UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

POWER SUPPLY QUALITY IMPROVEMENT USING DYNAMIC VOLTAGE RESTORER (DVR) IN IRAQI NETWORK

MASTER THESIS

Amir Hameed ABED

INSTITUTE OF SCIENCE AND TECHNOLOGY

ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT

OCTOBER 2017

UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

POWER SUPPLY QUALITY IMPROVEMENT USING DYNAMIC VOLTAGE RESTORER (DVR) IN IRAQI NETWORK

MASTER THESIS

Amir Hameed ABED

1406030010

INSTITUTE OF SCIENCE AND TECHNOLOGY

ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT

Supervisor: Assist. Prof. Dr. JAVAD RAHEBI

AMIR HAMEED ABED, having student number 1406030010 and enrolled in the Master Program at the Institute of Science and Technology at the University of Turkish Aeronautical Association, after meeting all of the required conditions contained in the related regulations, has successfully accomplished, in front of the jury, the presentation of the thesis prepared with the title of: "POWER SUPPLY QUALITY IMPROVEMENT USING DYNAMIC VOLTAGE RESTORER (DVR) IN IRAQI NETWORK".

Supervisor : **Assist. Prof. Dr. Javad Rahebi**
University of Turkish Aeronautical Association

Jury Members : **Assist. Prof. Dr. Hüseyin POLAT**
Gazi University

Assist. Prof. Dr. Özgür KELEKÇİ
University of Turkish Aeronautical Association

Assist. Prof. Dr. Javad Rahebi
University of Turkish Aeronautical Association

Thesis Defense Date: 25.10.2017

UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

I hereby declare that all the information in this study I presented as my Master's Thesis, called "Power Supply Quality Improvement Using Dynamic Voltage Restorer (DVR) In Iraqi Network" has been presented in accordance with the academic rules and ethical conduct. I also declare and certify on my honor that I have fully cited and referenced all the sources I made use of in this present study.

25/10/2017
Amir Hameed ABED

ACKNOWLEDGEMENTS

I am grateful to The Almighty GOD for helping me to complete this thesis. My Lord mercy and peace be upon our leader Mohammed peace be upon on him, who invites us to science and wisdom, and members of his family and his followers.

I would like to express gratitude to my supervisor, Assist. Prof. Dr. Javad Rahebi for their patience, encouragement, useful advice, discussion, comments and understanding my situation. He gave me opportunities to present my work in front of experts in the field.

I would like to thank my parents supporting me throughout my academic career. Without their moral support, interest, and encouragement for my academic work, the completion of this effort would not have been possible. Thanks to my brothers, sisters, family and friends.

I would like to express my profound gratitude to sons Abdullah, Mohammed and Ayham, to whom this work is dedicated, for every time they needed me but I wasn't there. For missing me throughout my study.

The most of all my sincere love and infinite appreciation goes to my wife, for being everything in my life, for his patience, supporting and invaluable assistance.

Last, but not least my thanks go to all people who have supported this research directly or indirectly.

October 7017 Amir Hameed ABED

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC	:	Alternative Current
APF	:	Active power Filter
BESS	:	Battery Energy Storage System
CPD	:	Custom Power Device
DC	:	Direct Current
DSC	:	Distribution Series Capacitor
DSTATCOM	:	Distribution Static Compensator
DVR	:	Dynamic Voltage Restorer
EPQ	:	Electrical Power Quality
EPS	:	Electric Power System
ES	:	Electrical System
FACTS	:	Flexible AC Transmission Systems
HV	:	High Voltage
ICT	:	Information Communication Technology
IGBT	:	Insulated Gate Bipolar Transistor
LC	:	Inductor, Capacitor
LV	:	Low Voltage
MC	:	Matrix Converter
MV	:	Medium Voltage
PCC	:	Point of Common Coupling
PCE	:	Power Conditioning Equipment
PFC	:	Power Factor Corrector
PI	:	Proportional-Integrator
PKW	:	Per Kilowatt
PLL	:	Phase Locked Loop
PQ	:	Power Quality
PQP	:	Power Quality Problem
PS	:	Power System
PWM	:	Pulse Width Modulation
SETC	:	Static Electronic Tap Changer
SMPS	:	Switch Mode Power System
SSCB	:	Solid State Circuit Breaker
SVC	:	Static Var compensation
THD	:	Total Harmonic Distortion
TSC	:	Thyristor Switched Capacitors
UPS	:	Uninterruptible Power Supply
VSC	:	Voltage Source Converter
VSI	:	Voltage Source Inverter

