INVESTIGATIONS ON THE ROLE OF DSTATCOM FOR POWER QUALITY IMPROVEMENT IN DISTRIBUTION NETWORKS

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POWER SYSTEMS & ELECTRIC DRIVES

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled "Investigations on the Role of DSTATCOM for Power Quality Improvement in Distribution Networks " in partial fulfillment of requirement for the award of the M.E in POWER SYSTEMS AND ELECTRIC DRIVES submitted in the 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 matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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ABSTRACT

In 20th century the expansion of power system and electronic devices has been grown at very fast rate. The most noticeable topic for electrical engineer is Power Quality in recent years. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a misoperation of end user equipments. With Power quality problem utility distribution networks, industrial loads, sensitive loads etc. are suffered. With the restructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality is going to take newer dimensions. To overcome the problem related to power quality Custom power devices are introduced. A number of power quality solutions are provided by Custom power devices. 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 is use in the present work. The fast response of the Distribution Static Compensator (DSTATCOM) makes it the efficient solution for improving power quality in distribution systems. DSTATCOM can use with different types of controllers. The device consider in this work is Distribution Static Synchronous Compensator (DSTATCOM) with PI controller to improve the of power quality under different abnormal conditions like single line to ground fault, double line to ground fault in distribution networks with static linear and static non- linear loads.

LIST OF ABBREVIATIONS

PQ	Power Quality
DSTATCOM	Distribution Static Synchronous Compensator
DVR	Dynamic Voltage Restorer
PCC	Point Of Common Coupling
UPQC	Unified Power Quality Compensator
VSI	Voltage Source Inverter
IRPT	Instantaneous Reactive Power Theory
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
UCES	Ultra Capacitor Energy Storage
ASD	Adjustable Speed Drive
IGBT	Insulated Gate Bipolar Transistors
VSC	Voltage source Convertor
PI	Proportional Integral
SVC	Static Var Compensator
AC	Alternating Current
APF	Active Power Filters
CSI	Current Source Inverter
FACTS	Flexible Alternating Current Transmission System
ESS	Energy Source System
KV	Kilo Volt
CPD	Custom Power Devices
MVA	Mega Volt Ampere
SSSC	Synchronous Series Compensator Controller
STATCOM	Static Synchronous Compensator
DSTATCOM	Distribution Static Synchronous Compensator
V	Voltage
T	Time

LIST OF FIGURES

Figure 2.1 Voltage Sag 8

Figure 2.2 Very Short Interruptions 9

Figure 2.3 Long Interruptions 9

Figure 2.4 Voltage Spike 10

Figure 2.5 Voltage Swell 10

Figure 2.6 Harmonic Distortion 11

Figure 2.7 Voltage Fluctuation 12

Figure 2.8 Noise 12

Figure 2.9 Voltage Unbalance 13

Figure 2.10 Other loads connected to PCC 13

Figure 2.11 Local and global solutions 14

Figure 3.1 CBEMA curve 17

Figure 3.2 Basic configuration of DSTATCOM 19

Figure 3.3 Basic configuration of DVR 20

Figure 3.4 Basic Configuration of UPQC 21

Figure 4.1 V-I characteristic of a STATCOM 23

Figure 4.2 Current compensation 24

Figure 4.3 Single line diagram of statcom 26

Figure 4.4 Equivalent circuit of a STATCOM 27

Figure 4.5 Working of statcom 28

Figure 4.6 V-I characteristic of a STATCOM 28

Figure 5.1 Simulink Model of Test System 33

Figure 5.2 Load current (with compensation) 34

Figure 5.3 Load current (without compensation) 34
Figure 5.4 Load current (with compensation) 36
Figure 5.5 Load current (without compensation) 36
Figure 5.6 Load current (with compensation) 37
Figure 5.7 Load current (without compensation) 37
Figure 5.8 Simulink model of test system with static non linear load 38
Figure 5.9 Load current (with compensation) 39
Figure 5.10 Load current (without compensation) 39
Figure 5.11 Load current (with compensation) 40
Figure 5.12 Load current (without compensation) 40
Figure 5.13 Load current (with compensation) 41
Figure 5.14 Load current (without compensation) 41
Figure 5.15 THD (with compensation) 42
Figure 5.16 THD (with compensation) 42

TABLE OF CONTENTS

CERTIFICATE i
ACKNOWLEDGEMENT ii
ABSTRACT iii
LIST OF ABBREVIATIONS iv
LIST OF FIGURES v
TABLE OF CONTENTS vii

CHAPTER 1. INTRODUCTION 1-8

1.1 OVERVIEW 1
1.2 LITERATURE SURVEY 2
1.3 SCOPE OF WORK 7
1.4 ORGANIZATION OF THESIS 7

CHAPTER 2. POWER QUALITY PROBLEMS AND SOLUTIONS 9-16

2.1 INTRODUCTION 9
2.2 PROBLEMS REGARDING POWER QUALITY 9
2.2.1 Voltage Sag (Or Dip) 9
2.2.2 Very Short_Interruptions 10
2.2.3 Long Interruptions 10
2.2.4 Voltage Spike 11
2.2.5 Voltage Swell 11
2.2.6 Harmonic Distortion 12
2.2.7 Voltage Fluctuation 12
2.2.8 Noise 13
2.2.9 Voltage Unbalance 14
2.3 EFFFECTS OF POOR QUALITY ON POWER SYSTEM DEVICES 14
2.4 POWER QUALITY SOLUTION STRATEGIES 16

2.4.1 Local Solutions 16
2.4.2 Global Solutions 16

CHAPTER 3. CUSTOM POWER 17-23

3.1 INTRODUCTION 17
3.2 NEED OF CUSTOM POWER DEVICES 17
3.3 CUSTOM POWER DEVICES 18
3.3.1 Distribution Static Synchronous Compensator 20
3.3.2 Dynamic voltage restorer / regulator 21
3.3.3 Active Power Line Conditioner 22
3.3.4 Unified Power Quality Conditioner 22

CHAPTER 4. DISTRIBUTION STATCOM 24-31

4.1 INTRODUCTION 24
4.2 PRINCIPLE OF SHUNT CURRENT COMPENSATION 25
4.3 PRINCIPLE OF DSTATCOM 26
4.4 ADVANTAGES OF STATCOM 30
4.5 PI CONTROLLER 30

CHAPTER 5. TEST SYSTEM AND RESULTS 32-42

5.1 INTRODUCTION 32
5.2 PARAMETERS OF DSTATCOM TEST SYSTEM 32
5.3 SIMULINK MODELS OF THE TEST SYSTEM WITH STATIC LINEAR LOAD 33
5.4 RESULTS UNDER DIFFERENT FAULT CONDITIONS 34
5.4.1 CASE 1. Single Line to Ground Fault Condition 34
5.4.2 CASE 2. Double Line to Ground Fault Condition 35
5.4.3 CASE 3. Three Phase Line to Ground Fault Condition 36

5.5 SIMULINK MODEL OF TEST SYSTEM WITH STATIC NON LINEAR LOAD 37
5.5.1 CASE 1. Single Line to Ground Fault Condition 39
5.5.2 CASE 2. Double Line to Ground Fault Condition 40
5.5.3 CASE 3. Three Phase Line to Ground Fault Condition 41
CHAPTER 6. CONCLUSION AND FUTURE SCOPE OF WORK 43
6.1 CONCLUSION 43
6.2 FUTURE SCOPE 43
REFERENCES 44-46

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

In recent years, Power engineers are increasingly concerned over the quality of the electrical power. In modern industries, load equipment uses electronic controllers which are sensitive to poor voltage quality and will shut down if the supply voltage is depressed and may mal-operate in other ways if harmonic Distortion of the supply voltage is excessive. Much of this modern load equipment itself uses electronic switching devices which then can contribute to poor network voltage quality. The introduction of competition into electrical energy supply has created greater commercial awareness of the issues of power quality while equipment is now readily available to measure the quality of the voltage waveform and so quantify the problem.

Along with advance technology, the organization of the worldwide economy has evolved towards globalization and the profit margins of many activities tend to decrease. The increased sensitivity of the vast majority of processes like (industrial, services and even residential) to PQ problems turns the availability of electric power with quality a crucial factor for competitiveness in every activity sector. The continuous process industry and the information technology services are most critical area. Due to disturbance, a huge amount of financial losses may happen, with the consequent loss of productivity and competitiveness.

Many efforts have been taken by utilities to fulfill consumer requirement, some consumers require a level of PQ higher than the level provided by modern electric networks. This implies that some measures must be taken in order to achieve higher levels of Power Quality.

The FACTS devices and Custom power devices are introduced to electrical system to improve the power quality of the electrical power. DVR, STATCOM/DSTATCOM, ACTIVE FILTERs, UPFC, UPQC etc are some of the devices used to improve the power quality of the voltage and current. With the help of these devices we are capable to reduce the problems related to power quality.

Under the thesis work among the different custom power devices DSTATCOM has been used to improve the quality of power under different conditions.

1.2 LITERATURE SURVEY

A large amount of research is carried out in the field of custom power. A brief literature review related to DSTATCOM is presented as follows:

Bhim Singh, *et al.* [1] focuses on power quality development of power electronic technology which rises to aspects like power-factor correction, voltage regulation and load balancing of linear load. Dstatcom is realized using a three leg IGBT static and dynamic performance. A hysteresis low voltage FACTS device discus which can help to improve power rule based carrier-less PWM current controller is used to derive quality problems in distribution system. Gating pulses for the IGBT switches. It is observed that DSTATCOM improves power quality in electric distribution systems. It is effective in compensating reactive power and improving the numbers of compensators for power factor power quality of the distribution system.

H. Nasiraghdam, *et al.* [2] introduces a new control method for balanced and unbalanced voltage sag mitigation using DSTATCOM. The control system has two loops in order to regulate compensator current and load voltage. Delayed signal cancellation has been used for sequence separation. The compensator should protect sensitive loads against different types of voltage sag. Performance of the proposed method is investigated under different types of voltage sags for linear and nonlinear loads.

J. Sun, *et al.* [3] explain Voltage flicker, a phenomenon of annoying light intensity fluctuation, which is caused by large rapid industrial load changes, it has been a major concern for both power companies and customers in the area of power quality. Distribution Static Compensator (DSTATCOM) has fast response which makes it the efficient solution for improving power quality in distribution systems. A voltage flicker phenomena in a distribution system is modeled and simulated and Voltage flicker mitigation studies with a current controlled PWM-based DSTATCOM are discussed

Sung-Min Woo, *et al.* [4] discusses the concept of Flexible Alternating Current Transmission Systems (FACTs) and Custom Power is widely studied by the researcher. FACTs use Power electronic devices and methods to control the high-voltage side of the network for improving the power flow. Custom Power is for low-voltage distribution, and improving the poor power quality and reliability of supply affecting factories, offices and homes**.** Custom

Power Devices is classified into three categories by their structures such as Dynamic Voltage Restorer (DVR), Distribution STATCOM (DSTATC0M) and Unified Power Quality Compensator (UPQC).

G. Molina, *et al.* [5] investigates the dynamic performance of a distribution static compensator coupled with energy source system (ESS) for improving the power quality of distribution systems. Also presented integrated DSTATCOM/ESS compensator is analyzed as a voltage controller, a power factor controller and an active power controller. Modeling and control approaches are proposed, including a detailed modeling of the DSTATCOM/ESS

Pierre Giroux, *et al.* [6] presents a study of the modeling of a STATCOM (Static Synchronous Compensator) used for reactive power compensation in a distribution network. The power circuits of D-STATCOM, Static and dynamic performance of a E3 Mvar D-STATCOM on a 25-kV network is evaluated. An “average modeling” approach is proposed to simplify the PWM inverter operation and to accelerate the simulation for control parameters adjusting purpose. Simulation performance obtained with both modeling approaches are presented and compared.

Afshin LASHKAR ARA, *et al.* [7] presents the power electronic devices and technical review in various power engineering levels. Flexible AC Transmission System are effective equipments on power control in energy transmission systems. In addition, the power electronics-based equipment, which are called power conditioners are use to solve power quality problems. The topologies of these equipments are similar to those used in FACTS equipment, power conditioners are also called Distribution FACTS (DFACTS). Also the principal operating modes and application of STATCOM, SSSC, UPFC, DSTATCOM, DVR and UPQC are discussed and compared.

Ben-Sheng Chen, *et al.* [8] presents an analytical approach to harmonic analysis of a static synchronous compensator (STATCOM) based on Bessel functions of the first kind is described and a novel STATCOM controller with a fixed modulation index reference to minimize voltage and current harmonics. Harmonic analysis of the STATCOM using the proposed analytical approach reveals that the total harmonic distortion of the STATCOM output voltage is minimal as the modulation index is fixed at unity at steady state

S.V Ravi Kumar, *et al.* [9] tells about the power quality problems and describe the techniques of correcting the supply voltage sag, swell and interruption in a distributed system. 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 of them based on the VSC principle. A DVR injects a voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption.

Wei-Neng Chang, *et al.* [10] proposes a distribution level static synchronous compensator (DSTATCOM) for fast load compensation of unbalanced loads in electric power distribution systems. For fast response requirement, a new feed forward compensation scheme is derived and employed. Compensation scheme of the DSTATCOM is derived with the symmetrical components method. Computer simulation with the program Matlab/Simulink software is use to verify the effectiveness of the proposed DSTATCOM.

