

**PERFORMANCE COMPARISON OF DSTATCOM, DVR AND OPEN
UPQC IN A DISTRIBUTION NETWORK WITH
DYNAMIC LOAD AND INDUSTRIAL DRIVE**

Dissertation

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**MASTER OF ENGINEERING
IN
POWER SYSTEMS**

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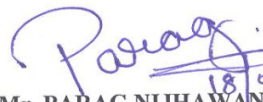
I, hereby, certify that the Thesis entitled “Performance Comparison of DSTATCOM, DVR and Open UPQC in a Distribution Network with Dynamic Load and Industrial Drive” in the partial fulfillment of the requirement for the degree of Master of Engineering in *Power Systems*, submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala is an authentic 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.


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Dedicated to My Parents

ABSTRACT

Dynamic Voltage Restorer (DVR) is a series compensator which can compensate for power quality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags, and voltage swells. Distribution Static Compensator (DSTATCOM) is a shunt compensator which can compensate for power quality problems such as current harmonics, current unbalance, reactive current, etc. Unified Power Quality Conditioner (UPQC) is a custom power device that consists of shunt and series converters connected back to back and deals with load current and supply voltage imperfections. Open UPQC consists of DVR and DSTATCOM without common DC link. The chief objective of this thesis is to develop models of DVR, DSTATCOM and OPEN-UPQC for enhancement of power quality under various operating conditions. In this work, an open UPQC is used to compensate for high power load of 250MVA consisting of Dynamic load and DTC motor drive. It is then simulated experimentally to mitigate voltage sag/swells and harmonic currents. Traditional dq-theory is applied with PI controller to investigate the performance of series, shunt, and combination of series-shunt compensators. The operation of open UPQC isolates the utility from current quality problems of load and in the same time, isolates the load from voltage quality problems of utility. In this work, the effectiveness of DVR, DSTATCOM and Open UPQC are compared for a 3-phase distribution network with Dynamic load and DTC induction motor drive.

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LIST OF ABBREVIATIONS

LG	Single Line To Ground
LLG	Double Line To Ground
LLL	Three Phase Fault
IEEE	Institute Of Electrical And Electronics Engineers
DVR	Dynamic Voltage Restorer
DSTATCOM	Distribution Static Synchronous Compensators
AC	Alternating Current
FACTS	Flexible Ac Transmission Systems
ASD	Adjustable Speed Drives
FOC	Field Orientated Control
APF	Active Power Filters
BESS	Battery Energy Storage System
DC	Direct Current
DFACTS	Distribution Facts
DIN	Distortion Index
PI	Proportional Integral
SVPWM	Space Vector Pulse Width Modulation
PWM	Pulse Width Modulation
FFT	Fast Fourier Transform
FOC	Field Oriented Control
FT	Fourier Transform
GTO	Gate Turn- Off Thyristor
HVDC	High Voltage Direct Current
IEC	International Electro Technical Commission
IGBT	Insulated Gate Bipolar Transistors
IPQT	Instantaneous P-Q Theory
MATLAB	Matrix Laboratory
MOSFET	Metal Oxide Semiconductor Field Effect Transistors
PCC	Point of Common Coupling

PLL	Phase Lock Loop
PQ	Power Quality
SMES	Super Conducting Magnetic Energy Systems
SPWM	Sinusoidal Pulse Width Modulation
SSCB	Solid State Circuit Breaker
UPS	Uninterruptible Power Supplies
SSSC	Static Synchronous Series Compensator
SSTS	Solid State Transfer Switch
SVC	Static Var Compensator
UPFC	Unified Power Flow Controller
UPQC	Unified Power Quality Controller
THD	Total Harmonic Distortion
PCC	Point of Common Coupling
VSC	Voltage Source Converter
AUPF	Average Unity Power Factor
ISCT	Instantaneous Symmetrical Component Theory
AGCT	Average Global Control Theory
IGCT	Instantaneous Global Control Theory

CHAPTER 1

INTRODUCTION

1.1. OVERVIEW

One of the main responsibilities of a utility system is to supply electric power in the form of sinusoidal and currents with appropriate magnitudes and frequency for the customers at the points of common coupling (PCC). Although the generated voltage of synchronous machines in power plants are almost sinusoidal, some unsighted conditions such as lightning and short circuit faults and non linear loads cause steady state error or transient voltages and current disturbances. For instance, electric arc furnaces cause voltage fluctuations, power electronic converters generate current harmonics and distort voltage waveforms, and short circuits faults result in voltage sags and swells [1-4]. On the other hand most customer loads such as computers, microcontrollers and hospital equipment are sensitive and unprotected to power quality disturbances and their proper operation depends on the quality of the voltage that is supplied to them.

This is possible only by ensuring an uninterrupted flow of power at proper voltage and frequency levels. As a result of this, FACTS devices and Custom power devices are introduced to electrical system to improve the power quality of the electrical power. With the help of these devices we are capable to reduce the problems related to power quality. There are many types of Custom Power devices. Some of these devices include Active Power Filters (APF), Surge Arresters (SA), Battery Energy Storage Systems (BESS), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid State Fault Current Limiter (SSFCL), Solid-State Transfer Switches (SSTS), Static VAR Compensator (SVC), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Distribution Static synchronous Compensators (DSTATCOM) and Uninterruptible Power Supplies (UPS), Unified power quality conditioner (UPQC). But in this work, the main focus is kept only on DSTATCOM, DVR and OPEN UPQC.

A DVR is based on power electronic converter, placed in series with sensitive load to protect critical loads from all supply side disturbances. The DVR is a promising and effective device for power quality enhancement due to its quick response and high reliability.

A DSTATCOM is a shunt compensator, based on power electronic converter. It is connected in shunt at PCC to protect critical loads from all load side disturbances. The

DSTATCOM is an effective device to reduce current variations and harmonics from the distribution network.

The open unified power quality conditioner (UPQC), composed of a power-electronic series main unit installed in the medium-voltage/low-voltage (LV) substation, along with several power-electronic shunt units connected close to the end users. The series and parallel units do not have a common dc link, so their control strategies are independent of each other.

1.2. LITERATURE REVIEW

Power quality is a comprehensive term that squeezes all features related with amplitude, phase and frequency of the voltage and current waveforms existing in a power circuit. Poor power quality may result from transient conditions accumulate in the power circuit or from the non-linear loads.

Power distribution systems ought to deliver their customers with an associate degree uninterrupted flow of energy with smooth sinusoidal voltage at the contracted magnitude level and frequency, but the distribution systems, have several nonlinear loads, which significantly affect the quality of power supplies [1-4].

The concept of custom power was introduced by **N.G.Hingorani** [6]. The term custom power means the utilisation of power electronic controllers for distribution systems. The custom power devices will increases the quality and reliability of the power that is delivered to the customers. Customers are increasingly demanding more exigent quality in the power supplied by the electrical company.

Comprehensive review of compensating type custom power devices, issues of power quality, survey of power quality issues, standards and indices proposed by different agencies and different approaches to boost power quality from time to time [6-9].

Power quality can be classified into three categories that is, voltage stability, continuity of supplying power, and voltage. Based on this classification, several examples of power quality level definitions were presented by **Toshifiimi Ise** *et. al.* [5]

Afshin Lashkar Ara *et. al.* [10] described the power electronic devices and technical review in various power engineering levels. In addition, the power electronics-based equipment, which are called power conditioners are use to solve power quality problems. Power conditioners are also called Distribution FACTS (DFACTS) devices. [1] presents the comparison of the operating modes and applications of FACTS

devices (such as STATCOM, SSSC, UPFC, DSTATCOM, DVR and UPQC) in transmission and distribution systems.

Juan W. Dixon *et. al.* [11] presented a series active power filter working as a sinusoidal current source, which is in phase with the mains voltage. The amplitude of the fundamental current in the series filter is controlled with the help of error signal generated between the load voltage and a pre established reference. The control provides the effective correction of power factor, harmonic distortion, and load voltage regulation.

T.Devaraju *et. al.* [12] proposed that power quality problem is an occurrence manifested as a non standard voltage, current or frequency that results in a failure of equipments. Utility distribution networks, sensitive industrial loads, and critical commercial operations all suffer from various types of outages and service interruptions which can cost significant financial loss per incident based on process down-time, lost production, idle work forces, and other factors. In this electromagnetic transient studies are presented for the following two custom power controllers: the distribution static compensator (DSTATCOM), and the dynamic voltage restorer (DVR).

Mahesh Singh *et. al.* [13] demonstrated that power quality measures can be applied both at the user end and also at the utility level. The work identifies some important measures that can be applied at the utility level without much system upset. The models of custom power equipment, namely D-STATCOM and DVR are presented and applied to mitigate voltage dip which is very prominent as per utilities are concerned using a new PWM-based control scheme. It was observed that in case of DSTATCOM capacity for power compensation and voltage regulation depends mainly on the rating of the dc storage device.

A DVR system based on downstream fault limiting function and a flux charge model feedback controller has been proposed and integrated by **Yun Wei Li** *et. al.* [14]. It would act as a large virtual inductance in series with the distribution feeder in fault condition. It can protect from sudden sags and swells and it minimizes the stress on the DC Link.

For the compensation of power quality problems viz. voltage sags, voltage harmonics and voltage imbalances a two level DVR with repetitive controller was introduced by **Pedro Roncero-Sanchez** *et. al.* [15]. They observed that repetitive controller specialty is fast transient response and it ensures for any sinusoidal input and any sinusoidal disturbance to zero error in steady state condition. For the implementation of controller, they used either stationery reference frame or rotating reference frame.

Steady state analysis based DVR was demonstrated by **Arindam Ghosh and Gerard Ledwich** [16]. Time varying reference voltages of a DVR can be obtained through different options. VSI is used to realize the structure of the DVR.

Parag Nijhawan and Rajan Sharma [16] focuses on power quality improvement with DSTATCOM on feeders feeding linear loads, nonlinear loads and DTC induction motor drive. In this paper, effectiveness of DSTATCOM in distribution networks to compensate the load current harmonics under various operating and fault conditions is discussed and implemented. A dqo transformation based PWM current controller is used to derive gating pulses for the IGBT switch. It is observed that DSTATCOM is effective in compensating current, harmonics, reactive power and improving the power quality of the distribution system.

Parag Nijhawan et. al. [17] evaluated the performance of a carrier phase shifted pulse-width modulation (PWM) multilevel inverter (five-level)-based distribution static synchronous compensator (DSTATCOM) and compared it with that of a PWM inverter based-DSTATCOM with induction furnace load. Simulink is used for illustrating the multilevel inverter based DSTATCOM for reducing harmonic distortion in the load current with induction furnace load in the distribution network.