ABSTRACT

POWER SUPPLY QUALITY IMPROVEMENT USING DYNAMIC VOLTAGE RESTORER (DVR) IN IRAQI NETWORK

ABED, Amir Hameed

Master, Department of Electrical & Electronic Engineering

Thesis Supervisor: Assist. Prof. Dr. Javad RAHEBI

October -2017, 66 pages

Power quality (PQ) is a matter of importance and concern in today's world. It has become paramount with the appearance in recent years of electronic consumer devices that distortions in the power grid be minimized. The use of electronic power equipment has increased fast, which is leading to various problems of PQ. The voltage swells and sags are the major for PQ problems affecting industrial consumers. The best method to overcome these problems is through the use of custom power devices. The solution to this problem may be implemented using force devices, one example of which is known as a Dynamic Voltage Restorer (DVR), a device that is generally useful and efficient for power devices in electrical distribution grids. It has a fast-dynamic response for any disturbance and it is smaller size and lower in cost. In this thesis, the work was analyzed by MATLAB/SIMULINK and a detailed review of the components of the DVR device as well as about the control methods available by the proportional Integrator (PI) with pulse width modulation (PWM) for the device, has been chosen the best section for the control strategies and the performance optimization capability of the device. The results obtained have proven the capability of a DVR device in mitigating the PQ problems in a medium and low voltage distribution system as well as a detailed explanation for researchers in this field.

Keywords Power Quality (PQ), Dynamic Voltage Restorer (DVR), Proportional-Integrator (PI), Pulse Width Modulation (PWM), Voltage Source Converter (VSC).

ÖZET

IRAK AĞINDAKİ DİNAMİK GERİLİM GEREKTİRİCİSİ (DVR) KULLANARAK GÜÇ KAYNAĞININ İYİLEŞTİRİLMESİ

ABED, Amir Hameed

Yüksek Lisans, Elektrik ve Elektronik Mühendisliği Bölümü

Tez Danışmanı: Yardımcı Doç. Dr. Javad RAHEBİ

Ekim -2017, 66 sayfa

Güç kalitesi (PQ) bugünün dünyasında önem ve endişe konusudur. Son yıllarda tüketici elektroniği cihazlarının, güç şebekesindeki bozulmalarının minimuma indirgenmesi ile birlikte en önemli unsur haline geldi. Elektronik güç teçhizatının kullanımı hızla artmış ve bu da PQ'nun çeşitli sorunlarına yol açmıştır. Voltaj şişer ve sarkmalar, endüstriyel tüketicileri etkileyen PQ problemlerinin başlıca parçalarıdır. Bu problemlerin üstesinden gelmenin en iyi yolu özel güç aygıtları kullanmaktır. Bu sorunun çözümü elektrik dağıtım ağlarındaki güç aygıtları için, genelde yararlı ve etkili bir aygıt olan, Dinamik Voltaj Geri Yükleyici (DVR) diye bilinen bir güç aygıtı kullanılarak gerçekleştirilebilir. Herhangi bir probleme karşı hızlı ve dinamik bir tepki verir. Ayrıca daha küçük boyutta ve daha düşük maliyetlidir. Bu çalışmada, MATLAB/SIMULINK analiz yaptı ve cihaz için darbe genişliği modülasyonu (PWM) ile orantılı Integrator (PI) tarafından sağlanan kontrol yöntemleri ve DVR cihazının bileşenleri hakkında detaylı bir inceleme yapıldı. Kontrol stratejileri ve cihazın performans optimizasyon kapasitesi için en iyi bölüm seçildi. Elde edilen sonuçlar, bir DVR cihazının orta ve alçak gerilim dağıtım sisteminde, PQ problemlerini azaltma yeteneğini ve bu alandaki araştırmacılar için ayrıntılı bir açıklama olduğunu kanıtladı.