Arindam Ghosh, *et al.* [11] presents load compensation using a distribution static compensator (DSTATCOM). It is assumed that the DSTATCOM is associated with a load that is remote from the supply. It is shown that the operation of a DSTATCOM assuming that it is connected to a stiff source in such situations will result in distortions in source current and voltage at the point of common coupling. To avoid this, the DSTATCOM is connected in parallel with a filter capacitor that allows the high frequency component of the current to pass. This however generates control issues in tracking, as standard controls such as a hysteresis control are not suitable in these circumstances. This paper proposes a new switching control scheme and demonstrates its suitability for this problem. It also proposes a scheme in which the fundamental sequence components of a three-phase signal can be computed from its samples. The overall performance of the proposed scheme is verified using digital computer simulation studies.

Bhim Singh, *et al.* [12] presents different control strategies for DSTATCOM (Distribution Static Compensator) for power quality improvement for a three-phase, three-wire distribution system. A three-leg voltage source inverter (VSI) configuration with a dc bus capacitor is employed as DSTATCOM. The hysteresis as well as PWM current controllers are designed, analyzed and compared for PI controller and sliding mode controller

Dinesh Kumar, *et al.* [13] describes the modeling and analysis of distribution static compensator (DSTATCOM), which is capable of balancing the source currents in spite of unbalanced and non-linear load currents. In addition to balance the supply current, the power factor can be set to a desired value. The theory of instantaneous symmetrical components is used here to extract the three-phase reference currents. These reference currents are then tracked using voltage source inverter (VSI), operated in a hysteresis band control technique. The detailed simulation results are presented to support the concept. The two-level and three-level inverter topologies are used to realize the compensator. It is demonstrated that three level inverter gives less total harmonic distortion (THD) in source currents as compare to two level inverter.

Walmir Freitas, *et al.* [14] presents a dynamic study about the influences of ac generators (induction and synchronous machines) and distribution static synchronous compensator (DSTATCOM) devices on the dynamic behavior of distribution networks. The performance of a DSTATCOM as a voltage controller or a power factor controller is analyzed. The impacts of these controllers on the stability and protection system of distribution networks with distributed generators are determined. Computer simulation results show that a DSTATCOM voltage controller can improve the stability performance of induction generators significantly. On the other hand, a DSTATCOM power factor controller may adversely affect the stability performance of synchronous generators. It has also been observed that a DSTATCOM has no influence on short-circuit currents provided by ac generators during faults.

Bhim Singh, *et al.* [15] discuss DSTATCOM (Distribution Static Compensator) for load balancing, neutral current elimination, power factor correction 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.

M. G. Molina, *et al.* [16] describes the dynamic modeling and the control design of a distribution static compensator (DSTATCOM) coupled with ultra-capacitor energy storage (UCES) for improving the power quality of power systems. Three modes of operation are considered, i.e. voltage control for voltage fluctuations ride-through, current/voltage harmonics mitigation and dynamic active power control. New models and control schemes are proposed.

Zhang Dongliang, *et al.* [17] analyzed the circuit of DSTATCOM. The dynamic model of DSTATCOM based on three-level voltage inverter is established by way of lead-in switch function. Control method of DSTATCOM is focal point of this research. The dissertation determines the detection means based on instantaneous reactive power. PWM control by tracking the current technology achieve to direct control. The simulating results prove the DSTATCOM put forward in the dissertation can realize dynamic var compensation effectively.

Dr. Ibrahim Oumarou, *et al.* [18] deals with the optimal location and parameters of Unified Power Flow Controllers (UPFCs) in electrical power systems. The UPFC is one of the most promising FACTS devices in terms of its ability to control power system quantities. Shunt FACTS devices are used for controlling transmission voltage, power flow, reducing reactive losses, and damping of power system oscillations for high power transfer levels. In this paper the optimal location of a shunt FACT device is investigated for an actual line model of a transmission line having series compensation at the center. As one of the most promising FACTS devices in terms of its ability to control power system quantities, UPFC Effect of change in degree of series compensation on the optimal placement of the shunt FACTS device to get the highest possible benefit is studied. The results obtained shown that optimal placement of the shunt FACTS device varies with the change in the level of series compensation.

Rajesh Gupta, *et al.* [19] analyzed the performance of voltage-source converter-based shunt and series compensators used for load voltage control in electrical power distribution systems, when a nonlinear load is connected across the load bus. The comparison has been made based on the closed-loop frequency response characteristics of the compensated distribution system. A distribution static compensator (DSTATCOM) as a shunt device and a dynamic voltage restorer (DVR) as a series device are considered in the voltage-control mode for the comparison. The power-quality problems which these compensator address include voltage sags/swells, load voltage harmonic distortions, and unbalancing. The effect of various system parameters on the control performance of the compensator can be studied using the proposed analysis. In particular, the performances of the two compensators are compared with the strong ac supply (stiff source) and weak ac-supply (non-stiff source) distribution system.

João Afonso, *et al.* [20] describes the development of a low cost shunt active power filter with digital control, which allows dynamic power factor correction and both harmonics and zero-sequence current compensation. The active filter controller is based on the instantaneous power theory (p-q theory) and was implemented using a standard 16 bits microcontroller. The p-q theory is introduced followed by the presentation of some active power filters topologies. Then a brief description of the implemented solution is made, including references to software tools used for simulation and system development. Experimental results are also presented, showing the good performance of the developed active filter.

P. M. Meshram, *et al*. [21] presents that proliferations of the non-linear devices cannot be restricted at transmission and distribution level because of their compactness and power handling capacity but they also draw non-linear current and hence degrade the power quality. The different non-linear loads at the distribution side are adjustable speed drives, fluorescent lighting and personal computers (PC's), television sets, refrigerators etc. Authors propose the controller at the distribution side, i.e., between the utility and the customer for the improvement of the quality of supply and therefore it is called DFACTS device. The concept is for different types of loads i.e. linear balanced; linear unbalanced; non-linear balanced and non-linear unbalanced

1.3 SCOPE OF WORK

It was observed from the literature Survey that, the field of power quality and custom power devices plays an important role in power system. DSTATCOM is one of the custom power device used in distribution system for the improvement of power quality. Different type of controller namely fuzzy, hysteresis, PI, and PID are reported in literature to compensate various PQ problems. In this work, the effectiveness of PI controller based DSTATCOM to the power quality under different conditions like single line to ground fault, double line to ground fault under static linear and static non linear loads, is investigated.

1.4 ORGANIZATION OF THESIS

The work carried out in the thesis has been summarized in six chapters.

Chapter 1 briefs the overview, literature view and scope of work. It also contains the organization of thesis.

Chapter 2 deliberates on definitions of power quality and problems associated. It also contains solution strategy.

Chapter 3 discuss introduction of custom power, need of custom power and custom power devices.

Chapter 4 deliberates on introduction of STATCOM, principle of shunt current compensation, principle of STATCOM/DSTATCOM.

Chapter 5 discuss test and result, introduction, parameter of the test system, Simulink model of the test system with linear load and their results, Simulink model of the test system with non linear load and their results.

Chapter 6 contains the conclusion and future scope.

CHAPTER 2

POWER QUALITY PROBLEMS AND SOLUTIONS

2.1 POWER QUALITY

Power Quality is a term that mean different to different people. Institute of Electrical and Electrical Engineers (IEEE) standard IEEE 1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.”

A simpler words Power quality is a set of electrical boundaries that allow a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. This definition embraces two things that we demand from an electrical device which are performance and life expectancy

2.2 PROBLEMS REGARDING POWER QUALITY [22]

2.2.1 Voltage Sag (Or Dip)

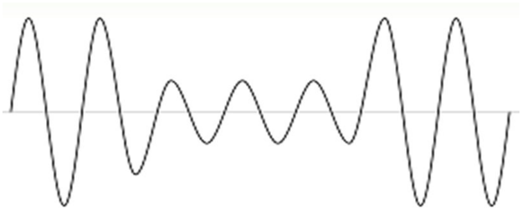

Figure-2.1: Voltage Sag

Description: A decrease of 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.

Causes: 1) Faults in consumer’s installation Faults on the transmission or distribution network Most of the times faults occur on parallel feeders.

2) Connection of heavy loads and start-up of large motors.

Consequences: 1) Tripping of contactors and electromechanical relays

2**)** Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a process stoppage.

3) Disconnection and loss of efficiency in electric rotating machines.

2.2.2 Very Short Interruptions

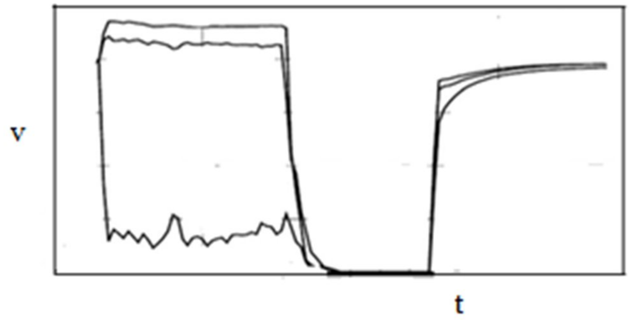

Figure-2.2: Very Short Interruption

Description: Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes: 1) The main fault causes are insulation failure, lightning and insulator flashover.

2) Mainly due to the opening and automatic recloser of protection devices to decommission a faulty section of the network.

Consequences: 1) Loss of information and malfunction of data processing equipment.

2) Tripping of protection devices.

3) Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal with this situation.

2.2.3 Long Interruptions

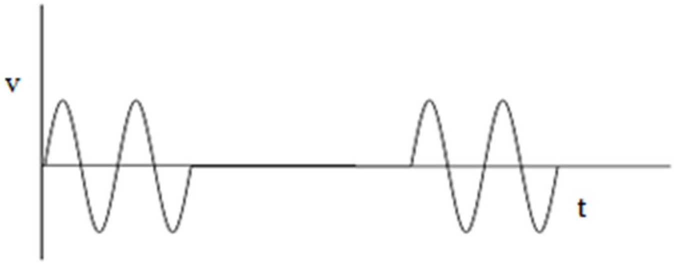

Figure-2.3 Long Interruptions

Description: Total interruption of electrical supply for duration greater than 1 to 2 seconds.

Causes: 1) Equipment failure in the power system network.

2) Storms and objects (trees, cars, etc) striking lines or poles.

3) Fire and human error.

4) Bad coordination or failure of protection devices.

Consequences: 1) Stoppage of all equipment.

2.2.4 Voltage Spike

Figure-2.4: Voltage Spike

Description: Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

Causes: 1) Lightning.
2) Switching of lines or power factor correction capacitors.
3) Disconnection of heavy loads.

Consequences: 1) Destruction of components (particularly electronic components) .
2) Failure of insulation materials.
3) Data processing errors or data loss.
4) Electromagnetic interference.

2.2.5 Voltage Swell

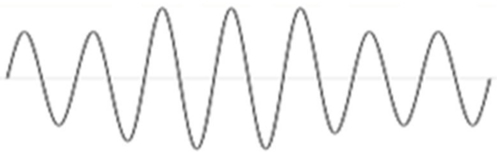

Figure-2.5: Voltage Swell

Description: 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.

Causes: 1) Start/stop of heavy loads, badly dimensioned power sources.
2) Badly regulated transformers (mainly during off-peak hours).

Consequences: 1) Flickering of lighting and screens.
2) Data loss.

3) Stoppage or damage of sensitive equipment, if the voltage values are too high.

2.2.6 Harmonic Distortion

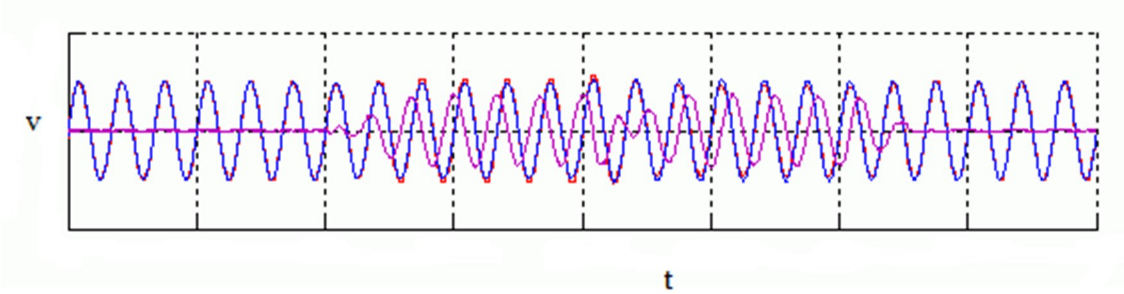

Figure-2.6: Harmonic Distortion

Description: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes: 1) **Classic sources:** electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors.

2) **Modern sources:** all non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

Consequences: 1) Increased probability in occurrence of resonance.

2) Neutral overload in 3-phase systems.

3) Overheating of all cables and equipment.

4) Loss of efficiency in electric machines.

5) Electromagnetic interference with communication systems

2.2.7 Voltage Fluctuation

Description: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.

Causes: 1) Frequent start/stop of electric motors (for instance elevators).

2) Oscillating loads.

3) Arc furnaces.

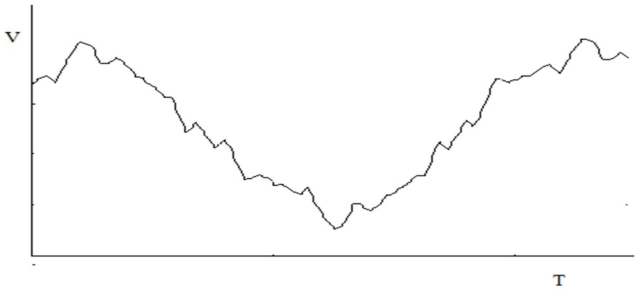

Figure-2.7: Voltage Fluctuation

Consequences: Most consequences are common to under voltages. The most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

2.2.8 Noise

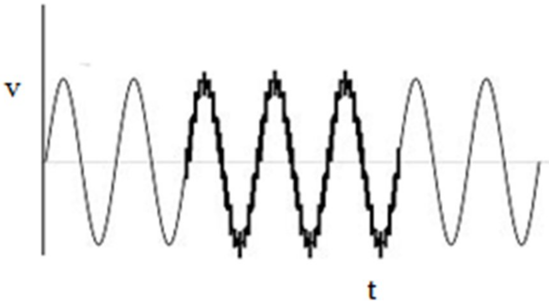

Figure-2.8: Noise

Description: Superimposing of high frequency signals on the waveform of the power-system frequency.