Parag Nijhawan and Rajan Sharma [18] focused on power quality improvement with DSTATCOM on feeders feeding field oriented controlled induction motor drive as load. In this paper, role of DSTATCOM to improve power quality of distribution network under normal operating and fault conditions is investigated. Comparison of THD analysis for FOC induction motor drive load under normal and various faults conditions with or without DSTATCOM is also discussed in this paper. DSTATCOM is realized using IGBT and dqo transformation based PWM current controller is used to derive 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.

Parag Nijhawan et. al. [19] presented the application of DSTATCOM in a distribution network with induction furnace load. The induction furnace load is generating the appreciable amount of harmonic distortion. This distortion results due to the design and operation of the induction furnace. This harmonic distortion can even affect the performance of other loads connected in the system. DSTATCOM is a shunt connected custom power device to improve the power quality. It does so by injecting a compensating current into the power system network. In this paper, the SIMULINK model representing the application of

DSTATCOM with PI controller for reducing the harmonic distortion of the distribution network with induction furnace load is presented.

Parag Nijhawan et. al. [20] proposed the application of Distribution static synchronous compensator (DSTATCOM) with fuzzy controller in a distribution network with induction furnace load. In this paper, the results obtained for the SIMULINK model illustrating the application of DSTATCOM with Fuzzy controller for reducing the harmonic distortion in the load current in the distribution network with induction furnace load, are presented.

Parag Nijhawan and Ankush Malhar [21] realized UPQC using Simulink tool and it is tested for varying load condition and single line to ground fault. Comparison of voltage and current level in different operating condition is done along with the comparison of Total Harmonic Distortion (THD) level with and without UPQC compensation is presented. UPQC is realized using IGBT based PWM-VSI inverter having a DC bus capacitor. A dqo transformation based PWM current controller is used to derive gating pulses for the IGBT switch. It is seen that UPQC is effective in compensating current, harmonics, reactive power and improving the power quality of the distribution system.

G.O. Suvire and P.E. Mercado [22] presented a distribution static synchronous compensator (DSTATCOM) coupled with a flywheel energy storage system (FESS) to mitigate problems introduced by wind generation in the electrical systems. A dynamic model of the DSTATCOM/FESS device is briefly presented and a technique to control the active power exchanged between the device and the power system is proposed. Simulation test on the behaviour of the device are analysed when it works in combination with wind generation in the electrical system. Results show a satisfactory performance of the proposed control techniques along with a high effectiveness to smooth the active power fluctuations of wind generation and to contribute to the recovery of the frequency.

G. Siva Kumar et. al. [23] presents a device that will enhance power quality i.e. unified power quality conditioner (UPQC). The UPQC could be a versatile device that might operate as series active filter and shunt active filter. It can obey objectives like, maintaining a balanced sinusoidal (harmonic free) nominal voltage at the load bus, removing harmonic current from the supply, load balancing and power factor correction.

R.N.Bhargavi, et. al. [24] presents that causes of a poor power quality are harmonic currents, poor power factor, supply voltage variations, etc. Voltage sag/swell, momentary interruption, under/over voltages, noise and harmonics are the most common power quality

issues. A new connection for a unified power quality conditioner (UPQC) to improve the power quality of two feeders in a distribution system is proposed. This paper illustrates how UPQC can improve the quality of power by mitigating all these PQ disturbances.

K. Palanisamy *et. al.* [25] presents a novel control strategy for the case of 3-phase 3-wire Unified Power-Quality Conditioner (UPQC) based on the concepts of instantaneous active and reactive Power theory. The UPQC is presented as one of the major custom power solutions capable of mitigating the effect of supply voltage sags/swells, distortion, unbalance voltage at the point of common coupling (PCC) as well as load harmonics, unbalance load and reactive power requirement of load. Using this control strategy harmonic detection, reactive power compensation, voltage sag and swell have been simulated and the results are analysed.

V. Khadkikar, *et. al.* [26] presents a single-phase unified power quality conditioner (UPQC) so that power quality issues may be resolved in single-phase systems. It is found that the UPQC in single-phase system effectively compensates the most common power quality issues, such as the load reactive power, load current harmonics, voltage harmonics, voltage sag, voltage swell and voltage flicker. Under distorted source voltage having total harmonics distortion (THD) of 14.1% with a non-linear load producing a distorted current (THD of 30.98%), the UPQC simultaneously compensates these harmonics resulting sinusoidal source current (THD of 3.77%) and load voltage (THD of 2.54%).

V. Khadkikar, *et. al.* [27] focuses on the application of active power conditioners to tackle power quality problems has become a matured subject. The paper is based on a unified approach for load and source compensation using Unified Power Quality Conditioner (UPQC). Performance of this UPQC has been evaluated with a typical industrial load with realistic parameters supplied by a polluted distribution network. The system performance for current harmonics, voltage harmonics, voltage sag and voltage swell has been evaluated.

Metin Kesler *et. al.* [28] suggested a new control method to compensate the power quality problems through a three-phase unified power quality conditioner (UPQC) under non-ideal mains voltage and unbalanced load conditions. The performance of proposed control system was analysed that it can improve the power quality at the point of common coupling (PCC) on power distribution system under non-ideal mains voltage and unbalanced load conditions.

A.Kazemi *et. al.* [29] gives a novel and easy to implement control strategy for unified power quality conditioner (UPQC). The control strategy of parallel active filter (PAF)

is based on fourier transform theory, while the control circuit of series active filter (SAF) is based on positive sequence detection theory. Operation of PAF using this proposed method compensates reactive power and current harmonics, while operation of SAF compensates imbalance, voltage harmonics and positive and zero sequence of supply voltages.

Luis F.C. Monteiro *et. al.*[30] presents a three-phase three-wire system in which unified power quality conditioner is used and for control purpose a dual control strategy is used for series active filter. The work presented a control strategy for shunt-active filter that guarantees sinusoidal, balanced and minimized source currents even under unbalanced and / or distorted system voltages. Then, this control strategy was extended to develop a dual control strategy for series-active filter. The paper develops the integration principles of shunt current compensation and series voltages compensation, both based on instantaneous active and non-active powers, directly calculated from a-b-c phase voltages and line currents.

Morris Brenna *et. al.* [31] presented the quality of supplied power is important to several customers. Power quality (PQ) is a service and many customers are ready to pay for it. A new device that can fulfil this role is the OPEN unified power quality conditioner (UPQC), composed of a power-electronic series main unit installed in the medium-voltage/low voltage (LV) substation, along with several power-electronic shunt units connected close to the end users. The series and parallel units do not have a common dc link, so their control strategies are independent of each other. This device can improvement in PQ, reducing the most common disturbances for all customers that are supplied by the mains (PQ) by using only the series unit. Therefore, this new simultaneously combine can improve the PQ and reduce the cost who needs high quality of power.

Sai Shankar *et. al.* [32] presented the unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to compensate both harmonics as well as reactive power. The UPQC has been modeled for both active and reactive power compensation using different control strategies. The behavior of UPQC has been analyzed with sudden switching of R-L loads, and R-C loads as well as occurrences of different shunt fault. The control scheme has been devised using PI controller in UPQC for real and reactive power control, and operation in case of switching and faults in transmission systems.

M. Vasudevan *et. al.* [33] presented a detailed comparison between adaptive intelligent torque control strategies of induction motor, emphasizing advantages and disadvantages. Induction motors are characterized by complex, highly non-linear, time varying dynamics and hence can be considered as a challenging engineering problem. The

advent of torque and flux control techniques have partially solved induction motor control problems, because they are sensitive to drive parameter variations and performance may deteriorate if conventional controllers are used. . In this the performance of the various sensor less intelligent Direct Torque Control (DTC) techniques of Induction motor such as neural network, fuzzy and genetic algorithm based torque controllers are evaluated. Adaptive intelligent techniques are used to achieve high performance decoupled flux and torque control.

Jiangyuan Le, et. al. [34] presents a nonlinear control strategy for unified power quality conditioner (UPQC) with better stability and dynamic performance in comparison with PI control and classical decoupled strategy. The analysis is based on the rotating reference frame(SRF), and the nonlinear property of UPQC mode is partially dealt through the exact linearization via feedback. The operation of control circuit has been explained using MATLAB software and simulation. The validity of control strategy is studied through simulation results.

RVD Ram Rao et. al. [35] proposed the quality of power is affected by many factors like harmonic contamination due to non-linear loads, such as large thyristor power converters, rectifiers, voltage and current flickering due to arc in arc furnaces, sag and swell due to the switching of the loads etc. One of the many solutions is the use of a combined system of shunt and active series filters like unified power quality conditioner (UPQC) This device is a combination of shunt active filter together with a series active filter in a back to-back configuration, to simultaneously compensate the supply voltage and the load current or to mitigate any type of voltage and current fluctuations and power factor correction in a power distribution network.

Naresh K. Kummari et. al.[36] presents number of control algorithms for load compensation using DSTATCOM. In this paper, nine control algorithms viz. instantaneous p-q theory, instantaneous modified p-q theory, synchronous reference frame theory, instantaneous p- q-r theory, average unity power factor (AUPF) theory, vectorial theory, instantaneous symmetrical components theory (ISCT), average global control theory (AGCT), and instantaneous global control theory (IGCT) are compared for different operating conditions of distribution system. The cases considered for system operation are nonlinear balanced load with balanced source, nonlinear unbalanced load with balanced source, nonlinear unbalanced load with unbalanced source, and nonlinear unbalanced load with non-sinusoidal balanced source. The performance of the system simulated on MATLAB

platform is evaluated considering source current total harmonic distortion (THD.), total distortion content (TDC), and neutral current magnitude. Result concluded that, ISCT, AGCT and IGCT, are able to meet the compensation requirement. Instantaneous p-q, modified p-q, instantaneous p-q-r, vectorial, and dq theories estimate the load side imaginary power, and then extract the compensator currents using the PCC voltages. Also, AUPF theories estimate the real power and source currents then extract the compensator currents derived from PCC voltages. Thus, they are unable to compensate the system when source is not ideal.

S. S. Wamane *et. al.* [37] presents two control strategies, IRP theory and SRF theory to extract reference current for UPQC, and to compare performance under distorted supply and non-linear load conditions. Simulink is used as a tool to prove the efficiency. The UPQC model proposed in this paper is to compensate the input voltage harmonics and current harmonics caused by nonlinear load.

A. Jeraldine Viji *et. al.* [38] presents a modified synchronous-reference frame (SRF)-based control method to Shunt active filter and instantaneous PQ (IPQ) theory based control technique for series active filter to compensate power-quality (PQ) problems through a three-phase four-wire unified PQ conditioner (UPQC) under unbalanced and distorted load conditions.