Anahtar kelimeler: Güç Kalitesi (PQ), Dinamik Gerilim Giderme (DVR), Oransal-İntegratör (PI), Darbe Genişlik Modülasyonu (PWM), Gerilim Kaynak Dönüştürücü (VSC).

CHAPTER ONE

INTRODUCTION

1.1 Introduction

When modern electrical and electronic devices began to evolve, the issue of power quality became one of the most important problems affecting sensitive electronic devices and sensitive loads such as medical devices, automotive manufacturing equipment, paper mills and semiconductor devices such as a switch-mode power supply (SMPS) and information communication technology (ICT) equipment. All these equipments are affected by the power supply disturbances. Therefore, becoming a demand for high power quality and voltage stability the important issue at the present time [1]. The loss of electrical power quality (EPQ) causes economic and commercial losses worldwide, losses in the industrial and commercial sector are estimated annually in the European Union (EU) have been estimated at around 100 billion euros annually due to power quality problems (PQPs) [2]. Today, the electrical power consumed in daily life and industrial it is becoming worrisome about the quality of power supplied and consumed but can solve these problems in two ways. The first is the use of custom power devices (CPDs) to mitigation the electrical power disturbances and the second use of the high-quality electric equipment which is less affected by the voltage fluctuations [3].

There are many custom power devices (CPDs) that can be used in electrical grids to solve the problems of power quality disturbances. These include static var compensator (SVC), uninterruptible power supplies (UPS), distribution static synchronous compensators (DSTATCOM), active power filters (APF), battery energy storage systems (BESS), thyristor switched capacitors (TSC), solid state circuit breaker (SSCB), dynamic voltage restorers (DVR), solid state transfer switches (SSTS), surge arrestors (SA), static electronic tap changers (SETC), distribution series capacitors (DSC) and power factor corrector (PFC), super conducting magnetic energy storage system (SMES) [4].

A DVR device was rated from the custom power devices (CPDs) and was used in the electrical networks. The results proved that the DVR has the high ability to solve the problems of electrical power quality and these problems are (swell, sag, short interruptions, long interruptions, harmonics, fluctuation voltage, unbalance voltage, noise, spike, transients) [5]. Also, from the advantages of a DVR is small in size and inexpensive compared to others devices [6].

The DVR has many advantages in mitigation and compensating all the disturbances in the electrical network, it is small in size and inexpensive compared with the other devices. However, there is a disadvantage in the DVR device. This disadvantage the DVR cannot compensate interruptions for a long time only short times. Due to the use of the battery store in the DVR device to compensate interruptions and the Stored energy cannot compensate interruptions for long periods [7]. But there are several studies to solve the problem of electrical interruptions of long periods by changing the energy storage to alternating current (AC) source[8].

DVR device technology is still in the development stage also the design is still at the level of study. In [9] discussed the design of the DVR and how to deal with voltage disturbances with emphasis on the size of the device, taking into account the cost and quality of the device, in the [10] has been processed the structure of the DVR device and in [11] has been added filters to accommodate the harmonics resulting from the large industrial load or high-voltage electronic equipment (HVDC converter).

In addition, a DVR connected in series with distribution networks and difficult to protect it from interfering with other protective devices present from the occurrence of short circuit. The main component of the DVR consists of a harmonics filter, injection transformer, series VSC, control system and energy storage. In this thesis, a DVR device will be designed with a focus on mitigation voltage swell, harmonics, sage and unbalance in Iraqi grids.