Causes: 1) Television diffusion, and radiation due to welding machines.

2) Electromagnetic interferences provoked by Hertzian waves such as microwaves.

3) Arc furnaces and electronic equipment.

4) Improper grounding may also be a cause.

Consequences: Disturbances on sensitive electronic equipment, usually not destructive may cause data loss and data processing errors.

2.2.9 Voltage Unbalance

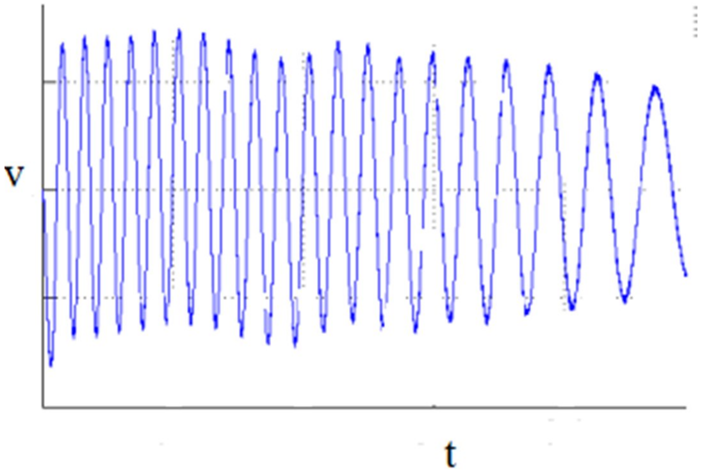

Figure-2.9: Voltage Unbalance

Description: A voltage variation in a three-phase system in which the three voltage magnitudes or the phase angle differences between them are not equal.

Causes:1) Large single-phase loads (induction furnaces, traction loads).

2) Incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).

Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all three phase loads. The most affected loads are three-phase induction machines.

2.3 EFFFECTS OF POOR QUALITY ON POWER SYSTEM DEVICES

Poor electric power quality has many harmful effects on power system devices and end users. What makes this phenomenon so important is that its effects are often not known until failure occurs. Therefore, insight into how disturbances are generated and interact into how they affect components is important for preventing failures. Even if failure does not occur, poor power quality and harmonics increase losses and decrease the lifetime of power components and end-use devices.

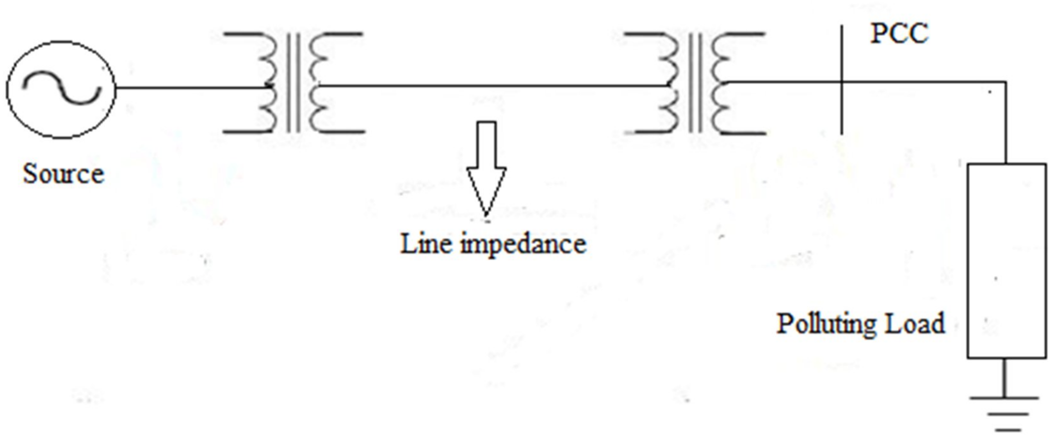

Figure-2.10: Other loads connected to PCC also suffer

Some of the main detrimental effects of poor power quality include the following:

1. Heating, noise and reduced life on capacitors, surge suppressors, rotating machines, cables and transformers, fuses, and customer's equipment.
2. Utility companies are particularly concerned that distribution transformer may need to be derated to avoid premature failure due to overheating.
3. Additional losses of transmission lines, cables, generators, AC motors and transformers may occur due to harmonics.
4. Failure of power system components and customer loads may occur due to unpredicted disturbances such as voltage and/or current magnifications due to parallel resonance and ferroresonance
5. Malfunction of controllers and protective devices such as fuse and relays is possible.
6. Interharmonics may occur which can which can perturb ripple control signals and can cause flicker at sub-harmonic levels.
7. Harmonic instability may be caused by large and unpredicted harmonic sources such as arc furnaces.

2.4 **POWER QUALITY SOLUTION STRATEGIES**

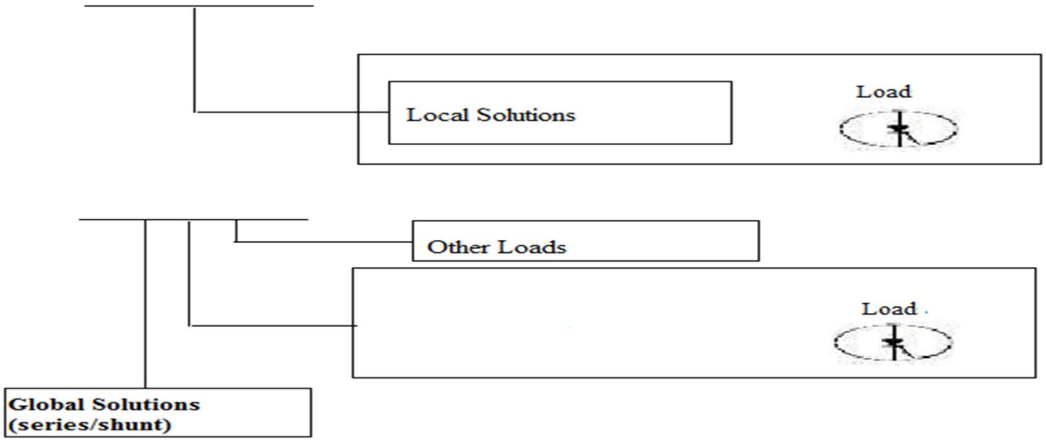

Figure-2.11: Local and global solutions

2.4.1 Local Solutions

Provide ‘ride through’ capability to the equipment so the equipment so that they can protected against certain amount of voltage sag and swell.

Disadvantage of this approach is that it cannot take care of existing polluting installations and further it is not always economical to provide the above arrangement for every equipment.

2.4.2 Global Solutions

Here independent compensating devices are installed at PCC so that overall PQ improves at PCC. Advantages of this approach is Individual equipment need not be designed according to PQ standards

CHAPTER 3

CUSTOM POWER

3.1 INTRODUCTION

In 1995 N.G. Hingorani introduced the concept of custom power which was an extension of the FACTS concept to distribution systems. The key objective is to improve power quality (PQ) and enhance reliability of power supply. The concept of FACTS was also proposed by Hingorani in 1988. The term `custom power' describes the value-added power that electric utilities will offer their customers. The value addition involves the application of high power electronic controllers (similar to FACTS) to distribution systems, at the supply end of industrial, commercial customers and industrial parks. The provision of custom power devices (CPD) is complementary to the individual end-use equipment at low voltages (such as UPS (Uninterruptible Power Supply) or standby generators).

The power quality has serious economic implications for customers, utilities and electrical equipment manufacturers. With modernization and automation of industry involves increasing use of electronic devices like computers, microprocessors and power electronic systems such as adjustable speed drives. Integration of non-conventional generation technologies such as fuel cells, wind turbines and photo voltaic with utility grids often requires power electronic interfaces. The power electronic systems also contribute to power quality problems (generating harmonics).

3.2 NEED OF CUSTOM POWER

As electric power is need of every industry. These industries have different types of loads. Some of the loads are very sensitive and need pure power or good quality of power otherwise the loads are effective by power quality of power for example, the problem of voltage sags can affect sensitive loads. However, there are no specific standards for different categories of equipment, except in the case of data processing equipment. Only Computer Business Equipment Manufacturers Association (CBEMA) has developed the CBEMA curve which describes the tolerance of main frame computers to the magnitude and duration of voltage variations on the power systems. Most of the Computer companies have their different tolerance, but the CBEMA curve has become a standard design target for sensitive equipment and also a common format for reporting power quality variations.

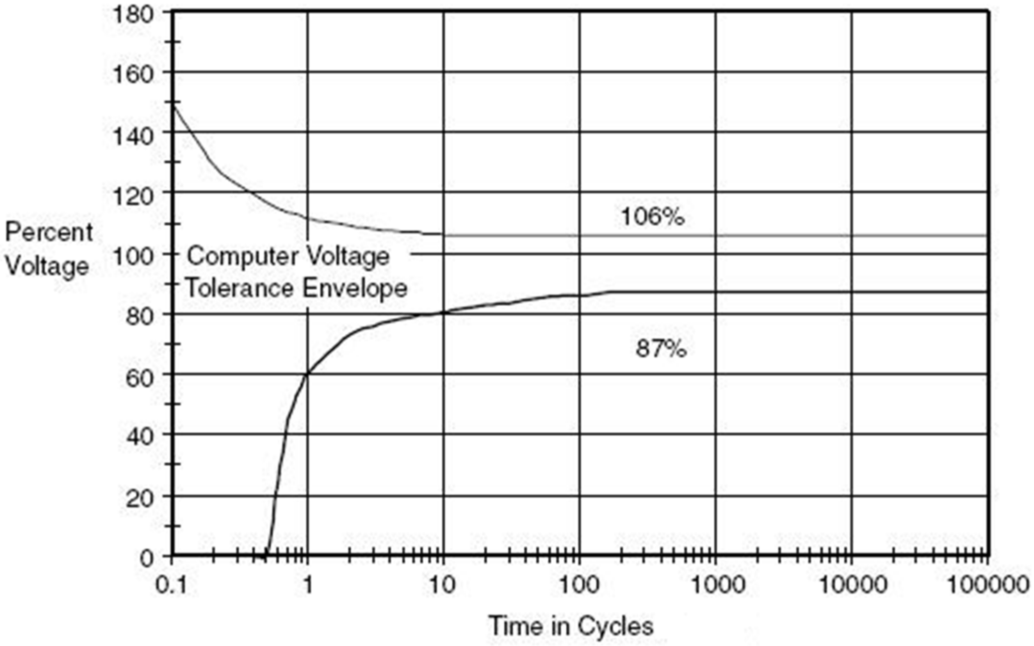

Figure-3.1: CBEMA curve

There are standards for the current and voltage harmonics based on THD. Typically, the voltage THD should be below 5%. The standards on voltage flicker are for PST · 1. The previous discussion indicates the requirement for compensating equipment to improve power quality and meet the specified standards. The major problems relate to voltage magnitude and waveform distortion. It is essential to provide reactive power compensation to improve power factor or regulate voltage under dynamic conditions. The operation of load at unity power factor is beneficial in:

(a) Reduction of losses and improved voltage profile and

(b) Better utilization of distribution feeders.

So to improve the power quality and the standards, we need or require compensating equipment, which can help to fulfill the standards.

3.3 CUSTOM POWER DEVICES

The introduction of power electronic loads has raised much concern about power quality problems caused by harmonics, distortions, interruptions, and surges. The use of electronic devices increase the power quality problem Equipment such as large industrial drives (e.g., cycloconverters) generate significantly high voltage and current (inter-, sub-) harmonics and create extensive voltage fluctuation. The addition of electronic devices is addition to power quality problem.

The application of harmonic filters and SVCs to radial transmission systems can offer partial solution to high THD levels and voltage fluctuations. Yet, the lack of dynamic capabilities of these devices limits them to bulk correction. In addition, they might be effective in one application but fail to correct other power quality issues.

Hingorani introduced the concept of custom power as the solution to V, P, and Q (voltage, active power, reactive power) compensation and power quality problems at the expense of high cost and network complexity. As FACTS controllers improve the reliability and quality of power transmission by simultaneously enhancing both power transfer capacity and stability custom power devices enhance the quality and reliability of power delivered to the customer. With a custom power device, a customer (e.g., a sensitive load) will be able to receive a prespecified quality of electric power with a combination of specifications including but not limited to:

- Magnitude and duration of over and under voltages with specified limits,
- Low harmonic distortion in the supply, load voltages, and currents.
- Small phase imbalance,
- Low flicker in the supply voltage,
- Control of power interruptions, and
- Control of supply voltage frequency within specified limits.

Classification of Custom power devices are based on their power electronic controllers, which can be either of the network reconfiguration type or of the compensation type. The network reconfiguration devices also called switchgear include the solid state and or static versions or current limiting, current breaking, and current transferring components. The compensation type custom power devices either compensate a load (e.g., correct its power factor, imbalance) or improve the quality for the supply voltage (e.g., eliminate its harmonics). They are either connected in shunt or in series or a combination of both. Custom power devices are classified as follows:

- Network – reconfiguration custom power devices include
- Solid state current limiter (SSCL),

- Solid – state breaker (SSB), and
- Solid state transfer switch (SSTS)

Compensation-custom power devices include

- Distributions STATCOM (DSTATCOM),
- Dynamic voltage restorer / regulator (DVR), and
- Unified power quality conditioner (UPQC).