IEEE 519-1992 standard [39] guide applies to all types of static power converters used in industrial and commercial power systems. The problems involved in the harmonic control and reactive power compensation of such converters are addressed, and an application guide is provided. Limits of disturbances to the AC power distribution system that affect other equipment and communications are recommended.

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 power supply is of utmost importance for the utilities to achieve global benefits. Different types of custom power devices are proposed to improve the power quality and to maintain voltage and current profile. Utility is responsible for maintaining voltage profile supplied to the consumers, while consumers are responsible for maintaining current profile at the PCC. Industrial loads such as induction motor drive, and dynamic loads causes fluctuations and degrade the power quality. In order to improve the quality of power, custom power devices like DSTATCOM, DVR and OPEN-UPQC has been used. The results are obtained by using MATLAB/ SIMULINK. The effectiveness of

DSTATCOM, DVR and OPEN-UPQC can be established for distribution network with industrial drive and dynamic load and can be tested under various operating conditions.

1.4. OBJECTIVES AND CONTRIBUTIONS

The main objectives of the thesis are to develop model for DVR, DSTATCOM and OPEN-UPQC for the enhancement of power quality in high power distribution network consisting of industrial drive and Dynamic load.

The following objectives have been laid down for this work:

1. Development of DVR with SRF theory and PI Controller simulation model and DVR performance analysis through simulation.
2. Development of DSTATCOM with SRF theory and PI Controller simulation model and DSTATCOM performance analysis through simulation.
3. Development of OPEN-UPQC with SRF theory and PI Controller simulation model and UPQC performance analysis through simulation.

The effectiveness of the DVR, DSTATCOM and OPEN-UPQC, in solving the power quality problems has been proved through simulations, model development and analysis. Research has been carried out to achieve the above mentioned objectives of the thesis.

1.5. ORGANISATION OF THESIS

This thesis is compiled in five chapters as per the details given below:

Chapter 1 highlights the brief introduction, summary of work carried out by various researchers. The scope of the work is also identified and the outline of the thesis is also given in this chapter.

Chapter 2 explains the power quality and different kinds of power quality problems and the various solutions that can be implemented to improve the quality of power in distribution networks.

Chapter 3 describes how the concept of custom power was introduced to improve the power quality and the brief introduction of different kinds of custom power devices.

Chapter 4 presents the results for various cases of compensation and the comparison of results obtained for various compensators.

Chapter 5 Conclusions and the scope of further work are presented.

2.1. DEFINATION OF POWER QUALITY

Power quality has different meanings to different people. The definition of power quality given in the IEEE dictionary originates in IEEE Std. 1100: *“Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment.”*

However, as is stated by Heydt (1998) and Bollen (1999), there is no single definition of the term “power quality”. For example, Heydt (1998) gives the following description: *“Power quality is the provision of voltages and system design so that the user of electric power can utilise electric energy from the distribution system successfully, without interference or interruption.”* The next explanation is provided by Bollen (1999): *“Power quality is the combination of voltage quality and current quality. Thus power quality is concerned with deviations of voltage and/or current from the ideal.”* On the other hand, power quality problems are described by Morán et. al. (1999) in the following way: *“A power quality problem exists if any voltage, current or frequency deviation results in a failure or in bad operation of the customer’s equipment. The quality of the power supply consists basically of two elements, the supply reliability and the voltage quality.”* Based on the previous descriptions it can be concluded that the concept “power quality” involves two parties: the supplier of the electricity and the user. The “power quality” can then be regarded as a measure of purity of the energy which is transferred from the supplier to the user.

Current quality is concerned with deviations of the current from the ideal. The ideal current is a single-frequency sine wave of constant frequency and magnitude. An additional requirement is that this sine wave is in phase with the supply voltage. Thus where voltage quality has to do with what the utility delivers to the consumer, current quality is concerned with what the consumer takes from the utility. Voltage and current are strongly related and if either voltage or current deviates from the ideal it is hard for the other to be ideal. Voltage quality is concerned with deviations of the voltage from the ideal. The ideal voltage is a single-frequency sine wave of constant frequency and constant magnitude. The term voltage quality can be interpreted as the quality of the product delivered by the utility to the customers. Power quality problem is defined as any power problem manifested in voltage,

current or frequency deviations that result in failure or mis-operation of customer equipment. The power supply system can only control the quality of the voltage, it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits. Any significant deviation in the waveform magnitude, frequency or purity is a potential power quality problem. Of course, there is always a close relationship between voltage and current in any practical power system. Although the generators may provide a near-perfect sine-wave voltage, the current passing through the impedance of the system can cause a variety of disturbances to the voltage (Dugan et al., 2003). Power quality is often considered as a combination of voltage and current quality. In most of the cases, it is considered that the network operator is responsible for voltage quality at the point of connection while the customer's load often influences the current quality at the point of connection (Bhattacharyya et al., 2007), (Meral, 2009).

2.2. SOURCES OF POOR POWER QUALITY

Sources of poor Power Quality are listed as follows [3]:

- Adjustable –speed drives
- Switching Power supplies
- Arc furnaces
- Electronic Fluorescent lamp ballasts
- Lightning Strike
- L-G fault
- Non- linear load
- Starting of large motors
- Power electronic devices

2.3. NEED OF POWER QUALITY

There is an increased concern of power quality due to the following reasons [2] :

1. New-generation loads that uses microprocessor and microcontroller based controls and power electronic devices, are more sensitive to power quality variations than that equipments used in the past.

2. The demand for increased overall power system efficiency resulted in continued growth of devices such as high-efficiency adjustable-speed motor drives and shunt capacitors for power factor correction to reduce losses. This is resulting in increasing harmonic level on power systems and has many people concerned about the future impact on system capabilities.
3. End users have an increased awareness of power quality issues. Utility customers are becoming better informed about such issues as interruptions, sags, and switching transients and are challenging the utilities to improve the quality of power delivered.
4. Most of the networks are interconnected these days. Integrated processes mean that the failure of any component has much more important consequences.

2.4. CLASSIFICATION OF POWER QUALITY PROBLEMS AND THEIR IMPACTS

The power quality is badly disturbed due to the extensively use of nonlinear and dynamic loads and various faults in power system. Moreover, the controlling equipment and electronic devices based on computer technology demand higher levels of power quality. This type of devices are sensitive to small changes of power quality, a short time change on PQ can cause great economical losses. Because of the two reasons mentioned above, no matter for the power business, equipment manufacturers or for electric power customers, power quality problems had become an issue of increasing interest. Under the situation of the deregulation of power industry and competitive market, as the main character of goods, power quality will affect the price of power directly in near future.

This thesis takes into account the most common power quality problems such as voltage sags/swells and current harmonics as shown in Figure-2.1. Together they account for high percentage of the power quality disturbances affecting most commercial and industrial customers.

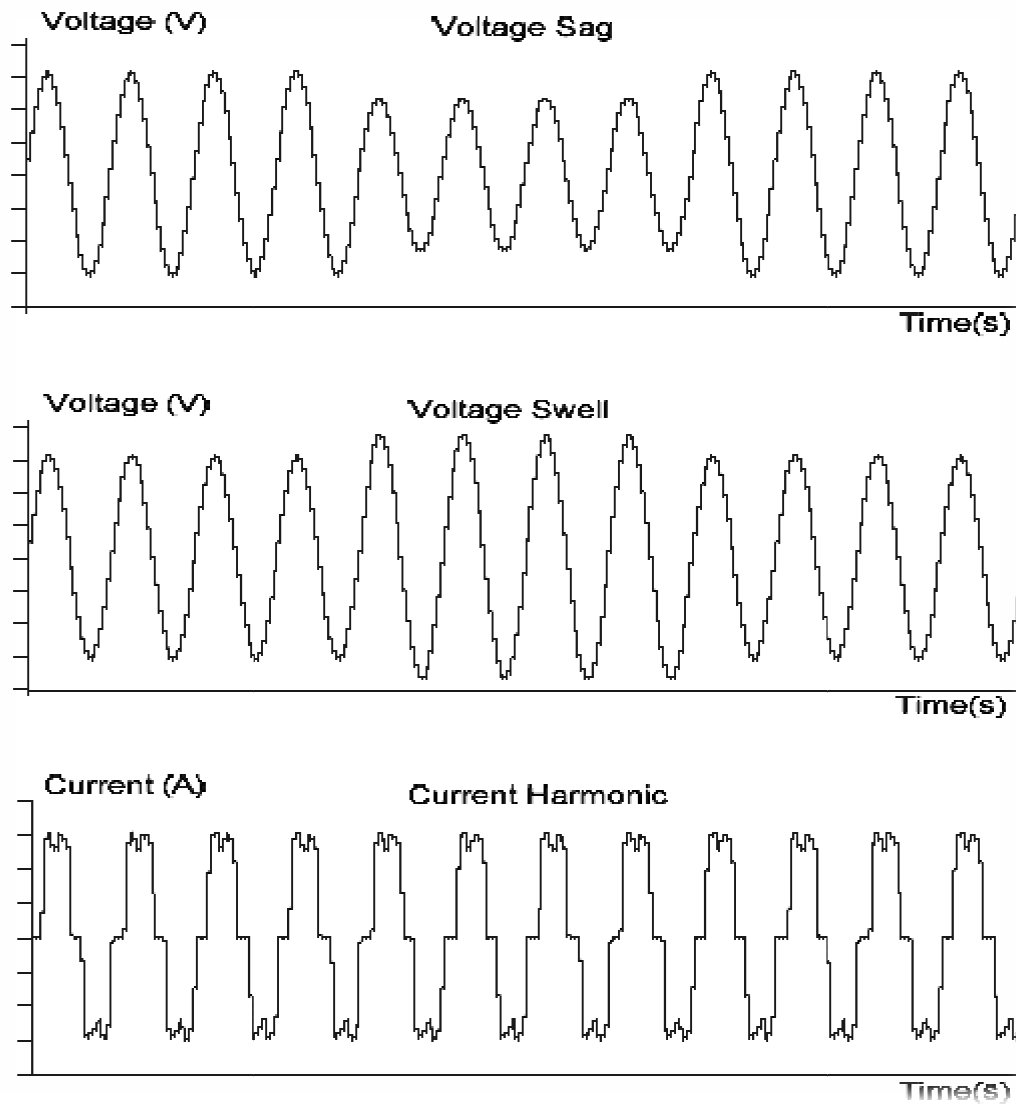


Figure-2.1: Most Common Types of Power Quality Problems

2.4.1. Voltage Sag

Voltage sag is defined as a decrease to between 0.1 and 0.9 per unit (pu) in rms voltage at the power frequency for durations from 0.5 cycle to 1 min. Voltage sags are generally related with system faults but can also be caused by energization of heavy loads or starting of large motors and overloaded wiring. The term sag describes a short-duration voltage decrease. Voltage sag problems in industrial equipment include (Eberhard et al., 2007) relays opening due to the dip affecting the relay's coil voltage, undervoltage sensors on the AC mains operating unnecessarily, incorrect reports from sensors, such as air flow sensors or water pressure sensors, circuit breakers or fuses operating, either due to the increase in current on non-dipped phases or (more often) due to a large increase in current

immediately after the dip or a small section of highly-sensitive electronics that responds incorrectly to the sag.