1.2 Problem Statement

Power quality is a major issue in power generation, transmission and distribution systems, as well as it is important for electric power consumers because it leads to financial and moral losses. There are many disturbances that distort the sine wave (sinusoidal) for source voltage and thus distort the sine wave for load voltage, this distorts leads to damage to electrical equipment sensitive for consumers.

There are many solutions to power quality problems, including custom power devices (CPDs), and these devices can be classified into two-part series and shunt compensation. The first one is shunt compensation, such as a distribution static compensator (DSTATCOM) and the second is series compensation such as dynamic voltage restorer (DVR) etc.

In this thesis, a DVR device was chosen for several reasons, including the ability the device to compensate and mitigate all the disturbances in the electrical network, the device can be linked to the low and medium voltage, small in size and inexpensive and fast in response compared with other devices.

1.3 Research Objectives

The aim objective of this study as follows:

1. Investigation of using DVR to improve power quality that related with voltage and compensate the power in the Iraqi distribution network.
2. Use a DVR to compensate for the missing part of the source voltage such as sag.
3. Use a DVR device to absorb the excess part of the source voltage such as swell.
4. Use a DVR to mitigation of harmonics that occur in source voltage (V_s).
5. The primary purpose of a DVR is to control all electrical network disturbances, improve the stability of a power system.

1.4 Scope of the Study

The scope of the study to mitigation of power quality problems using a DVR to mitigate and compensate voltage swell, sag, unbalances and harmonics. The topology of the dynamic voltage restorer (DVR) consists of five parts (Injection/ booster transformer, Energy storage, Voltage Source Inverter (VSI), Control System, Line Filter). The simulation was done using the MATLAB/Simulink program.

1.5 Significances of the Study

The mitigation of power quality problems is very important. Note that information communication technology (ICT) in offices, homes and production plants such as modern car factories, paper mills, medical laboratories and other factories that need uninterrupted power supply (UPS) and more reliable, without any disturbances. On the other hand, must abide by power supplier companies for their customers of uninterrupted power flow as well as high quality and more reliable to obtain a higher price per kilowatt (PKW) to raise the profits of the electricity supply companies as well as the keep on the consumer's equipment from damage.

1.6 Report of the thesis

This thesis is divided into six chapters.

In Chapter one, an overview of the subject and the research motivation for this work, which includes a comprehensive introduction to the subject with a statement of the problem, solutions for this problem as well as the objectives of the search, Why DVR device was selected and its advantages compared with the other devices, the scope of the study and the importance of this study.

In chapter two, general overview of DVR and related research work carried out on DVR device is presented.

In chapter three, an overview of power quality, which includes the definition of power quality, why we need the power quality, types of problems, their causes and effects and the most important solutions to the problem of power quality which including reducing the disturbances that are affecting on sensitive equipment as well as use custom power devices. Also in this chapter detailed explanation for the DVR, which includes parts the device, the way it works, the disturbances that have been processed by a DVR.

In chapter four, detailed description of the method used in the modeling process of the DVR and other components associated with it. Also, this chapter includes the design a DVR and link it to the three-phase radial network to the electrical network selected from the Iraqi networks to test the performance of the DVR as well as the calculation of the voltage injected.

In Chapter five, many simulations were performed to verify the performance of the DVR which was designed. The DVR has been tested on different types of disturbances for different loads (linear and nonlinear loads). The results obtained have been presented and discussed in detail.

In chapters six, conclusions, recommendations and future works for a DVR.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter explores theoretical and experimental literature related to the current study. In [12] Sandra emphasizes that, by reviewing existing literature that is related to the study, an additional knowledge on the topic to be studied would be gained. Also in this chapter general overview of DVR and related research work carried out on DVR device is presented.

2.2 Literature Review

Several DVR schemes had been reported and proposed for mitigation of PQ disturbances. The topology of DVR reported in the literatures include topology with energy storage and topology with no storage element. In this section, the review of work carried out by different researchers is presented.