Custom power devices are designed to improve the quality of power at their point of installation of the power distribution system. They are not primarily designed to improve the power quality of the entire system.

3.3.1 Distribution STATCOM (DSTATCOM)

The distribution STATCOM is similar to a transmission STATCOM in that it uses a VSC of the required rating. However, the VSC used in a DSTATCOM is a Type 1 converter with PWM control over the magnitude of the injected AC voltage while maintaining a constant DC voltage across the capacitor. Faster power semiconductor devices such as IGBT or IGCT are used instead of GTO. The rapid switching capability provided by IGBT (or IGCT) switches enable the use of more sophisticated control schemes to provide functions of balancing (by injecting negative sequence current), active filtering (by injecting harmonic currents) and flicker mitigation. A DSTATCOM can be viewed as a variable current source determined by the control functions. To increase the dynamic rating in the capacitive range, a fixed capacitor/filter can be used in parallel with DSTATCOM. By connecting an energy storage device such as a Superconducting Magnetic Energy Storage (SMES) on the DC side through a DC/DC power conditioner, it is possible to exchange real power with the network for a limited time (during momentary interruptions or large voltage sags).

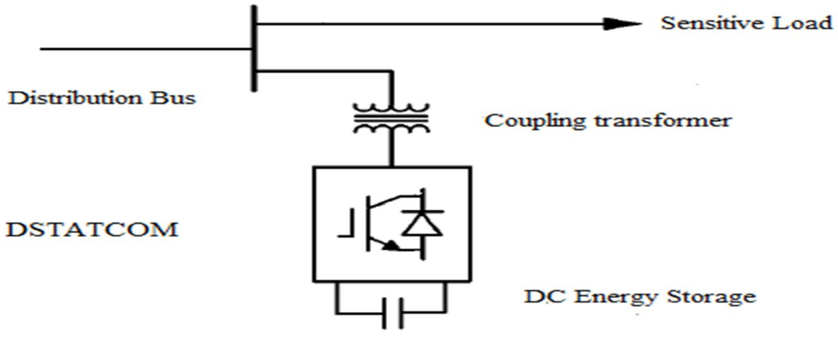

Figure-3.2: Basic configuration of DSTATCOM

3.3.2 Dynamic voltage restorer / regulator (DVR)

The Dynamic Voltage Restorer (DVR) is a series connected device analogous to a SSSC. The main function of a DVR is to eliminate or reduce voltage sags seen by sensitive loads such as semiconductor manufacturing plant or IT industry. DVR that have been installed so far are modular with ratings of 2 MVA per module. They have been designed to compensate three phase voltage sags up to 35% for duration of time less than half a second (depending on the requirement). If the voltage sag occurs only in one phase (caused by SLG faults) then the DVR may be designed to provide compensation for sags exceeding 50%. The energy storage required in capacitors is typically in the range of 0.2 to 0.4 MJ per MW of load served. A DVR is connected in series with the feeder using a transformer. The low voltage winding is connected to the converter. If the objective of a DVR is mainly to regulate the voltage at the load bus, it remains for most of the time in stand-by mode during which the converter is bypassed (no voltage is injected). Only when sag is detected, the DVR injects a series voltage of the required magnitude. It is necessary to protect a DVR against the fault currents (as in the case of a SSSC). A DVR with IGBT/IGCT devices can be controlled to act as a series active filter to isolate the load from voltage harmonics on the source side. It is also possible to balance the voltage on the load side by injecting negative and/or zero sequence voltages in addition to harmonic voltages.

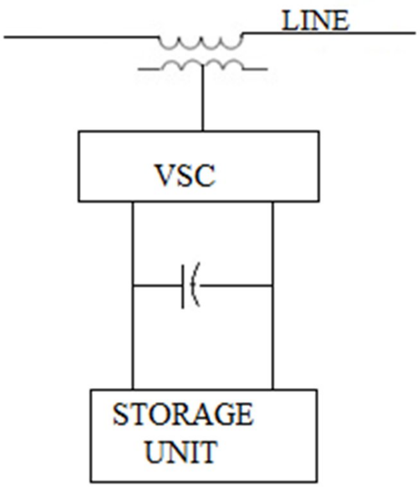

Figure-3.3: Basic configuration of DVR

3.3.3) Active power line conditioner

The APLC is converter based compensation device designed to improve the power quality of the entire distribution system by injecting corrective harmonic currents at selected (sensitive) buses.

It is usually necessary to use more than one APLC unit to improve the power quality of the entire distribution system. Therefore, APLC units can be considered as a group of shunt active filters; their placement, sizing, and compensation levels (e.g., orders, magnitudes, and phases of injected current harmonics) are optimally designed to improve the power quality of the entire distribution system. The number of required APLC units depends on the sever it of distortion the nature of the distribution system, and types of nonlinear loads, as well as the required quality of electric power. At present, the design of APLCs does not consider transient distortions and stability issues.

3.3.4 UNIFIED POWER QUALITY CONDITIONER (UPQC)

Unified power quality conditioners are viable compensation devices that are used to ensure that delivered power meets all required standards and specifications at the point of installation.

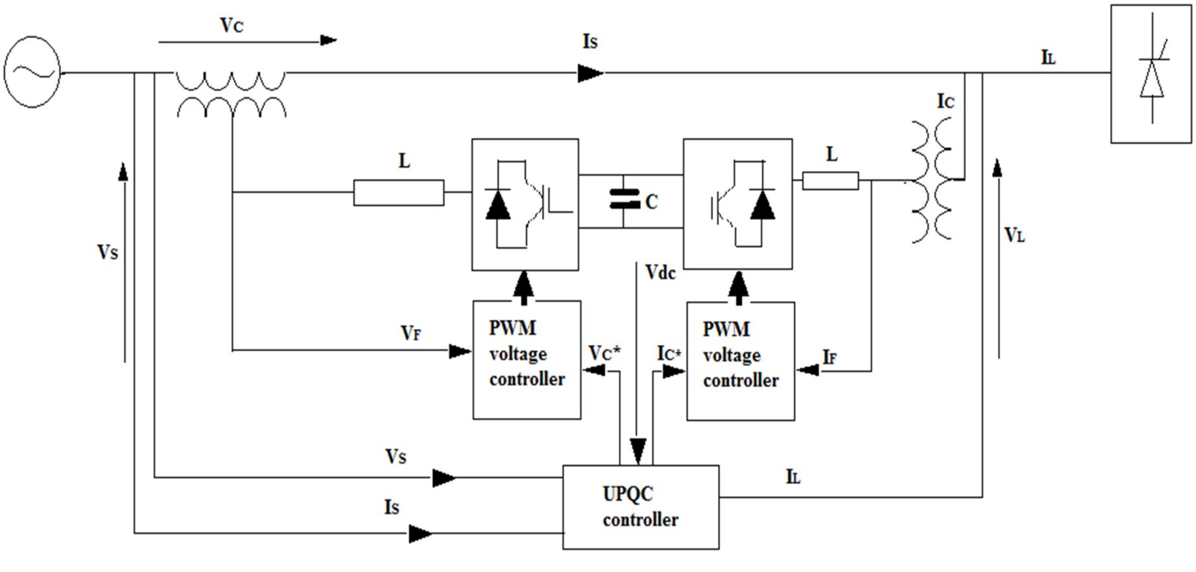

Figure3.4: Basic Configuration of UPQC

The ideal UPQC can be represented as the combination of a voltage source converter (injecting shunt current) and a common DC link (connected to a DC capacitor).

UPQC consist of combined series active power filter that compensates voltage harmonics of the power supply, and shunt active power filter that compensates harmonic currents of a non-linear load. This dual functionality makes the UPQC as one of the most suitable devices that could solve the problems of both consumers as well as of utility. UPQC, thus can help to improve voltage profile and hence the overall health of power distribution system

CHAPTER 4

DISTRIBUTION STATCOM

4.1 INTRODUCTION

STATCOM

In 1999 the first SVC with Voltage Source Converter called STATCOM (STATic COMpensator) went into operation. The characteristic of STATCOM are a similar to the synchronous condenser, the difference is that it is an electronic device, due to that it has no inertia and it is superior to the synchronous condenser in so many ways, such as better dynamics, a lower investment cost and lower operating and maintenance cost.

A STATCOM is build with Thyristors with turn off capability like GTO or to day IGCT or with more and more IGBTs. The structure and operational characteristic is shown in Figure-4.1. The static line between the current limitations has a certain steepness determining the control characteristic for the voltage. The advantage of a STATCOM is that the reactive power provision is independent from the actual voltage on the connection point.

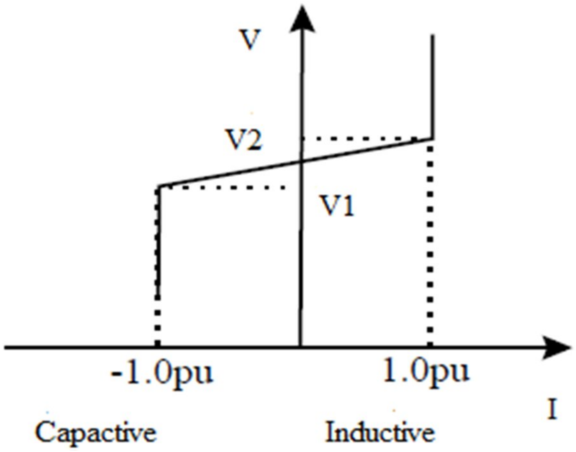

Figure-4.1: V-I characteristic of a STATCOM

In the distributed energy sector the usage of Voltage Source converters for grid interconnection is common practice today. The next step in STATCOM development is the combination with energy storages on the DC-side. The performance for power quality and balanced network operation can be improved much more with the combination of active and reactive power.

4.2 PRINCIPLE OF SHUNT CURRENT COMPENSATION

The basic concept of shunt active filtering is explained by the Figure 4.2. A nonlinear load draws a fundamental current component I_{LF} and a harmonic current I_{Lh} from the power system. The harmonic current Iish is induced by the source harmonic voltage V. A shunt active filter can compensate both harmonic currents I_{sh} and I However, the principal function of a shunt active filter is compensation of the load harmonic current I . This means that the active filter confines the load harmonic current at the load terminals, hindering its penetration into the power system. For simplicity, the power system is represented only by equivalent impedance X in Figure 4.1 if the load harmonic current I flow through the power system, it produces an additional harmonic voltage drop equal to X I that further degenerates the load terminal voltage V.

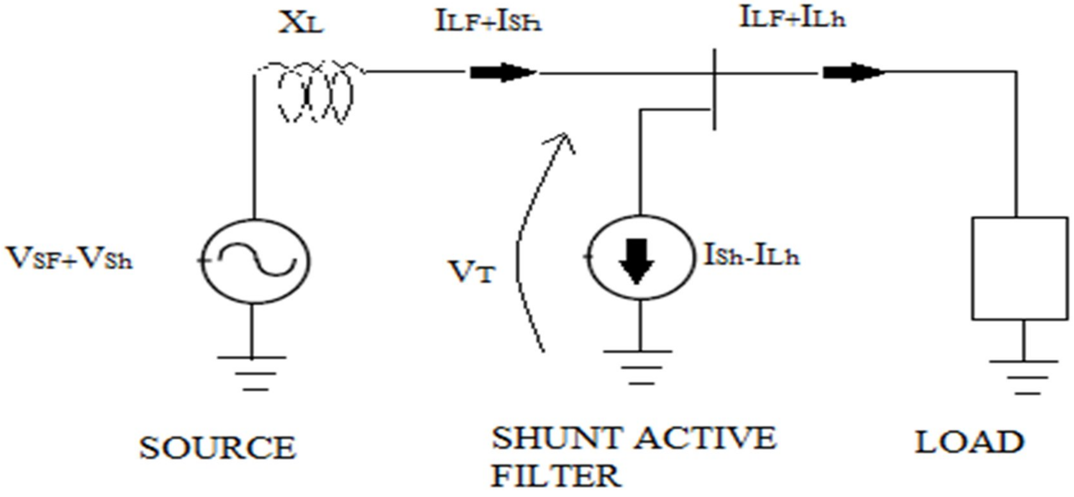

Figure 4.2: Current compensation

The principle of shunt current compensation shown in Figure 4.2 is very effective in compensating harmonic currents of loads. However a shunt active filter that realizes this principle of shunt current compensation should also draw an additional harmonic current I_{Sh} in order to keep the load terminal voltage sinusoidal and equal to $V_T = V_{SF} - X_L$. IF the harmonic voltage components cancel each other, so that the terminal voltage V is kept sinusoidal.

If the system impedance X_L is low, the harmonic current I_{Sh} that should be drawn by the shunt active filter can be very high. This can strongly, increase the power rating of the shunt active filter, making it impractical. Therefore, if the power system has high short-circuit capacity, which is the same as saying that it has a low equivalent impedance X_L,or if it has an already significant level of voltage distortion, the active filtering of current Ish should be left for other filter configurations for instance, an interesting solution is to install a series active filter at the load terminals for direct compensation of the harmonic voltage instead of the use of a shunt active filter to drain the harmonic current from the power system . Note that the principle of series voltage compensation is the complement shunt current compensation. In other words, if th series active filter generates a compensation voltage equal to V_{sh}. It forces the harmonic current to become zero. On the other hand, as mentioned above, if the shunt active filter draws compensation current equal to it confines the load harmonic current at the load terminals, hindering its penetration into the power system. Series active filters will be introduced in the next chapter.