A study of voltage sag effect has been done analytically in the time domain, by using dynamic load models mainly designed for stability analysis. The proposed system is analysed to compensate for voltage sag of 0.2 sec. occurred due to three phase fault at consumer end.

2.4.2. Voltage Swells

A voltage swell can be defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min. The voltage swells are usually associated with system fault conditions, but they are not as common as voltage sags. One way that a swell can occur is from the temporary voltage rise on the unfaulted phases during a single line to ground fault (Dugan et al., 2003). Swells can also be caused by switching off a large load or energizing a large capacitor bank, insulation breakdown, sudden load reduction and open neutral connection. Voltage swells can negatively affect the performance of sensitive electronic equipment, cause data errors, produce equipment shutdowns, may cause equipment damage and reduce equipment life. It causes nuisance tripping and degradation of electrical contacts.

2.4.3. Current Harmonic Distortion

The harmonic voltage and current distortion are strongly linked with each other because harmonic voltage distortion is mainly due to non-sinusoidal load currents. Current harmonic distortion requires over-rating of series components like transformers and cables. As the series resistance increases with frequency, a distorted current will cause more losses than a sinusoidal current of the same rms value (Bollen, 2001). Types of equipment that generate current harmonics are single-phase loads, switched mode power supplies, electronic fluorescent lighting ballasts, small Uninterruptible Power Supply (UPS) units and variable speed drives (Meral, 2009). The problems caused by current harmonics (Chapman, 2001a) are overloading of neutrals, overheating of transformers, nuisance tripping of circuit breakers, over-stressing of power factor correction capacitors and skin effect. Harmonic distortion levels can be described by the 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 the sum of the squares of each individual harmonic [22]. Voltage THD is

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

where V_1 is the rms magnitude of the fundamental component, and V_n is the rms magnitude of component n where $n = 2, 3, \dots, \infty$

Table 2.1: IEEE-519 current harmonic distortion limits [39]

Maximum current harmonic distortion in percent of I_{LH}						
Individual harmonic order (Odd harmonics)						
I_{SC}/I_{LH}	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<100	12.0	5.5	5.0	2.0	1.0	15.0
0>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above

Current distortions that results in a DC offset, e.g., half-wave converters, are not allowed

* All power generation equipment is limited to these values of current distortions, regardless of actual I_{SC}/I_{LH} .

These limits are proportional to the short circuit current ratio and each consumer must limit the current that they draw accordingly as shown in Table 2.1. The aim of the standard is to ensure that voltage harmonic distortion is kept low by limiting the current harmonics drawn by end users.

2.4.4. Voltage Fluctuations/Flickers

Voltage fluctuations are relatively small (less than 5 percent) variations in the rms line voltage. Cycloconverters, arc furnaces, and other systems that draw current not in synchronization with the line frequency are the main contributors of these variations. Most common effect of voltage flicker is an unwanted pulsating torque due to the fluctuation of the speed in electric drives.

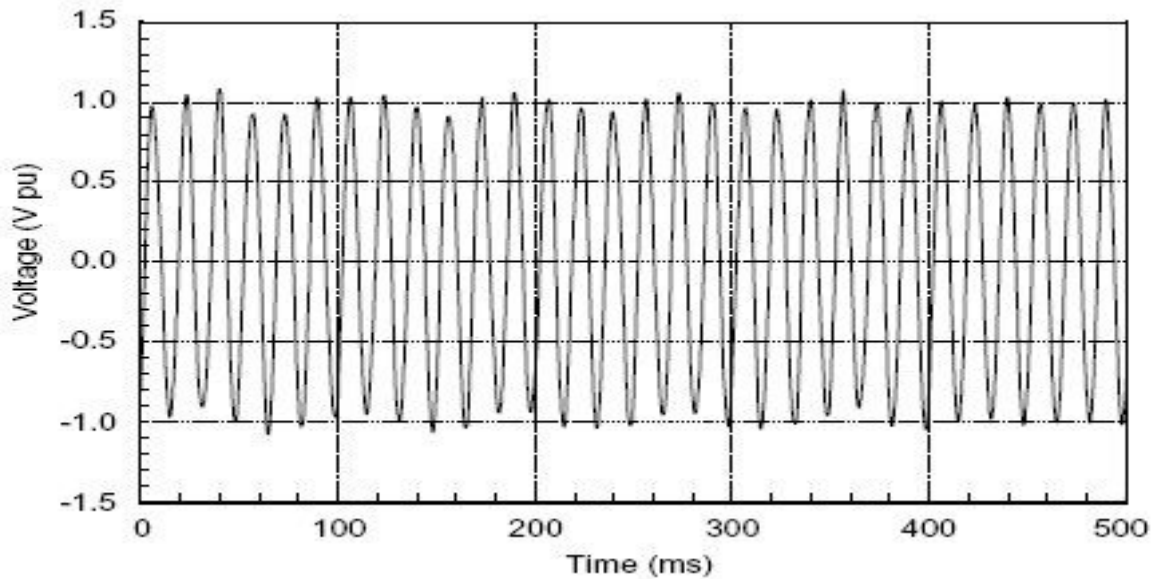


Figure-2.2.: Voltage Fluctuations or Flicker

2.5. SOLUTIONS TO POWER QUALITY PROBLEMS

The mitigation of power quality problems can be achieved in two ways. The solution to the power quality can be done from customer side or from utility side. First method is called load conditioning and the other method is line conditioning. Load conditioning ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion while the instalment of line conditioning systems suppresses or counteracts the power system disturbances. They are depend on PWM converters and connected in shunt or in series to low and medium voltage distribution system. Series active power filters must operate in conjunction with shunt passive filters in order to compensate the load current harmonics. Series active power filters operates as a controllable voltage source whereas shunt active power filters operate as a controllable current source.

(i) Lightning and Surge Arresters: Arresters are designed for lightening the protection of transformers, but these are not sufficient for limiting voltage to protect sensitive electronic control circuits from voltage surges.

(ii) Thyristor Based Static Switches: The static switch is a device for switching a new element into the circuit when the voltage support is needed. It has dynamic response time of about one cycle. It may be used in the alternate power line applications. To correct quickly for voltage spikes, sags or interruptions, the static switch may used to switch one or more of devices such as filter, capacitor, alternate power line, energy storage systems etc.

(iii) Energy Storage Systems: Storage systems may be used to protect sensitive production equipments from shutdowns due to voltage sags or momentary interruptions. The energy is fed to system for compensate for the energy that will lost by the voltage sag or interruption. These are usually DC storage systems such as batteries, UPS, superconducting magnet energy storage (SMES), storage capacitors or even fly wheels driving DC generators. The output of these devices can be supplied to the system through an inverter on a momentary basis.

(iv) Electronic Tap Changing Transformer: A voltage-regulating transformer with an electronic load tap changer may be used with a single line from the utility. It may regulate the voltage drops up to 50% and requires a stiff system (short circuit power to load ratio of 10:1 or better).

(v) Harmonic Filters: Filters are used to reduce or eliminate harmonics. It is always advantage able to use a 12-pluse or higher transformer connection, rather than a filter. Usually, multiple filters are needed, each tuned to a separate harmonic. Each filter causes a parallel resonance as well as a series resonance, and each filter slightly changes the resonances of other filters.

3.1. INTRODUCTION TO CUSTOM POWER DEVICES

The concept of custom power was introduced by N.G.Hingorani [6]. The term custom power means the use of power electronics controllers for distribution systems. The custom power increase the quality and reliability of the power that is delivered to the customers. Customers are increasingly demanding quality in the power supplied by the electric company. Custom power is a strategy, which is designed primarily to meet the requirements of industrial and commercial customer. The concept of custom power is to use of power electronic or static controllers in the medium voltage distribution system aiming to supply reliable and high quality power to sensitive users. Power electronic valves are the basis of those custom power devices such as the static transfer switch, active filters and converter-based devices.

In a Custom Power system customer receives specified power quality from a utility or a service provider or at-the-fence equipment installed by the customer in coordination with the utility, which includes an acceptable combination of the following features:

- No (or rare) power interruptions
- Magnitude and duration of voltage reductions within specified limits.
- Magnitude and duration of over voltages within specified limits.
- Low harmonic voltage.
- Low phase unbalance.

3.2. Need of Custom Power

The increased use of automated equipment like adjustable speed drives, programmable logic controllers, switching power supplies, arc furnaces , automated production lines are far more vulnerable to disturbances than were the previous generation equipment and less automated production and information systems. Even though the power generation in most advanced country is fairly reliable, the distribution is not always so. Although not only reliability that the consumers want these days, the quality of power is too important for them. With the deregulation of the electric power energy market, the awareness regarding the quality of power has been increasing day by day among different categories of

customers. Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage.

3.3. Types of Custom Power Devices

There are many types of Custom Power devices. Some of these devices are Active Power Filters (APF), Surge Arresters (SA), Battery Energy Storage Systems (BESS), Solid State Fault Current Limiter (SSFCL), Solid-State Transfer Switches (SSTS), Static VAR Compensator (SVC), Dynamic Voltage Restorer (DVR), Distribution Static synchronous Compensators (DSTATCOM) and Uninterruptible Power Supplies (UPS), Unified power quality conditioner (UPQC). Custom power devices can be classified into two major categories[12]. One is network configuring type and the other is compensating type. The network reconfiguration devices are used for current limiting, current breaking and current transferring devices. There are mainly two devices are used for network reconfiguration:

- (a) SSCL (Solid State Current Limiter)
- (b) SSCB (Solid State Circuit Breaker)
- (c) SSTS (Solid State Transfer Switch)

Devices used for compensation are:

- (a) Active Power Filters (APF)
- (b) Distribution Static Compensator (DSTATCOM)
- (c) Dynamic Voltage Restorer (DVR)
- (d) Unified Power Quality Conditioner (UPQC)

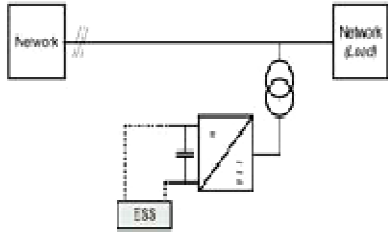
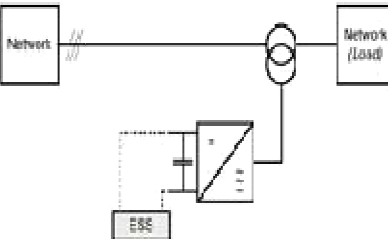
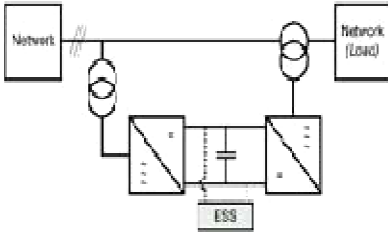
SSCL, SSCB, and SSTS are the most representative in this category. SSCL is a GTO based device that inserts an inductor in series with the power system and limits the fault current and once the fault is cleared the inductor is removed from the circuit. SSCB acts as a protection device. It isolates the faulty circuit from the power system. SSTS transfers rapidly the load from the faulted line to an alternative line to protect a sensitive load. Due to the use of GTO or thyristors in these devices, they are therefore called “solid state” devices.