(Babaei & Kangarlu, 2012) [13] proposed a solution to the problem various of PQ disturbance such as harmonic, swells, dips in the grid. The proposed DVR device solution is based on single-phase AC to AC converter which is energized from the faulty grid. The proposed DVR topology can be used for low, high and medium voltage levels with lower voltage rating switches. Topology for DVR device without energy storage elements or DC link, as a result, a DVR device is smaller in size. The performance of the proposed topology had been confirmed by laboratory scale prototype and simulation.

Compensation of voltage disturbances like voltage swells, sag, flickers and harmonics in distribution systems can also be done using a single-phase DVR. The work Babaei et al [14] proposed a DVR solution to mitigate voltage swells, sags, flickers and harmonics using direct AC/AC converter based DVR.

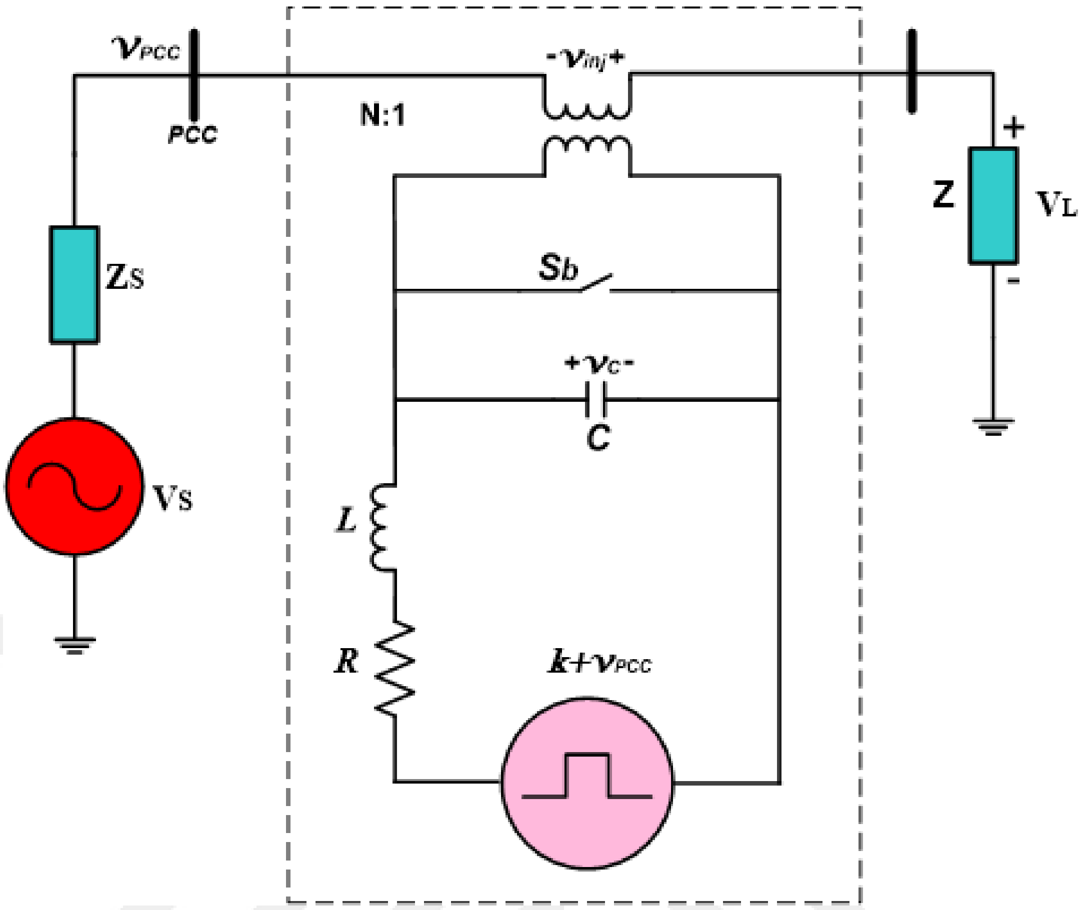


Figure 2.1: The proposed model of DVR device.

