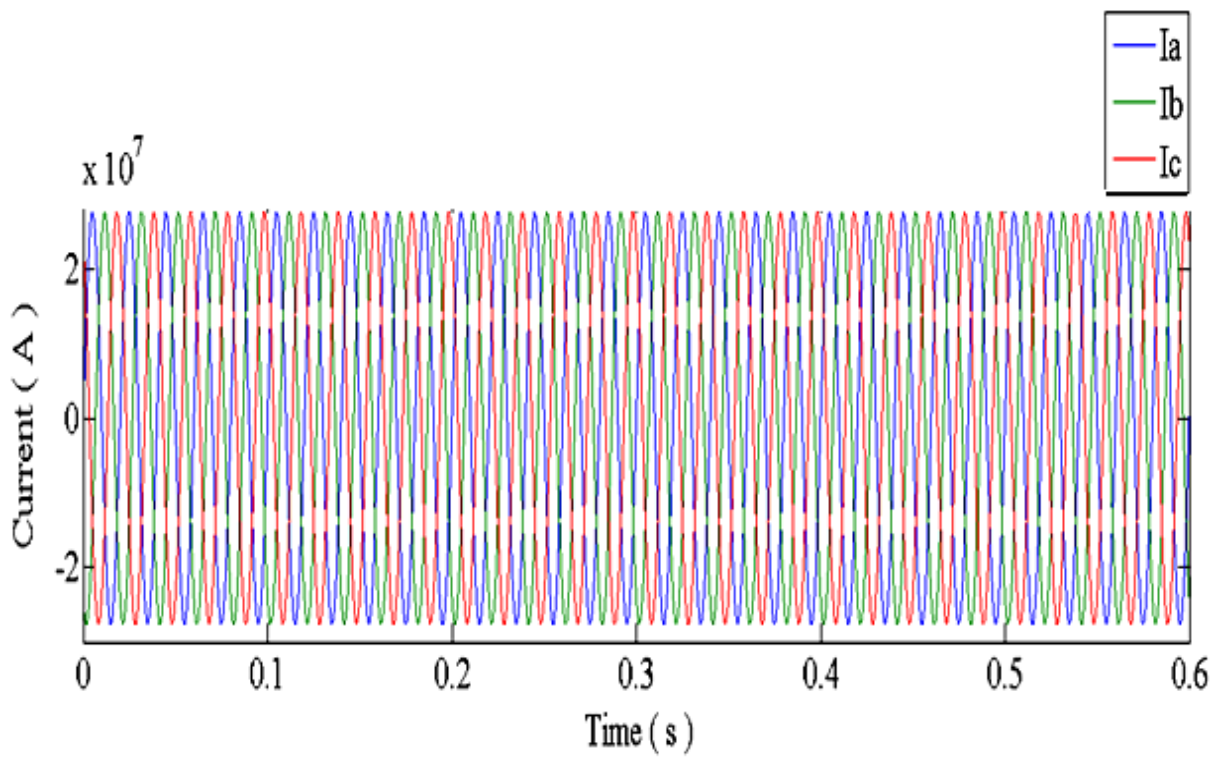


Figure-4.12: Waveform of Supply Current under Load Perturbation Condition

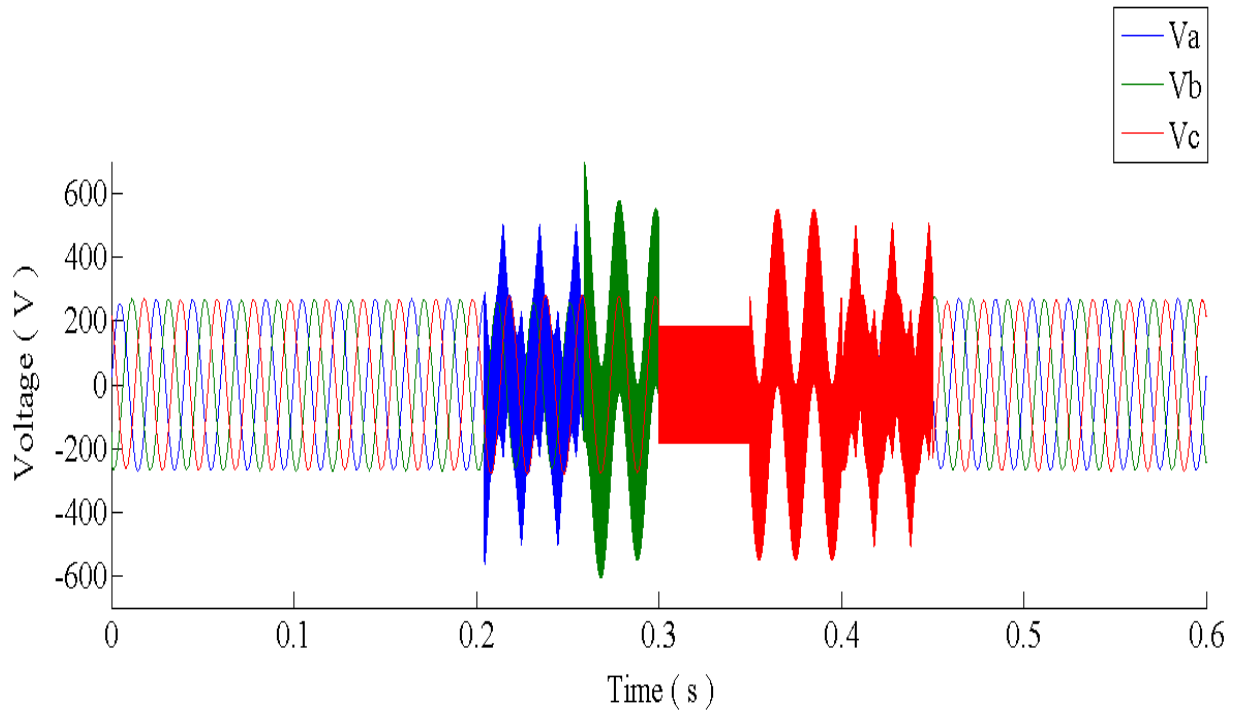


Figure-4.13: Waveform of Load Voltage under Load Perturbation Condition

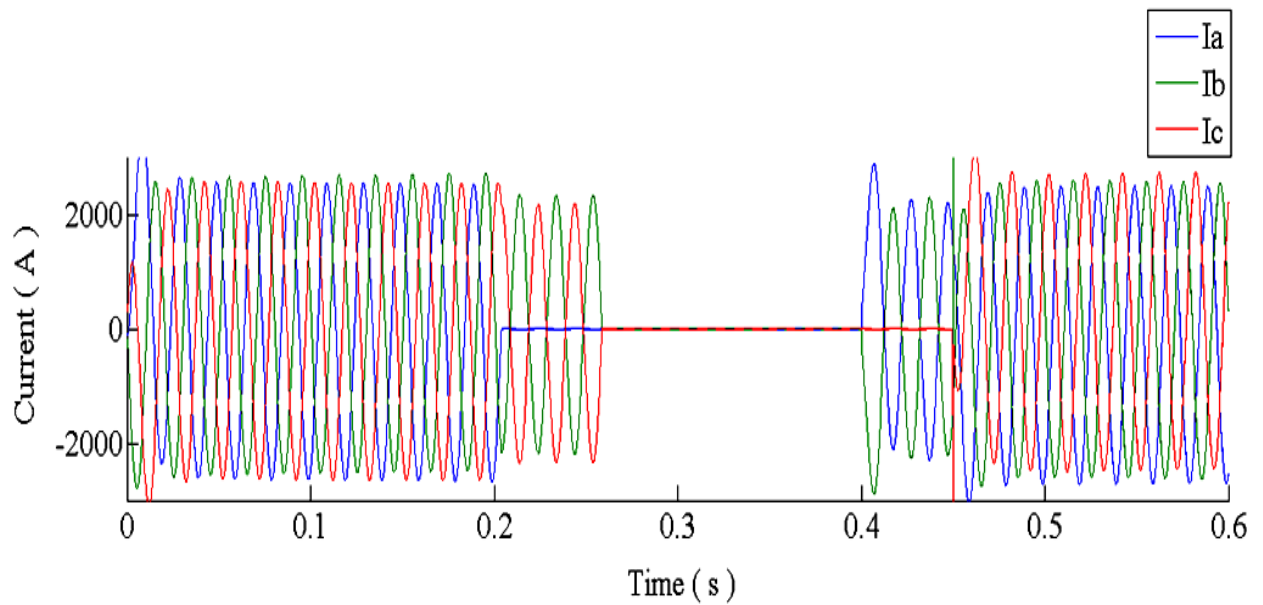


Figure-4.14: Waveform of Load Current under Load Perturbation Condition

CONCLUSIONS AND FUTURE SCOPE OF WORK

5.1 Conclusions

In this work, DSTATCOM has been modelled and simulated in MATLAB/SIMULINK environment. The operation of DSTATCOM has been investigated for active load and non-linear load drive using dqo transformation technique. Simulation shows the effectiveness of DSTATCOM in a distribution network with FOC induction motor drive as non-linear load and wind turbine coupled with asynchronous generator as active load. PI controller has been used to generate the switching signals. It is clear from comparison of THD analysis that DSTATCOM effectively removes the harmonic content from the source current under normal working condition and effectively able to balance the source current under load perturbation condition. Hence, it is concluded that DSTATCOM has a large scope in improving power quality levels in distribution systems.

5.2 Future Scope of Work

In this work, it is clear that DSTATCOM can effectively compensate harmonics from load current. The work can be extended in the following area:

- Many advanced controllers like fuzzy controller, artificial intelligence based adaptive fuzzy controller and state space vector technique can be used with DSTATCOM to improve the effectiveness of DSTATCOM in distribution networks.
- Multipulse converter based DSTATCOM with improved modulation techniques can be explored.
- The effectiveness of DSTATCOM can be established for distribution networks with typical non-linear loads like arc furnace.
- Multilevel inverter based DSTATCOM with improved modulation techniques can be explored.

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