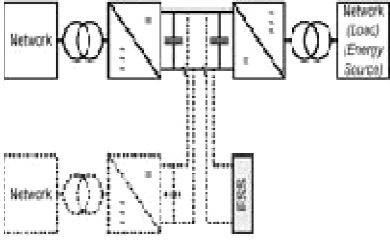
The compensating type devices are used for active filtering; load balancing, power factor correction and voltage regulation. The family of compensating devices include DSTATCOM (Distribution Static compensator), DVR (Dynamic voltage restorer) and Unified power quality conditioner (UPQC). DSTATCOM is connected in shunt with the power system while DVR is a series connected device that injects a rapid series voltage to

compensate the supply voltage. UPQC is the combination of DSTATCOM and DVR. It injects series voltage and shunt currents to the system[22].

Table-3.1. shows the circuit topology and tasks performed by the FACTS equipments in distribution system. Though there are many different methods to mitigate voltage sags and swells, but the use of a custom power device is considered to be the most efficient method to serve for different purposes and to provide with different economical justifications. The term Custom Power pertains to the use of power electronics controllers in a distribution system to deal with various power quality problems. It makes sure that customers get pre-specified quality and reliability of power supply [8]. This pre-specified quality of power may includes a single or the combination of the specifications like no power interruptions, low phase unbalance, low harmonic distortion in load voltage, low flicker at the load voltage, acceptance of fluctuations, magnitude and duration of overvoltage and under voltages within specified limits and poor factor loads without significant effect on the terminal voltage.

Table-3.1.: FACTS Equipments in Distribution System

Name	Topology	Preferred Tasks
<p>DSTATCOM (Distribution STATCOM)</p>		<ul style="list-style-type: none"> ✓ Flicker compensation ✓ Reactive power compensation ✓ Harmonic filter
<p>DVR (dynamic voltage restorer)</p>		<ul style="list-style-type: none"> ✓ Sag/swell compensation
<p>UPQC (unified power quality conditioner)</p>		<ul style="list-style-type: none"> ✓ Undervoltage/overvoltage compensation ✓ DSTATCOM and DVR advantages

<p>Direct current transmission & HVDC Light system</p>		<ul style="list-style-type: none"> ✓ Coupling of remote loads or remote energy sources ✓ Optimization of energy cost through coupling of bus bars or system parts
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3.3.1. Distribution Statcom (DSTATCOM)

The purpose of the DSTATCOM is to cancel load harmonics fed to the supply. The coupling of DSTATCOM is three phase, in parallel to network and load as shown in figure-3.1. It work as current sources, connected in parallel with the nonlinear load, generating the harmonic currents the load requires also balance them in addition to providing reactive power[6]. In order to compensate undesirable components of the load current the DSTATCOM injects currents into the point of common coupling. With an appropriated control strategy, it is also possible to correct power factor and unbalanced loads. This principle is applicable to any type of load considered a harmonic source.

Its advantage is that it of carries only the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. Shunt Active Power Filter in current control mode is also called as DSTATCOM.

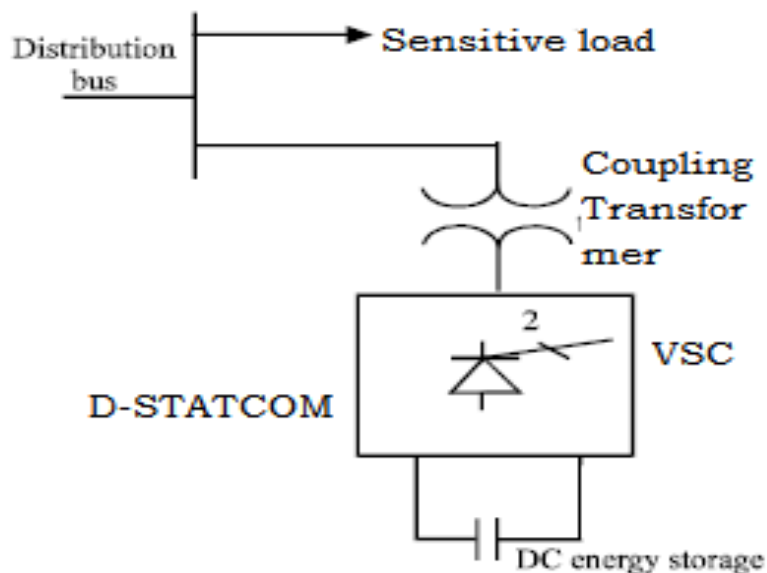


Figure-3.1: Distribution-STATCOM

3.3.2. Dynamic Voltage Restorer (DVR)

DVR injects a voltage component in series with the supply voltage as shown in figure-3.2, thus compensating voltage sags and swells on the load side. Control response is on the order of 3msec, ensuring a secure voltage supply under transient network conditions. Voltage injection of arbitrary phase with respect to the load current implies active power transfer capability. This active power is transferred via the dc link, and is supplied either by a diode bridge connected to the ac network, a shunt connected PWM converter or by an energy storage device. It works as a harmonic isolator to prevent the harmonics in the source voltage reaching the load in addition to balancing the voltages and providing voltage regulation.

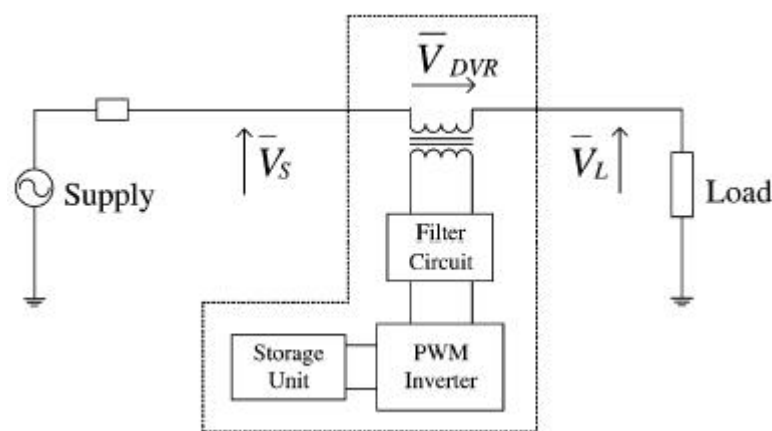


Figure-3.2: Dynamic Voltage Restorer

3.3.3. Unified Power Quality Controller (UPQC)

The best protection for sensitive loads from sources with inadequate quality, is shunt-series connection i.e. unified power quality conditioner (UPQC). Recent research efforts have been made towards utilizing unified power quality conditioner (UPQC) to solve almost all power quality problems for example voltage sag, voltage swell, voltage outage and over correction of power factor and unacceptable levels of harmonics in the current and voltage. The basic configuration of UPQC is shown in Figure-3.3

The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics [21]. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity sensitive loads to voltage flicker/imbalance.

Unified Power Quality Conditioner (UPQC) for non-linear and a voltage sensitive load has following facilities:

- ✓ It eliminates the harmonics in the supply current, thus improves utility current quality for nonlinear loads.
- ✓ UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase, therefore, no additional power factor correction equipment is necessary.
- ✓ UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag.
- ✓ The voltage injected by UPQC to maintain the load end voltage at the desired value is taken from the same dc link, thus no additional dc link voltage support is required for the series compensator.

The UPQC consists of two three phase inverters connected in cascade in such a manner that Inverter I is connected in series with the supply voltage through a transformer inverter II is connected in parallel with the load. The main purpose of the shunt compensator is to compensate for the reactive power demanded by the load, to eliminate the harmonics and to regulate the common dc link voltage. The series compensator is operated in PWM voltage controlled mode. It injects voltage in quadrature advance to the supply voltage (current) such that the load end voltage is always maintained at the desired value. The two inverters operate in a coordinated manner.

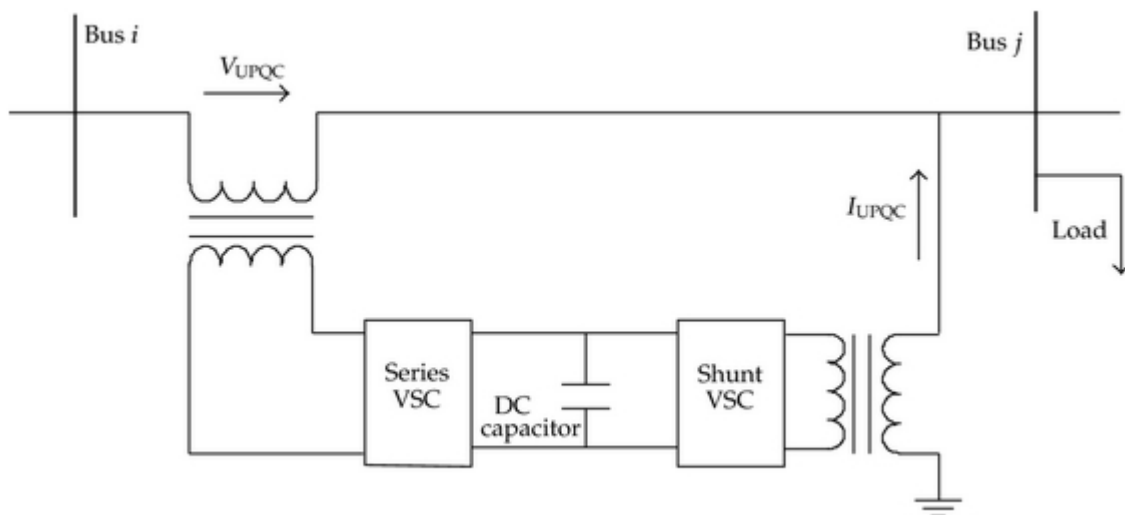


Figure-3.3: Unified Power Quality Controller

There are three principle elements to the custom power concept; these are:

- ✓ The Dynamic Voltage Restorer (DVR), it provides series compensation by voltage injection for power system sag and swell.
- ✓ The Distribution Static Compensator (D-STATCOM), it provides continuously variable shunt compensation by current injection for eliminating voltage fluctuations and obtaining correct power factor in three-phase systems. An ideal application of it is to prevent disturbing loads from polluting the rest of the distribution system.
- ✓ Unified Power Quality Conditioner (UPQC), it provide series and shunt compensation i.e. inject voltage in sag and swell condition and inject current for elimination of voltage fluctuations ,correct power factor, avoid pollution to rest of the distribution system.