The DVR consist of a bypass switch, a damping resistor with LC low pass filter, AC/AC converter and an injection transformer as shown in figure 2.1. The isolation of the distribution system is done by the injection transformer. The proposed topology is again extended to three-phase on the same principle of operation by Babaei et al. [15], with the introduction of two new topology for a three-phase DVR based on direct AC/AC converter to mitigate several power quality disturbances, like flickers, harmonics, dips, swell and unbalances. In each of the proposed topology presented, direct converter was employed as in Figure 2.2(a) & 2.2(b) respectively.

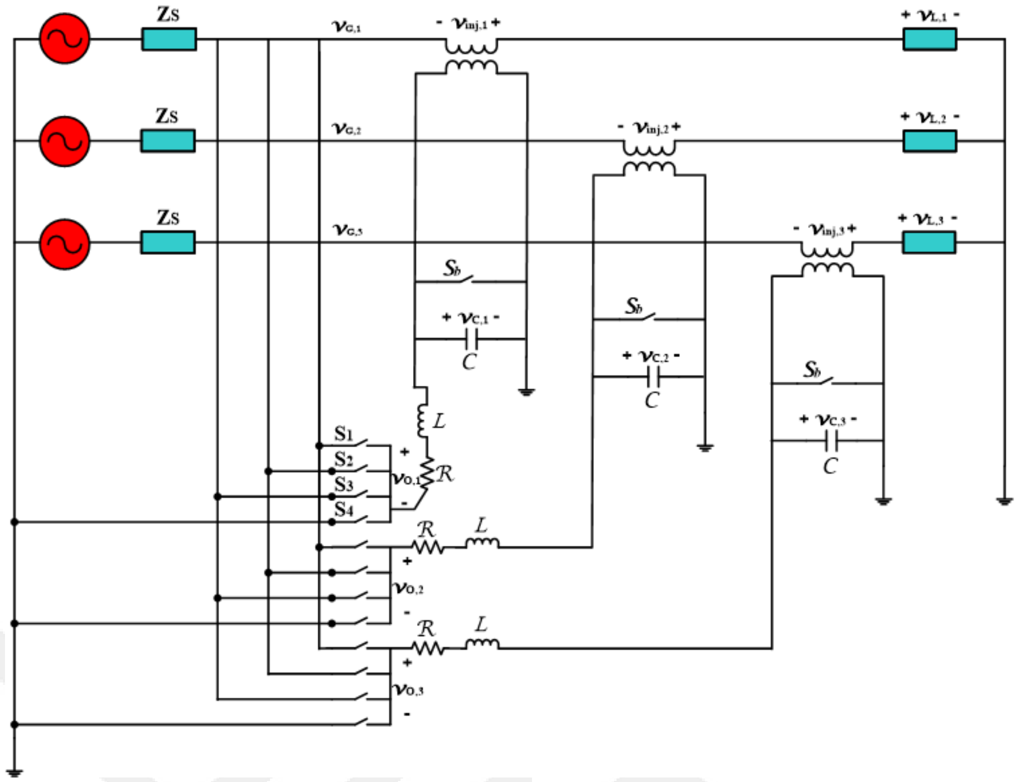


Figure 2.2: (a) Proposed topology [15].