The shunt active filter can be properly controlled to present a selective compensation characteristic. In other words, it is possible to select what current is to be compensated. That is it scan compensate the source current I_{Sh} and / or the load current or even and arbitratily chosen set of harmonic components of them. Most applications of shunt active filters are intended to compensate for the load current harmonics produced by a specific load.

Another interesting compensation function that a shunt active filter can realize is to provide harmonic damping in power lines, in order to avoid harmonic propagation resulting from harmonic resonances between the series inductances and shunt harmonics like V_{SF} in fig. 4.1 but rather a mitigation of voltage harmonics because of harmonic damping.

4.3 PRINCIPLE OF DSTATCOM [23]

A one-line diagram of a static compensator (STATCOM) is shown in Figure 4.3. The STATCOM shown in this figure consists of self-commutated converters using Gate Turn-Off (GTO) thyristors, a dc voltage source, a converter transformer, a step-up transformer, and a controller. Note that the step-up transformer is not normally necessary for the lower system voltage applications.

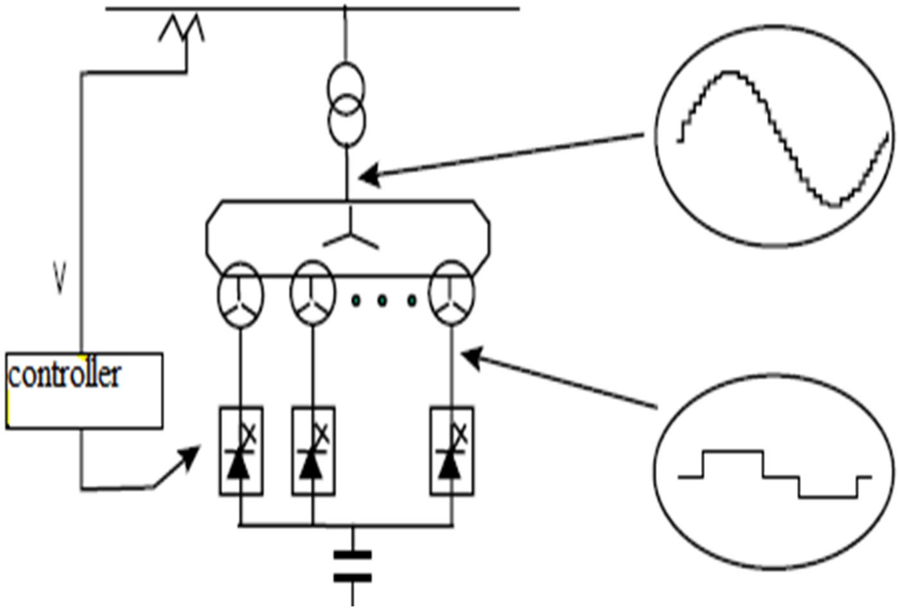

Figure- 4.3 Single line diagram of statcom

Each GTO converter generates a voltage that is stepped up by a line-side-series-connected multi-stage converter transformer. The converter transformer enables the build-up of a sine-wave voltage in both magnitude and phase. Because STATCOMs with multi-stage converter transformers do not generate significant internal harmonics, they generally require minimal, or no, harmonic filtering. If the number of firing pulses for the GTOs is increased (i.e., pulse-width modulation (PWM) order), the harmonics are further decreased. High-side voltage is generally used as a controller input, as Indicated in Figure-4.3.The equivalent circuit of a STATCOM system is shown in Figure- 4.4. The GTO converter with a dc voltage source and the power system are illustrated as variable ac voltages in this figure. These two voltages are connected by a reactance representing the transformer leakage inductance.

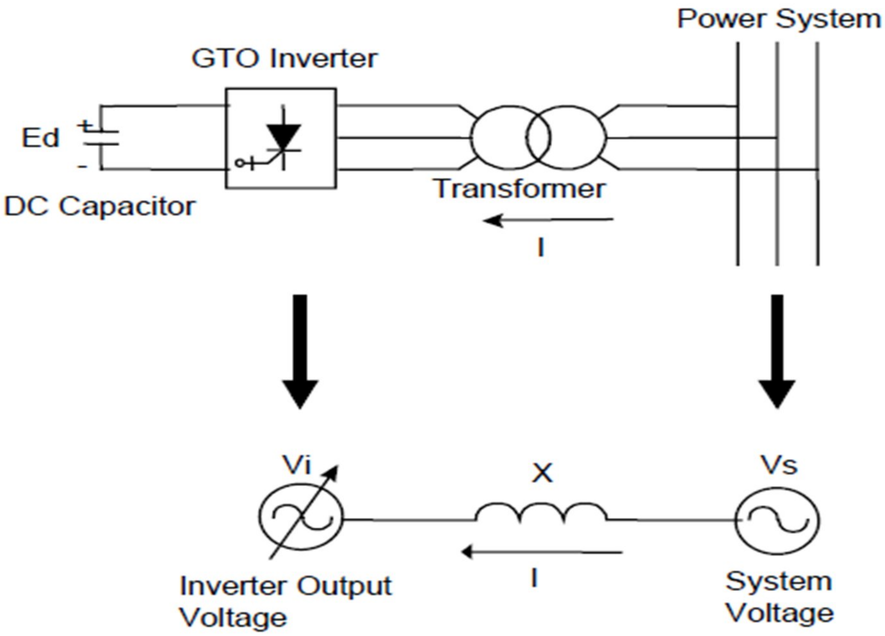

Figure-4.4: Equivalent circuit of a STATCOM

The basic principle of operation for a STATCOM is explained with the help of Figure- 4.5. The output voltage of the GTO converter (V_i) is controlled in phase with the system voltage (V_s), as shown in this figure, and the output current of the STATCOM (I) varies depending on Vi. If V_i is equal to V_s, then no reactive power is delivered to the power system. If V_i is higher than V_s, the phase angle of I is leading with respect to the phase angle of Vs by 90 degrees. As a result, leading reactive power flows from the STATCOM (capacitive mode). If V_i is lower than V_s, the phase angle of I is lagging with respect to V_s by 90 degrees.

As a result, lagging reactive power flows into the STATCOM (inductive mode). The amount of the reactive power is proportional to the voltage difference between V_s and V_i. Note that this is the same basic operating principal as a rotating synchronous condenser.

Working and V-I characteristic of the STATCOM is shown in figure in 4.5 and 4.6 respectively. The STATCOM smoothly and continuously controls voltage from V_1 to V_2, as shown in Figure 2-4. However, if the system voltage exceeds a low-voltage (V_1) or high-voltage limit (V_2), the STATCOM acts as a constant current source by controlling the converter voltage (V_i) appropriately.

Thus, when operating at its voltage limits, the amount of reactive power compensation provided by the STATCOM is more than the most-common competing FACTS controller, namely the Static Var Compensator (SVC). This is because at a low voltage limit, the reactive power drops off as the square of the voltage for the SVC, where $\mathrm{Mvar}=f_{(BV2)}$, but drops off linearly with the STATCOM, where $\mathrm{Mvar}=f_{(VI)}$. This makes the reactive power controllability of the STATCOM superior to that of the SVC, particularly during times of system distress.

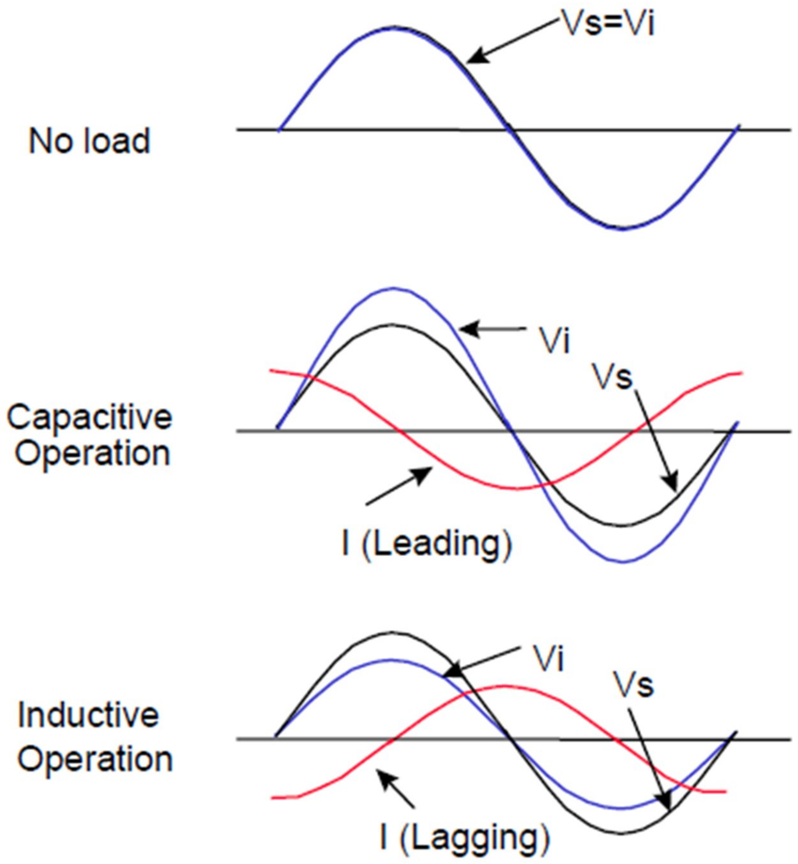

Figure-4.5: Working of STATCOM

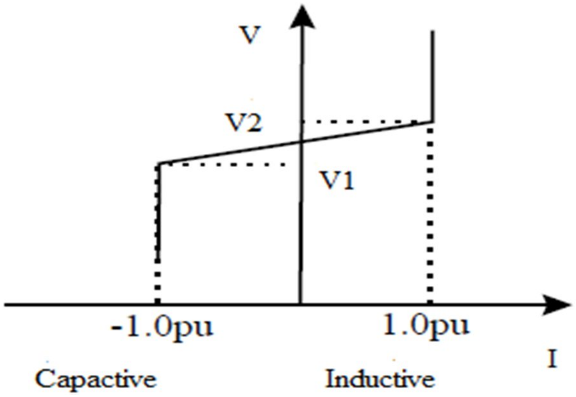

Figure-4.6: V-I characteristic of a STATCOM

4.4 ADVANTAGES OF STATCOM

1. Quicker response time (A STATCOM has a step response of 8 ms to 30 ms). This helps with compensation of negative phase current and with the reduction of voltage flicker.
2. Active power control is possible with a STATCOM (with optional energy storage on dc circuit). This could further help with system stability control.
3. No potential for creating a resonance point. This is because no capacitor banks or reactors are required to generate the reactive power for a STATCOM.
4. The STATCOM has a smaller installation space due to no capacitors or reactors required to generate Mvar, minimal or no filtering, and the availability of high capacity power semiconductor devices.

A modular design of the STATCOM allows for high availability (i.e., one or more modules of the STATCOM can be out-of-service without the loss of the entire compensation system).

4.5 PI CONTROLLER

4.5.1 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

Advantages and Disadvantages

To eliminate the offset, should be adjusted and reach a constant value when error becomes zero.

– The integral mode will change the bias value until the error becomes zero Eliminate offset

– The action is not immediate until the integral becomes significant. Also, the integral mode tends the system to be more oscillatory, even unstable

• **Advantages** (Combined benefits)

– Fast action

– Eliminate the offset

• **Disadvantage**

– Oscillatory or unstable with integral control

– One more parameter to tune

CHAPTER 5

TEST SYSTEMS AND RESULTS

5 .1 INTRODUCTION

Increasing automation in modem industry and deregulation has changed the requirements on Power Quality. Computer and process control equipment as well as drive converters are sensitive to deviations of the line voltage from the ideal sinusoidal. Voltage sags, harmonic distortion, flicker and interruption of power supply are the most common problems. In an increasing number of cases, where conventional equipment cannot solve these problems, PWM converter-based shunt connected Power Conditioners named DSTATCOM (Distribution Static Compensator) have been introduced. With energy storage added to the Power Conditioner even more flexibility in system operation and planning is provided for utilities and industry. In this thesis work, Simulink model of test system is analyzed. In this test model two similar loads with different feeders are considered. One of the feeder is connected to DSTATCOM and the other is kept as it is. This test system is analyzed under different fault conditions. System is also analyzed with non linear load under same fault conditions. The control technique implements a PI controller which starts from the difference between the injected current (DSTATCOM current) and reference current (identified current) that determines the reference voltage of the inverter (modulating reference signal).

5.2 PARAMETERS OF THE TEST SYSTEM

The modeled system has been tested on different fault conditions with linear as well as non linear load. The system is employed with three phase generation source with configuration of 25KV, 50 Hz. The source is feeding two transmission lines through a three phase, three windings transformer with power rating 250MVA, 50 Hz.

Winding 1: V1rms (ph-ph) = 25 KV, R1 = .002 (pu), L1 = .08002 (pu).

Winding 2: V2rms (ph-ph) = 11 KV, R2 = .002 (pu), L2 = .08002 (pu).

Winding 3: V3rms (ph-ph) = 11 KV, R3 = .002 (pu), L3 = .08002 (pu).

5.3 SIMULINK MODEL OF THE TEST SYSTEM WITH STATIC LINEAR LOAD

Simulink model of the test system is given in Figure-5.1. The system consists of two parallel feeders with similar loads of same rating. One of the line is connected to DSTATCOM and the other line is kept as it is. This system is analyzed under different fault conditions.