The proper selection of necessary custom power strategies in addition to accurate system modelling and appropriate protection devices will increase the power quality.

3.4. Superiority of UPQC over Other Devices

Each of Custom Power devices has its own benefits and limitations. The UPQC is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage and load current disturbances /imbalance. The most effective type of these devices is considered to be the Unified Power Quality Conditioner (UPQC). There are numerous reasons why the UPQC is preferred over the others. UPQC is much flexible than any single inverter based device. It can simultaneously correct for the unbalance and distortion in the source voltage and load current where as all other devices either correct current or voltage distortion. Therefore the purpose of two devices is served by UPQC only.

4.1. OBJECTIVES OF WORK

In this work, the role of various custom power devices i.e. DSTATCOM, DVR, and UPQC are analyzed:

- Distribution network having DTC motor as non-linear load
- Dynamic load is also placed with DTC motor load
- Compensation is analyzed over 3-phase ground fault
- Synchronous Reference Frame(SRF) theory has been implemented in both series and shunt compensator
- Controlling is done through PI controller

4.2. INDUSTRIAL DRIVE

DTC induction motor is a most common industrial drive. It acts as a non-linear load. A load is considered to be non-linear if its impedance changes with the applied voltage. The changing impedance means that the current drawn by the non-linear load will not be sinusoidal even when it is connected to a sinusoidal voltage. These non-sinusoidal currents contain harmonic currents that interact with the impedance of the power distribution system to create voltage distortion that can affect both the distribution system equipment and the loads connected to it.

DTC Induction motors have been widely used in the industry comparing to other rotating machinery, because of the existence of the large inductances in the induction motors which could weaken their ride-through capability, they are thought to be particularly vulnerable to voltage dips. The transient of the induction motors consists of electromagnetic transients and electromechanical transients. Voltage sag phenomenon is usually associated with fault and its subsequent clearance for a few cycles of the mains frequency.

4.3. DYNAMIC LOAD

The Dynamic Load block implements a three-phase, three-wire dynamic load whose active power P and reactive power Q vary as function of positive-sequence voltage. Negative-

and zero-sequence currents are not simulated. The three load currents are therefore balanced, even under unbalanced load voltage conditions.

The load impedance is kept constant if the terminal voltage V of the load is lower than a specified value V_{min} . When the terminal voltage is greater than the V_{min} value, the active power P and reactive power Q of the load vary as follows:

$$P(s) = P_0 \left(\frac{V}{V_0} \right)^{n_p} \frac{1 + T_{p1}s}{1 + T_{p2}s}$$

$$Q(s) = Q_0 \left(\frac{V}{V_0} \right)^{n_q} \frac{1 + T_{q1}s}{1 + T_{q2}s},$$

where

- V_0 is the initial positive sequence voltage.
- P_0 and Q_0 are the initial active and reactive powers at the initial voltage V_0 .
- V is the positive-sequence voltage.
- n_p and n_q are exponents (usually between 1 and 3) controlling the nature of the load.
- T_{p1} and T_{p2} are time constants controlling the dynamics of the active power P .
- T_{q1} and T_{q2} are time constants controlling the dynamics of the reactive power Q .

4.4. MODEL PARAMETERS

Table 4.1. Simulink model parameters

S.No.	SYSTEM ELEMENTS	PARAMETERS
1	SOURCE	3-Phase, 440V, 50Hz
2	Inverter Parameter	IGBT based, 3- arm, 6-Pulse, Carrier Frequency=1080 Hz , Sample Time= 5 μ s
3	PI Controller	$K_p= 0.5, K_i =100$
4	Transformer1	440/440V Y/Y
5	Injection Transformer	440/440-440 V Y/Y
6	DTC motor load	225MVA
7	Dynamic load	$P_0=50e3W, Q_0=25e3Var$