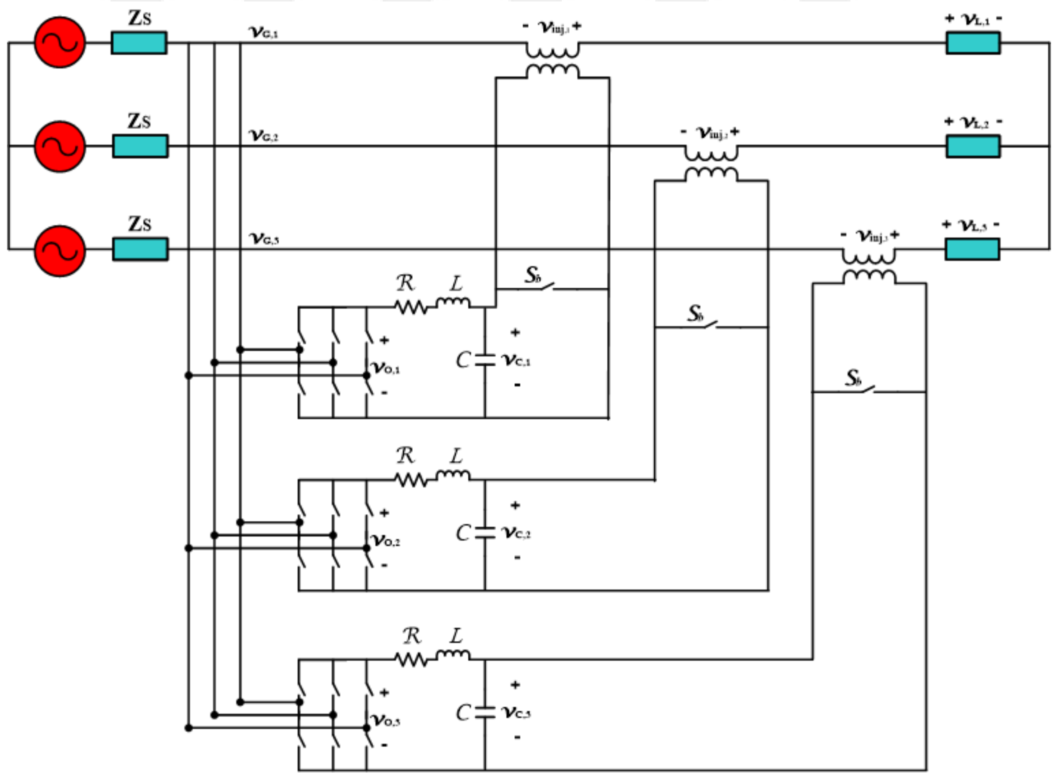


Figure 2.2: (b) Proposed topology [15].

An LC filter, a converter, a bypass switch, an injection transformer is used in each of the topology shown in Figure 2.2(a) and 2.2(b) respectively and are connected to the grid directly without any DC-link. A PWM control technique is used in the direct converter. The capabilities of both the single phase and three phase topologies and their control methods have been verified using simulation and experimental results shows that the system can compensate voltage sags, swells, harmonics and flickers.

(Babaei & Kangarlu, 2009) [16] proposed new matrix based converter topology for DVR without DC-link, that is capable of restoring voltage in an extremely disturbed network and can be used to mitigate voltage swell and dips in unbalance and balance condition, using 3-phase to single phase matrix converters as shown in figure 2.3.