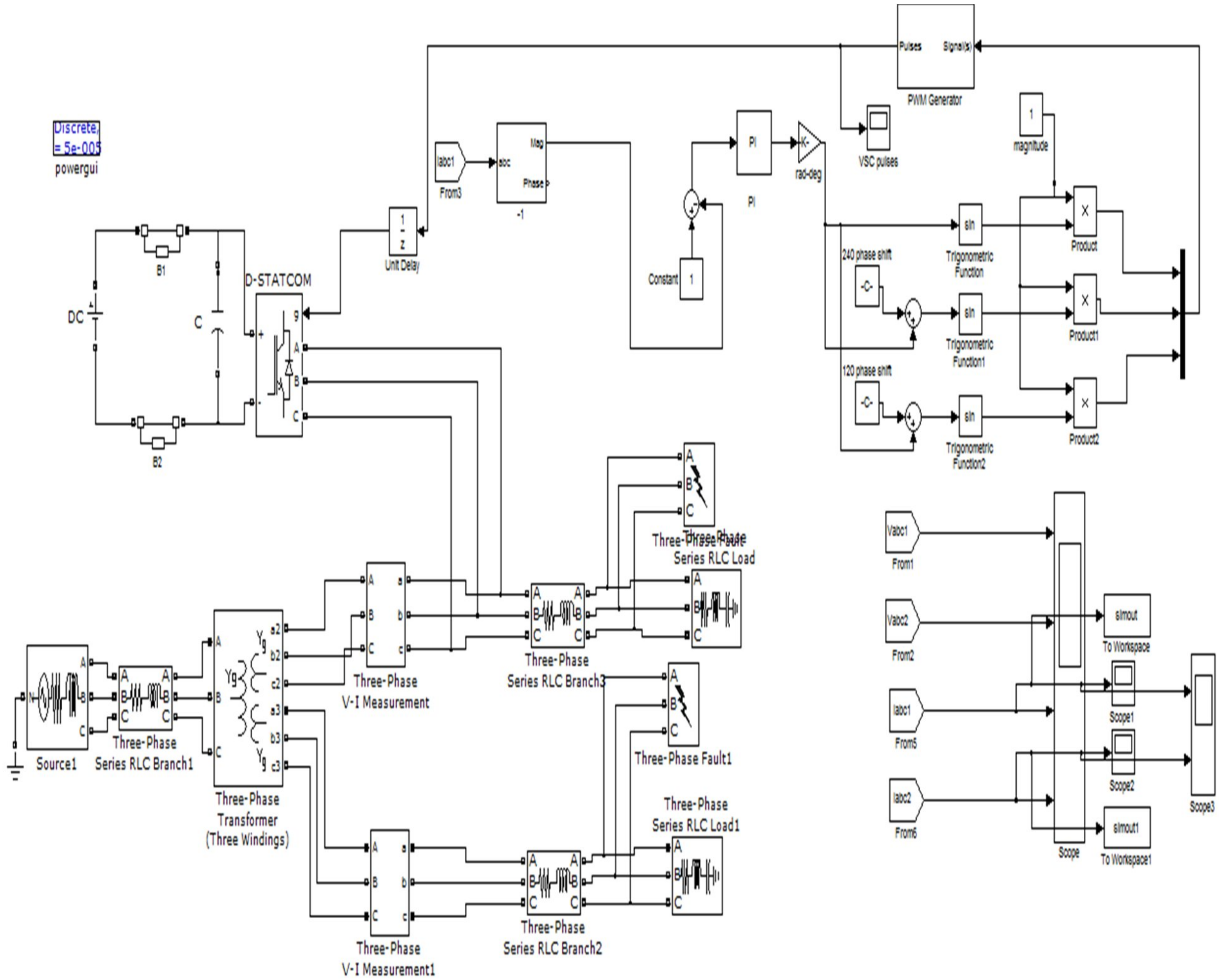

Figure-5.1: Simulink model of test system

5.4 RESULTS UNDER DIFFERENT FAULT CONDITIONS

Three different fault conditions are considered for the test system as shown in Figure-5.1. The three different fault conditions are single line to ground, double line to ground and three phase line to ground fault. The results for each fault condition are given one by one.

5.4.1 CASE 1. Single Line to Ground Fault Condition

In first case a single line to ground fault is considered for both the feeders. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.3s to 0.5s. The output wave for the load current with compensation and without compensation is shown in Figure-5.2, Figure-5.3 respectively

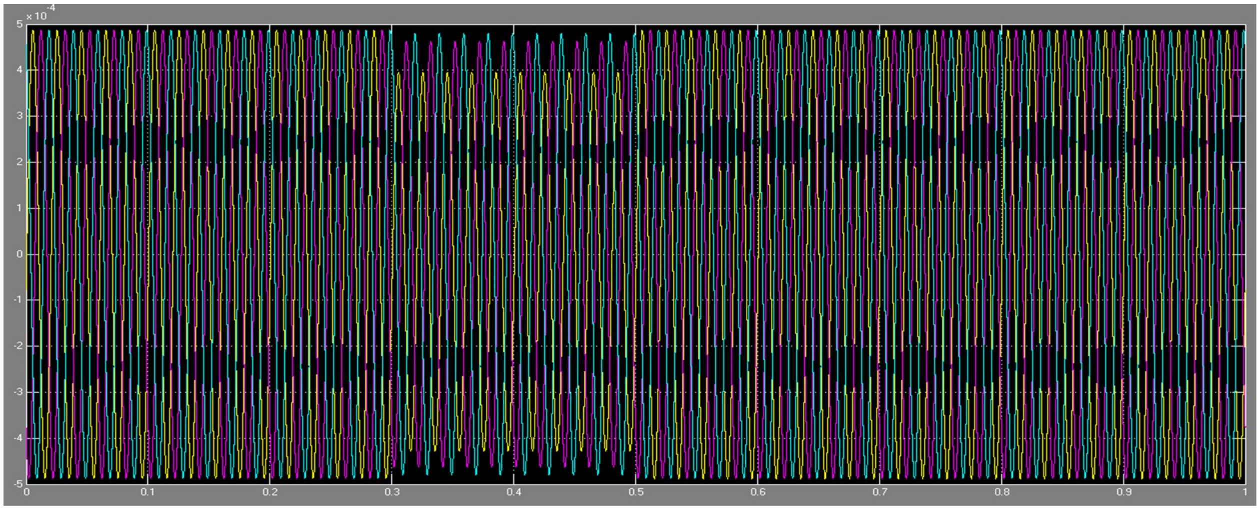

Figure-5.2: Load current (with compensation)

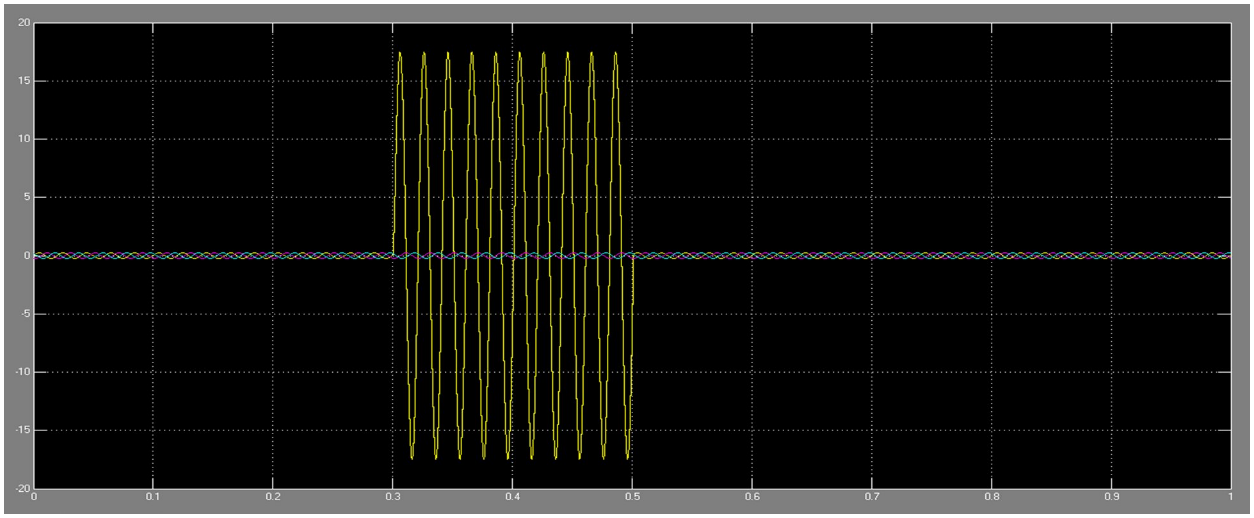

Figure-5.3: Load current (without compensation)

Here it is clear from the output wave shapes that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder. So, here the unbalancing in the system where DSTATCOM is connected is reduced clearly.

5.4.2 CASE 2. Double Line to Ground Fault Condition

In second case considered fault for both the feeders is double line to ground fault. For this fault resistance and ground resistance is 0.001ohm and 0.001ohm respectively. And the time duration for this fault is 0.3seconds to 0.5seconds. The output wave for the load current with compensation and without compensation is shown in figure-5.4 and Figure-5.5 respectively.

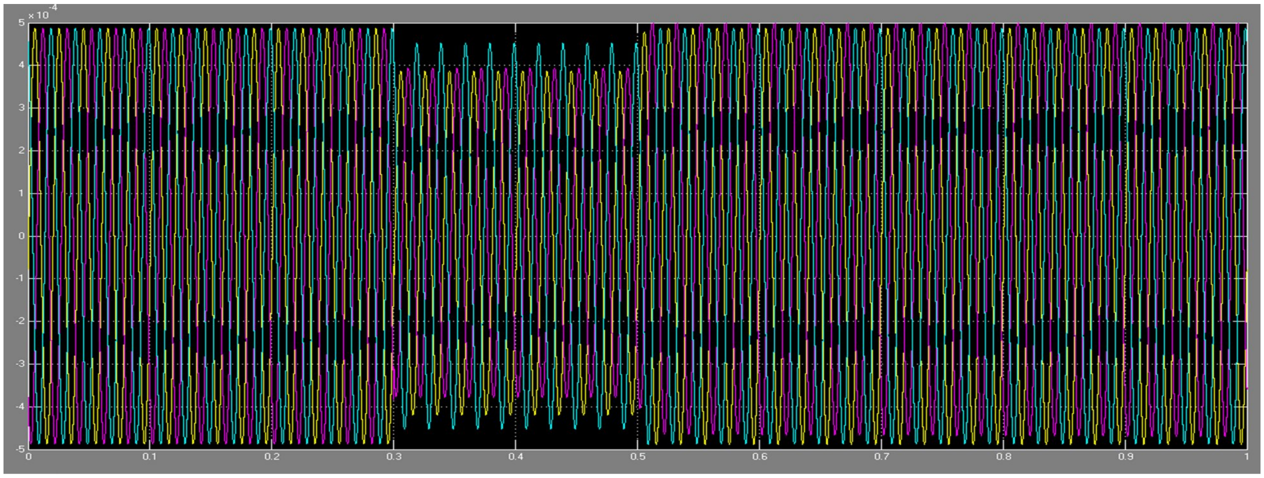

Figure-5.4 Load current (with compensation)

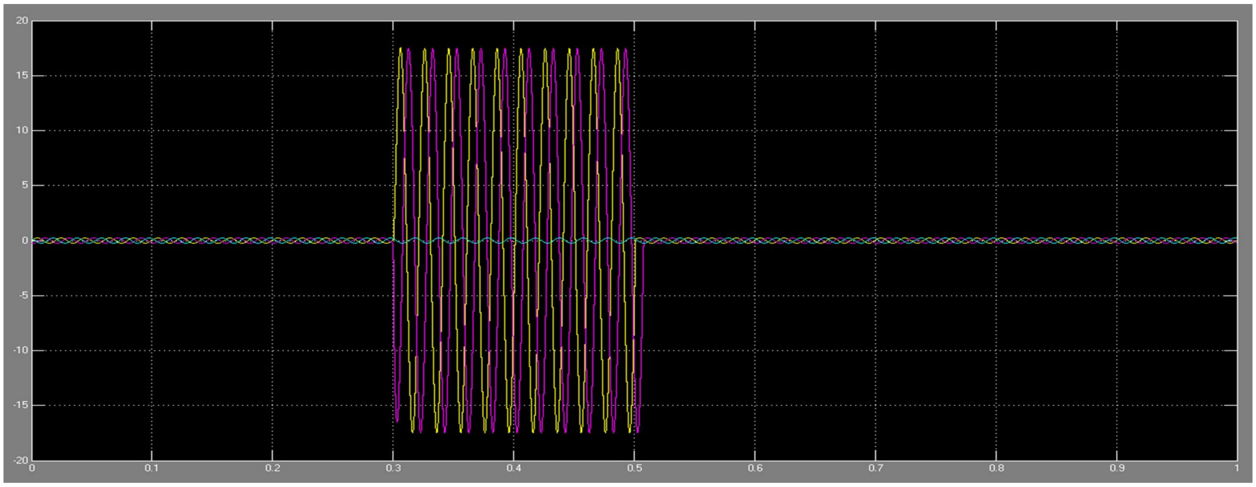

Figure-5.5 Load current (without compensation)

The output wave shapes clear that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder, but in system where the DSTATCOM is connected unbalancing is reduced clearly.

5.4.3 CASE 3. Three Phase Line to Ground Fault Condition

In third case a considered fault for both the feeders is three phase to line fault. The fault is created for the duration of 0.3s to 0.5s. And fault resistance and ground resistance is 0.001ohm and 0.001ohm respectively. The output wave for the load current with compensation and without compensation is shown in Figure-5.6 and Figure-5.7 respectively.