4.5. SIMULINK MODELS

1. DSTATCOM

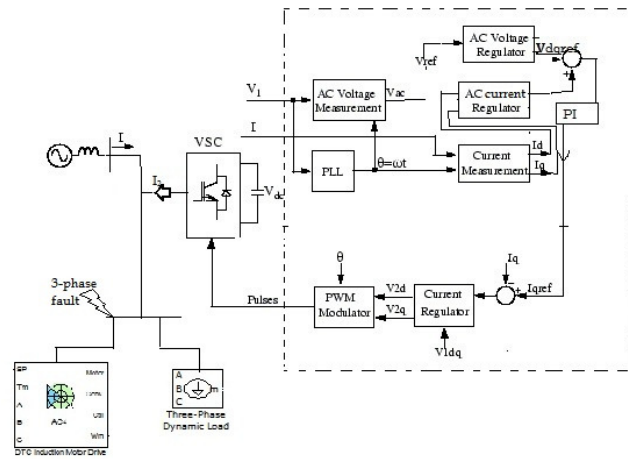


Figure-4.1: Simulink Model Of DSTATCOM

2. DVR

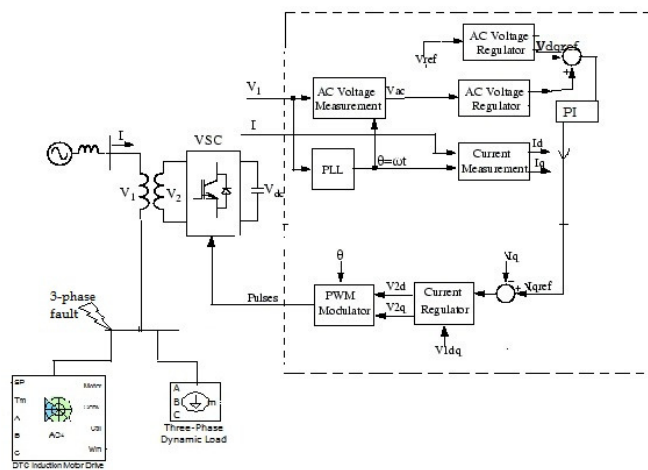


Figure-4.2: Simulink Model Of DVR

3. OPEN UPQC

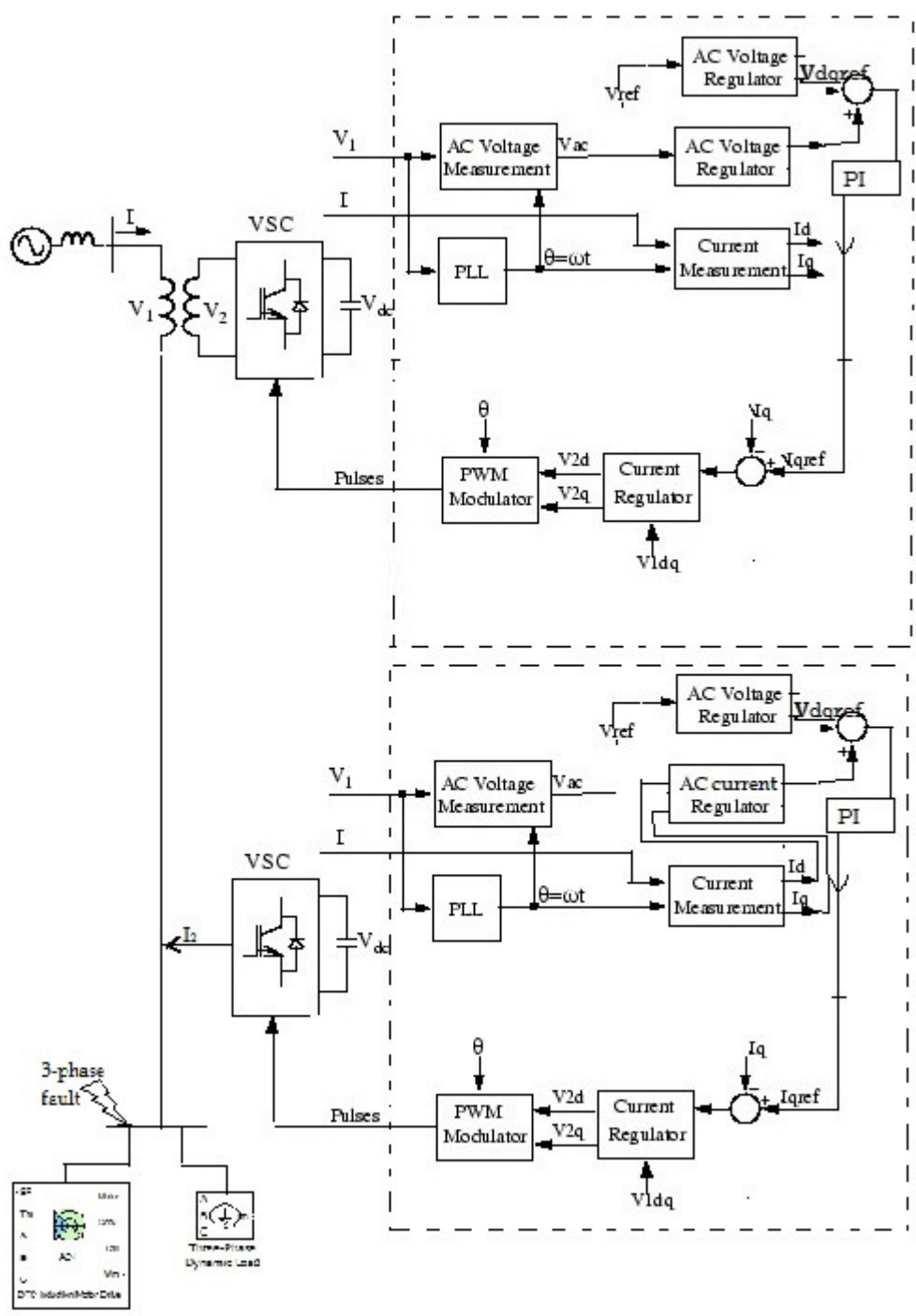


Figure-4.3: Simulink Model Of UPQC

4.6. WAVEFORM ANALYSIS

1. DSTATCOM

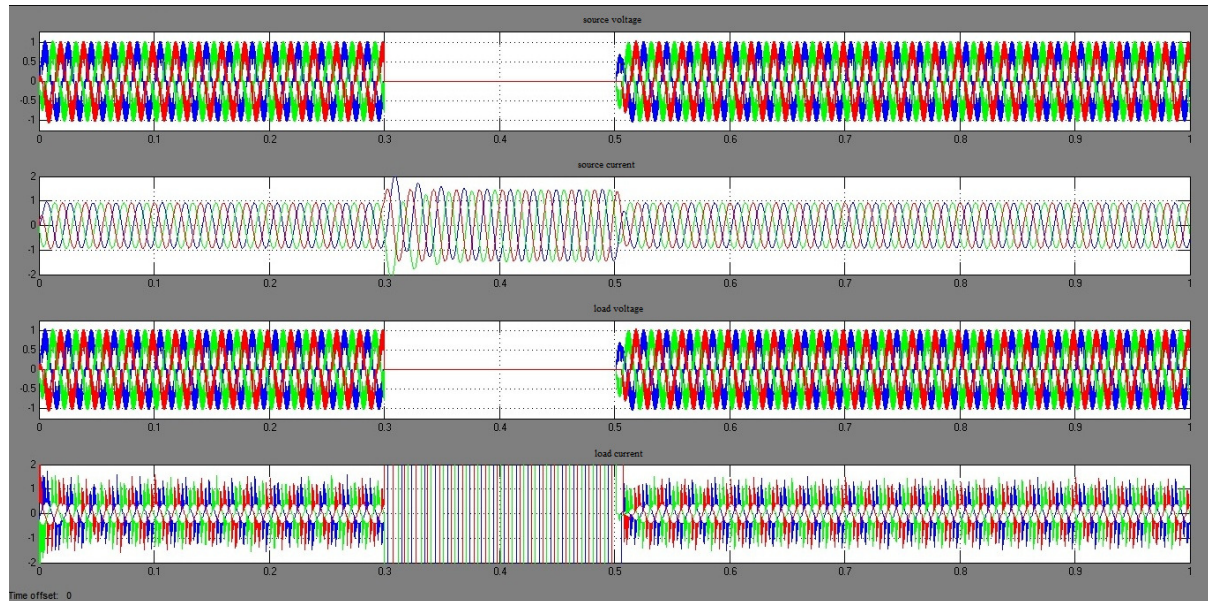


Figure-4.4: Source Voltage/Current, Load Voltage/Current Waveform of DSTATCOM

2. DVR

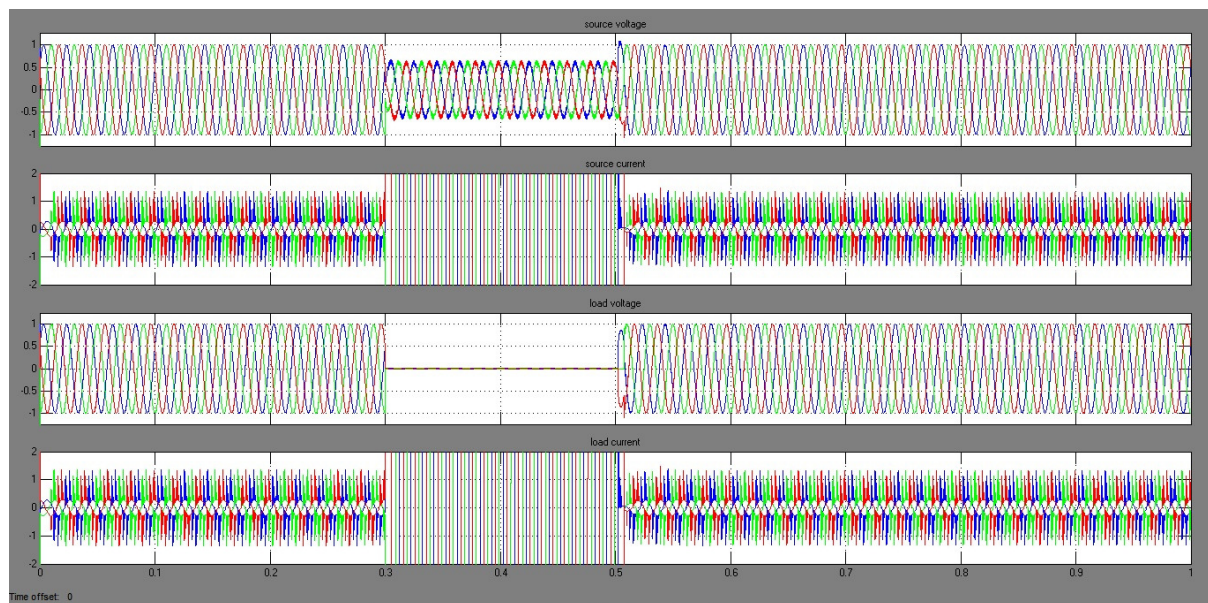


Figure-4.5: Source Voltage/Current, Load Voltage/Current Waveform of DVR

3. OPEN UPQC

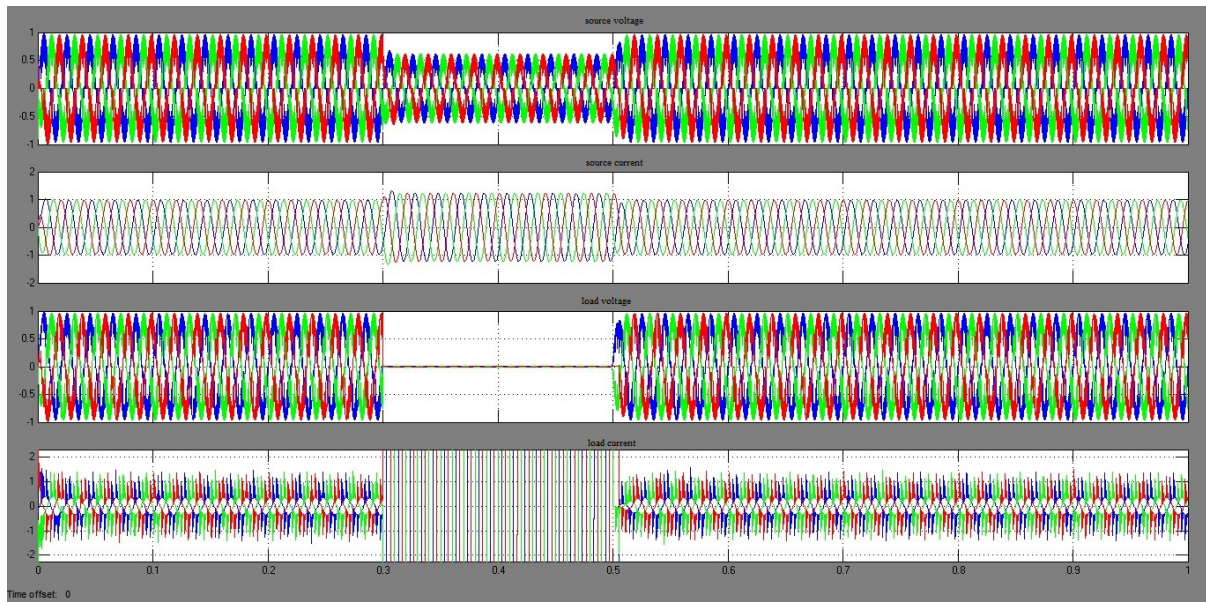


Figure-4.6: Source Voltage/Current, Load Voltage/Current Waveform of UPQC

4.7. SPECTRUM ANALYSIS

1. DSTATCOM

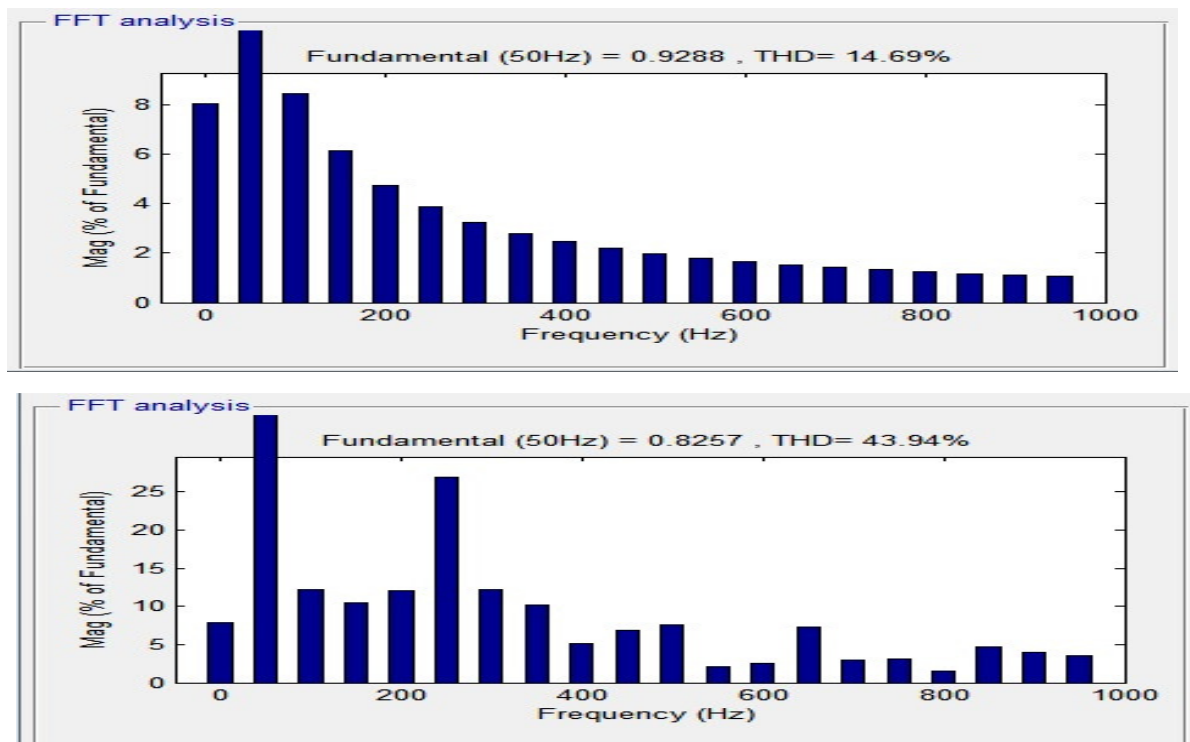


Figure-4.7: Spectrum Analysis of Source Current, Load Current of DSTATCOM

2. DVR

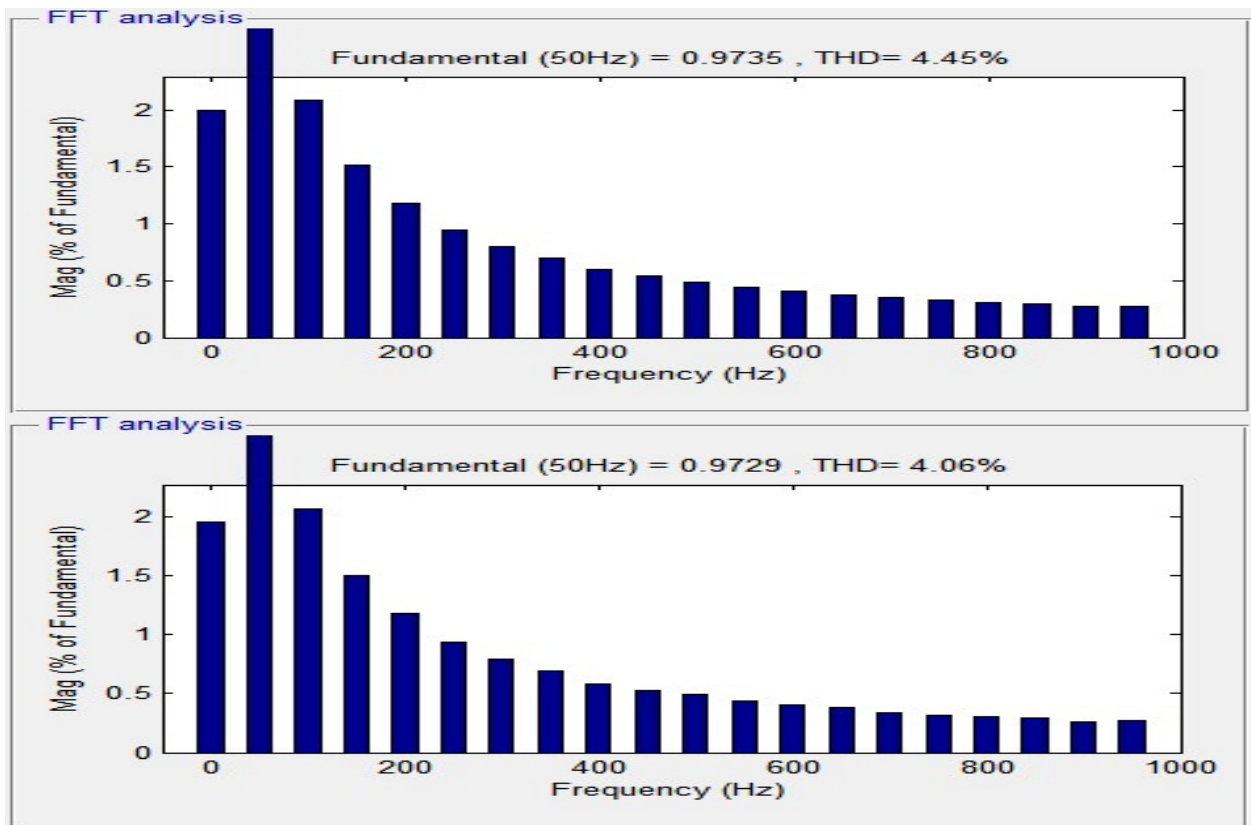


Figure-4.8: Spectrum Analysis of Source Voltage, Load Voltage of DVR

3. OPEN UPQC

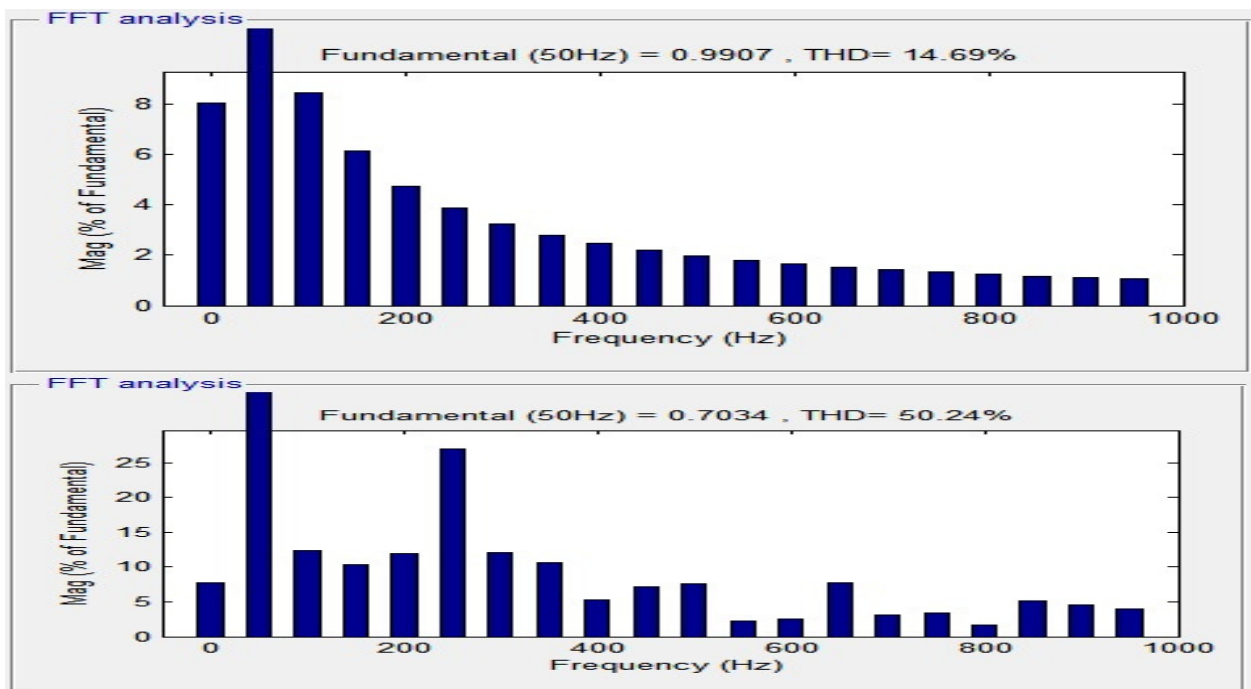


Figure-4.9: Spectrum Analysis of Source Current, Load Current of UPQC

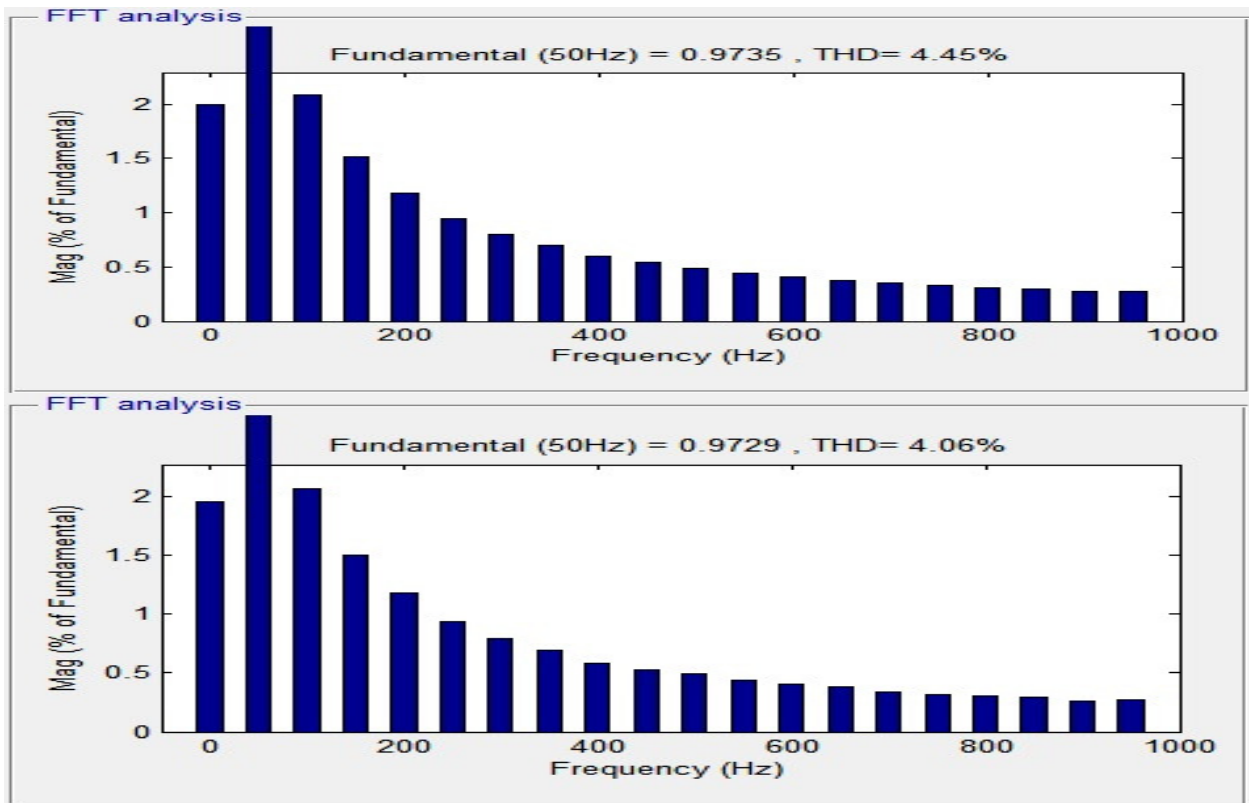


Figure-4.10: Spectrum Analysis of Source Voltage, Load Voltage of UPQC

5.1. CONCLUSIONS

In this thesis, work has been done to compare series, shunt, and series-shunt compensators. Performance analysis has been done by comparing the power quality of each compensator.