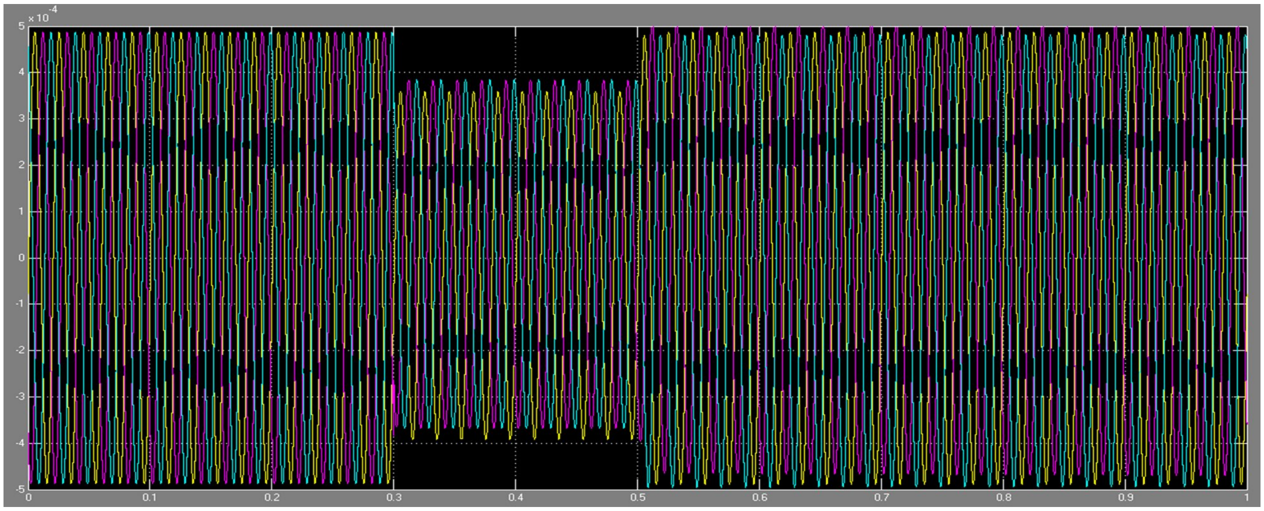

Figure-5.6: Load current (with compensation)

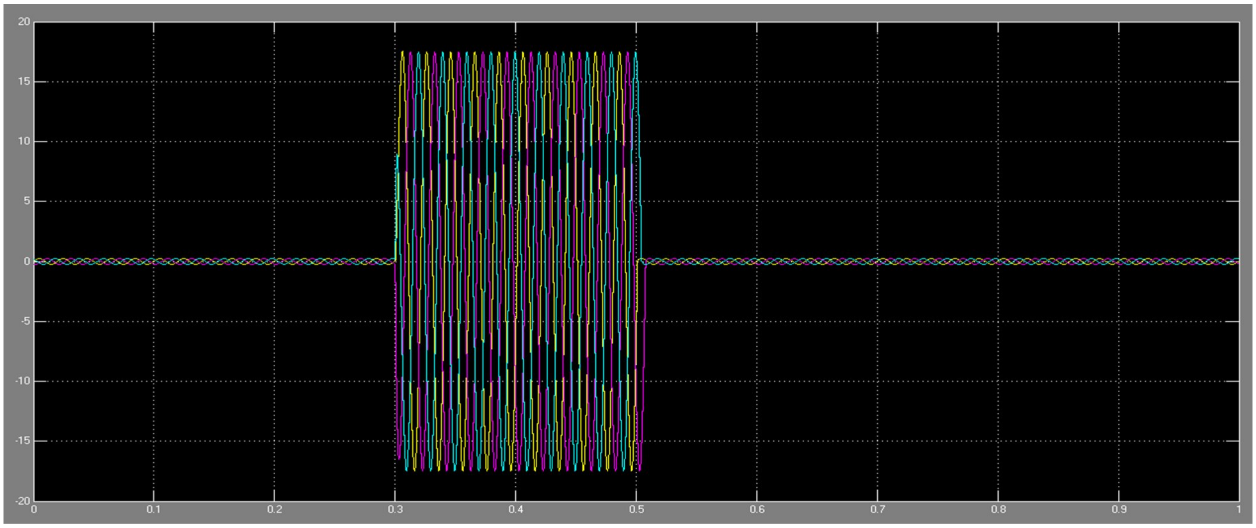

Figure-5.7: Load current (without compensation)

The Figure-5.6 and Figure-5.7 respectively shows the wave shapes that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder. And the system where DSTATCOM is connected unbalancing is reduced.

5.5 SIMULINK MODEL OF TEST SYSTEM WITH STATIC NON LINEAR LOAD

Simulink model of the test system is given in Figure-5.8. The system consists of two parallel feeders with similar loads of same rating. Here static non linear load is taken. One of the line is connected to DSTATCOM and the other line is kept as it is. This system is analyzed under different fault conditions.

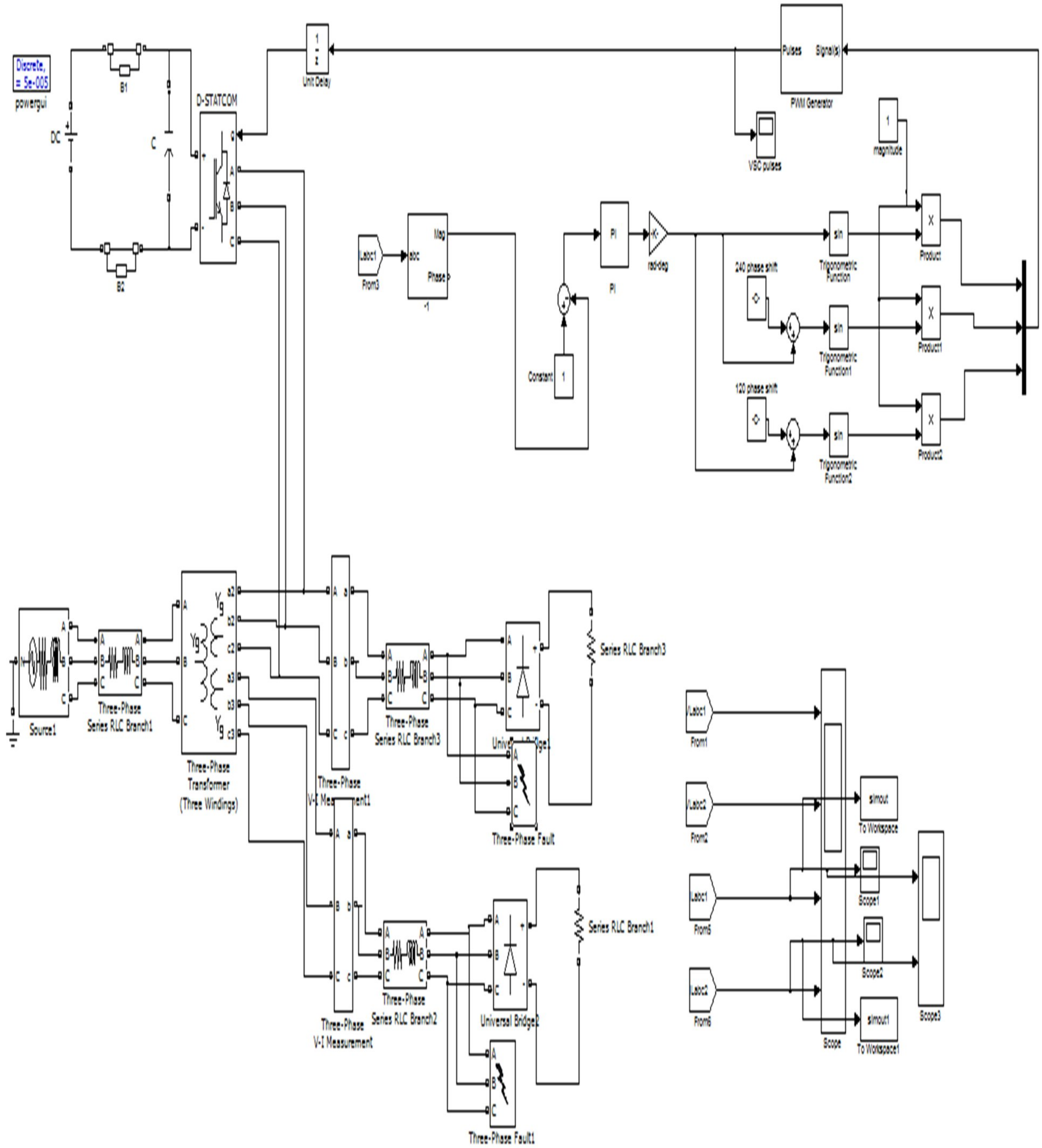

Figure-5.8: Simulink model of test system with non linear load.

5.5.1 CASE 1. Single Line to Ground Fault Condition

In this case a single line to ground fault is considered for both the feeders. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.2s to 0.6s. The output wave for the load current with compensation and without compensation is shown in Figure-5.9 and Figure-5.10 respectively.

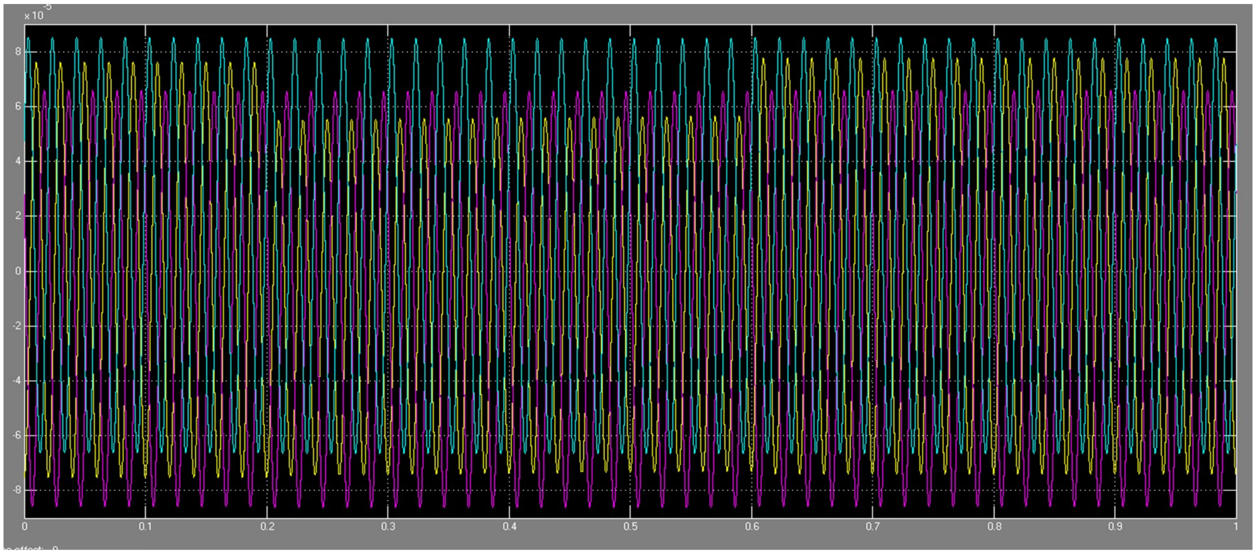

Figure-5.9: Load current (with compensation)

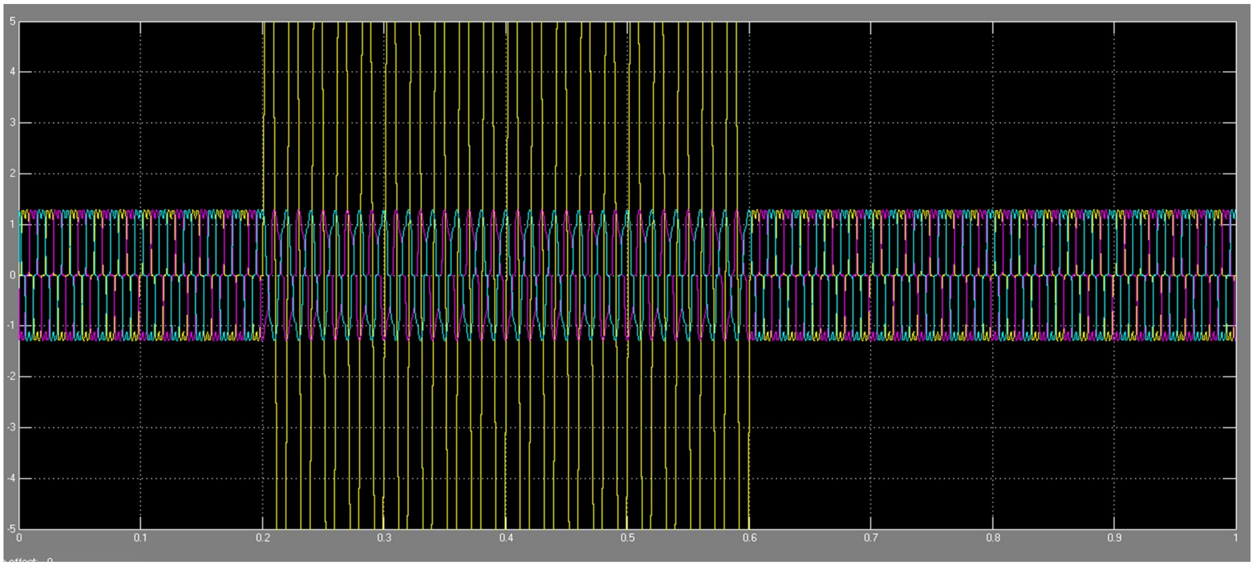

Figure-5.10: Load current (without compensation)

The output wave shapes clear that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder, but in system where the DSTATCOM is connected unbalancing is reduced clearly.

5.5.2 CASE 2. Double Line to Ground Fault Condition

In this case a Double line to ground fault is considered for both the feeders. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.2s to 0.6s. The output wave for the load current with compensation and without compensation is shown in Figure-5.11 and Figure-5.12 respectively.

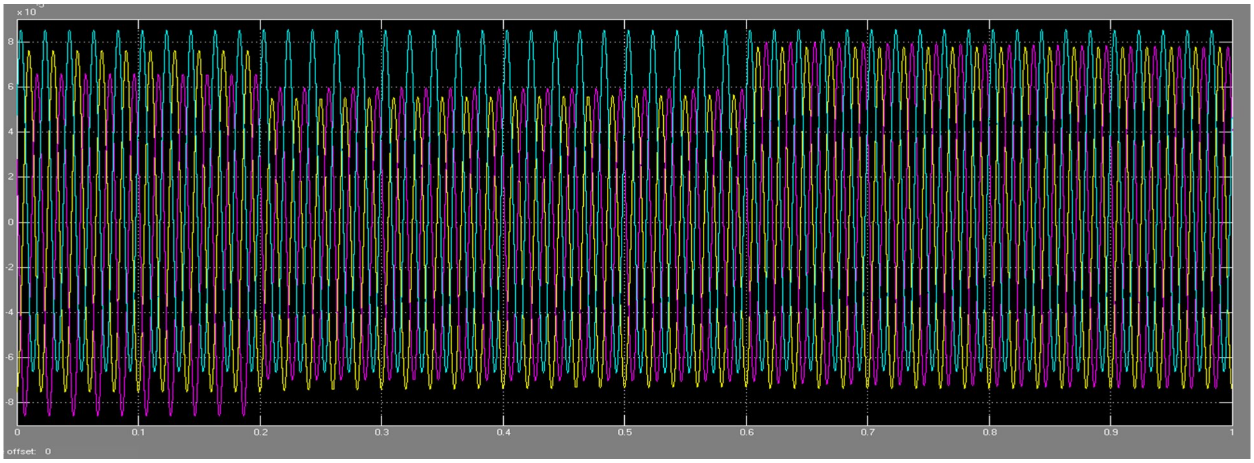

Figure-5.11: Load current (with compensation)

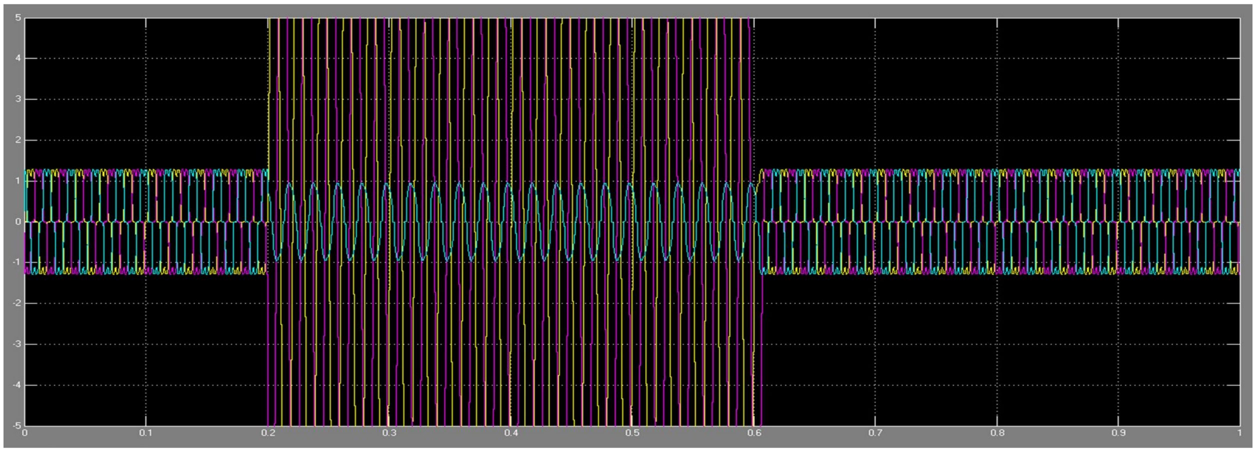

Figure-5.12: Load current (without compensation)

The Figure-5.11 and Figure-5.12 respectively, shows the wave shapes that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder. And the system where DSTATCOM is connected unbalancing is reduced

.5.5.3 CASE 3. Three Phase Line to Ground Fault Condition

In this case a three phase line to ground fault is considered for both the feeders. Here the fault resistance is 0.001 ohm and the ground resistance is 0.001 ohm. The fault is created for the duration of 0.2s to 0.6s. The output wave for the load current with compensation and without compensation is shown in Figure-5.13 and Figure-5.14 respectively.

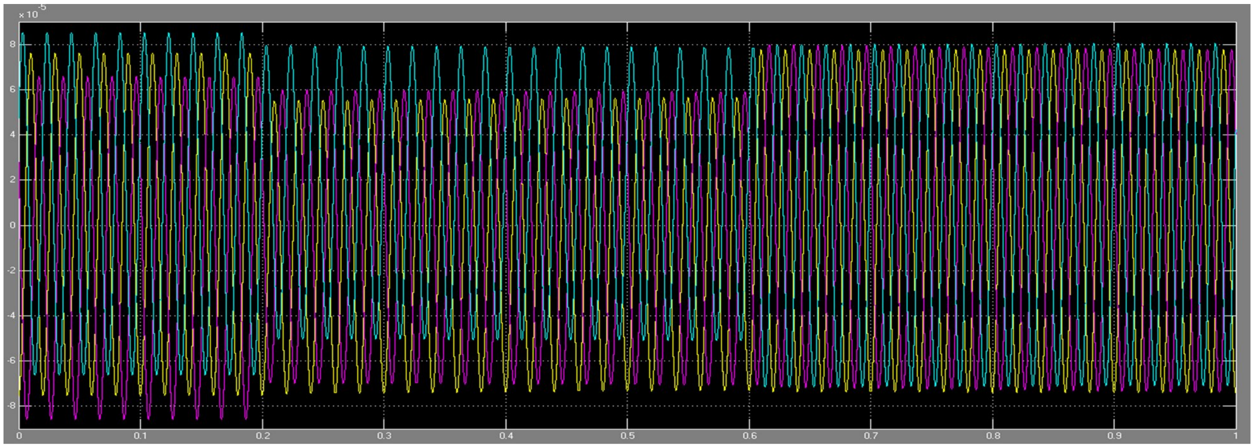

Figure-5.13: Load current (with compensation)

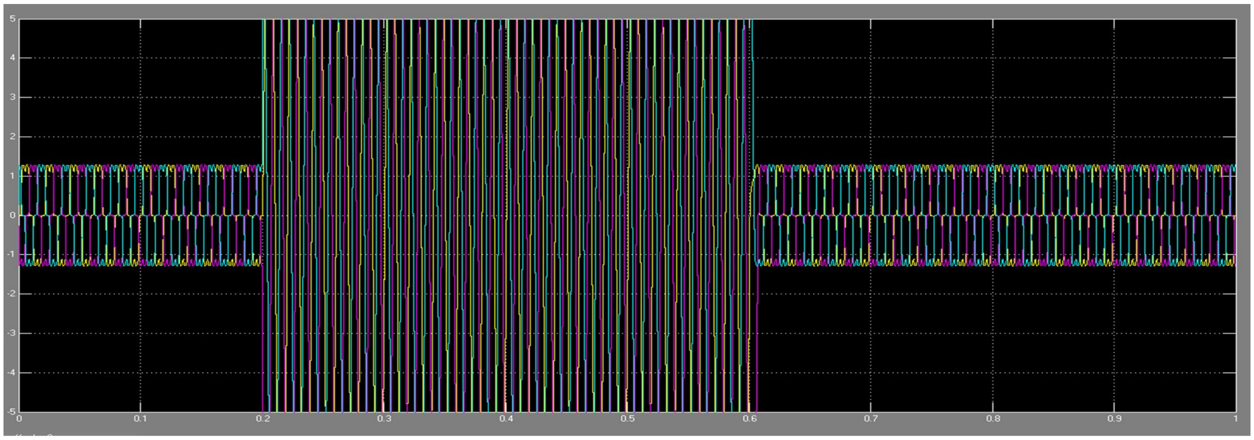

Figure-5.14: Load current (with compensation and without compensation)

Here it is clear from the output wave shapes that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder. So here the unbalancing in the system where DSTATCOM is connected is reduced clearly. These results become clear from the total harmonic distortion graphs, which are taken one by one for compensated and non compensated feeders with non linear loads.

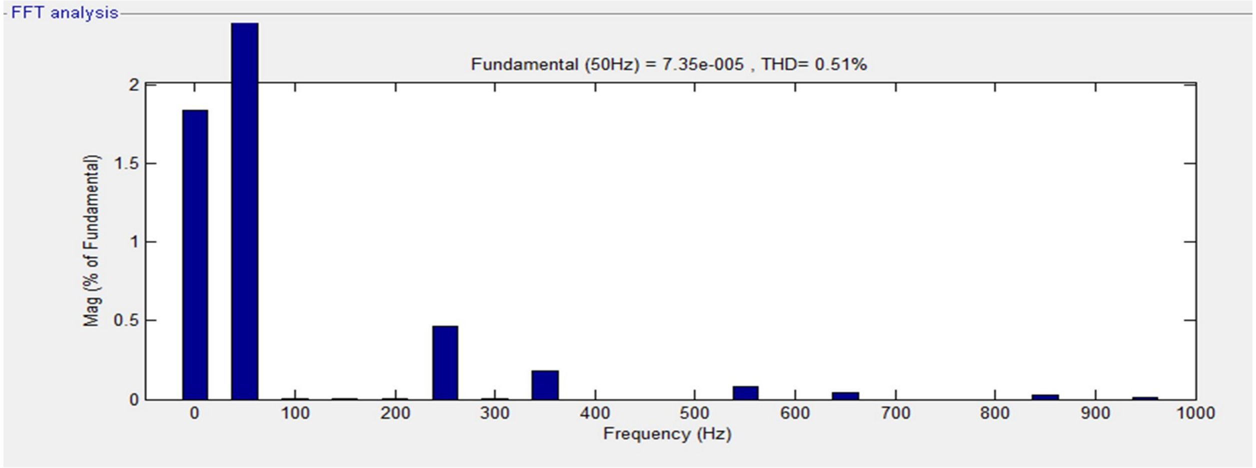

Figure-5.15: THD (with compensation)

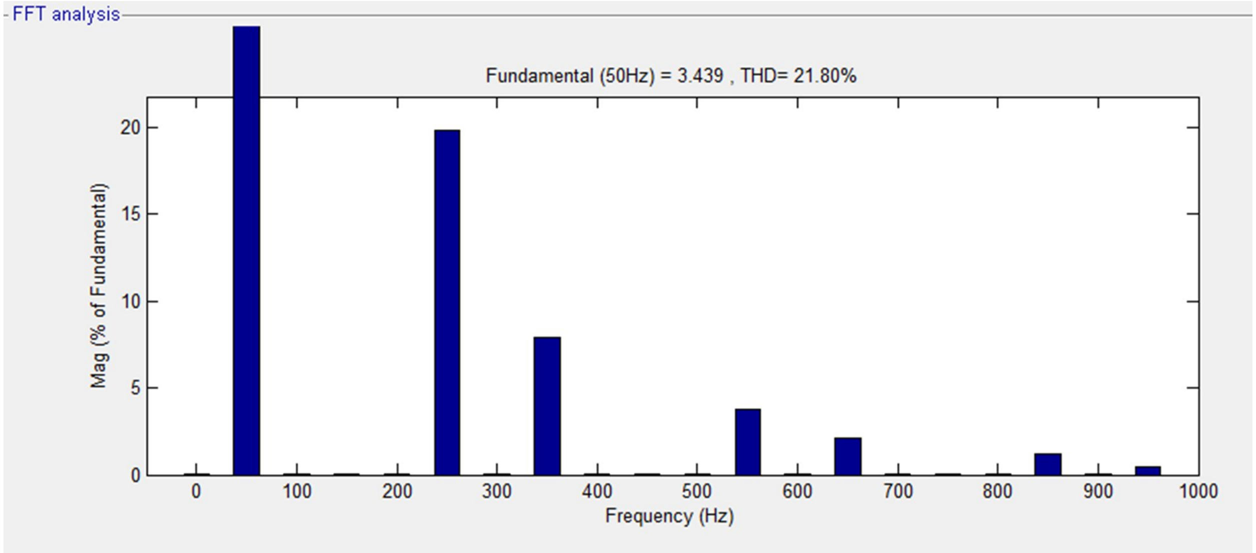

Figure-5.16: THD (without compensation)

The THD graphs with compensation and without compensation are given in Figure-5.15 and Figure-5.16. The total harmonic distortion without compensation is 21.80%, which is reduced to 0.51% where DSTATCOM is connected.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

In this work, the investigation on the role of DSTATCOM is carried out to improve the power quality in distribution networks with static linear and non linear loads. PI controller is used with the device to enhance its performance. Test system is analyzed and results are presented in the previous chapter. The results give the satisfactory applications of DSTATCOM in the distribution networks under different fault conditions and it can be concluded that DSTATCOM effectively improves the power quality in distribution networks with static linear.

6.2 FUTURE SCOPE

In this thesis work it is shown that DSTATCOM can compensate harmonics in current. The work can be expanded in the following area:

1. Other advanced controllers like fuzzy controller, adaptive fuzzy controller can be employed with DSTATCOM to increase the effectiveness of DSTATCOM in distribution networks.
2. Dynamic loads can be considered in future work and the effect of DSTATCOM with them can be studied.

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