DSTATCOM is proved to compensate current levels under faulty conditions. Current harmonics has been reduced considerably. Harmonics generated at load side has THD of 43.94% which has been compensated to 14.69% at PCC. Even the current level increased during fault duration has also been compensated to a desired level.

DVR is proved to compensate voltage levels under faulty conditions. Voltage harmonics has been reduced considerably. Harmonics generated at source side has THD of 4.45% which has been compensated to 4.06% at load end. Even the voltage sag during fault duration has also been compensated to a desired level.

UPQC is proved to compensate current and voltage levels under faulty conditions. Voltage and current harmonics has been reduced considerably. Current harmonics generated at load side has THD of 50.24% which has been compensated to 14.69% at PCC. Voltage Harmonics generated at source side has THD of 4.45% which has been compensated to 4.06% at load end. Even the current and voltage level during fault duration has also been compensated to a desired level.

5.2. FUTURE SCOPE OF WORK

The presented work can be extended in other following related areas:

- Custom power devices can be tested against various loads.
- The more advanced controllers such as fuzzy controller, artificial neural network, AUPF, ISCT, AGCT, IGCT theories can also be used with UPQC to make the system more effective.
- Effectiveness UPQC can be investigated by multi-level converters.
- Effect of Z-source inverters can be investigated for various CP devices

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