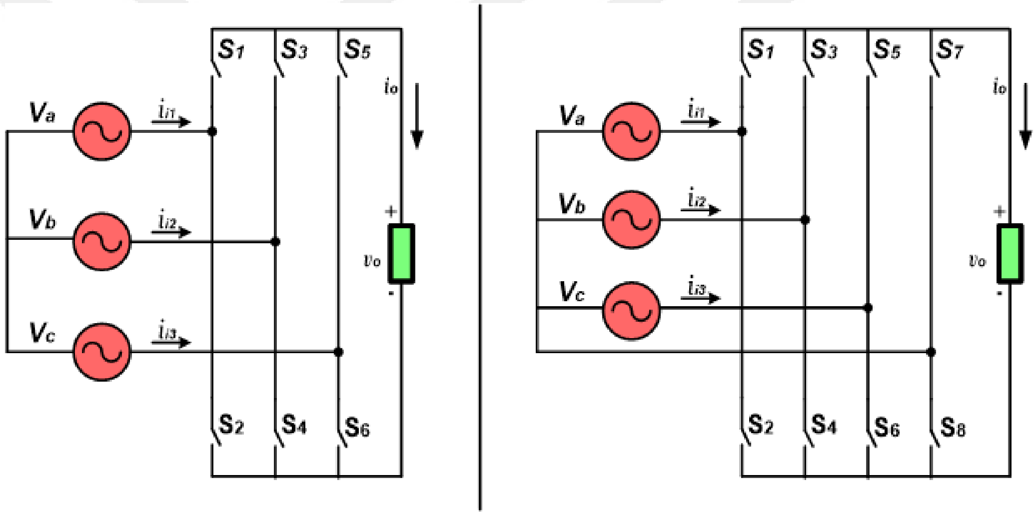


Figure 2.3: 3-phase to single phase MC (a) Using 6 switches, (b) Using 8 switches [16]

The voltage produced from the matrix converters (MC) is fed to the faulty network through a three-single phase transformer, while the matrix converters are directly connected to the main supply as in figure 2.4. In the absence of a disturbance in the network, the matrix converter doesn't operate, because at that moment, the load voltage is equal to the supply voltage. But at an instant when a disturbance such as voltage dip and swell is encountered, the matrix converter immediately switched on to operate and compensate the missing voltage due to voltage dip and suppress the voltage due to swell. The problem with this proposed topology is that each MC has a high number of switches.

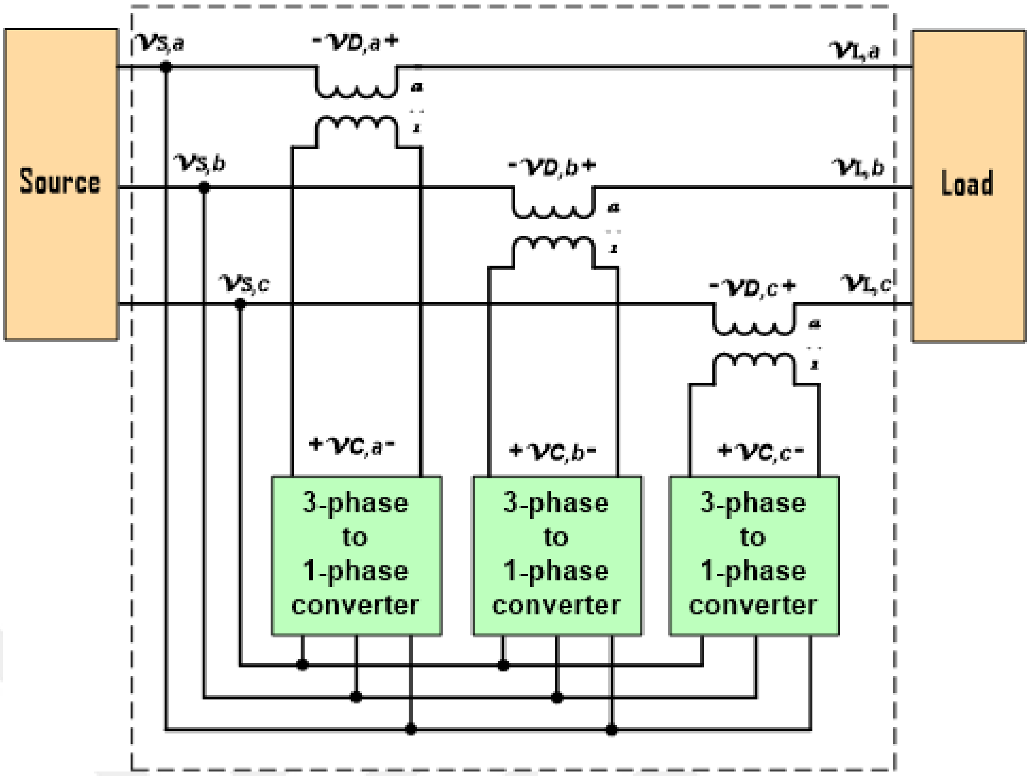


Figure 2.4: Power circuit of the DVR [16].

The number of switching devices in [17] is reduced in the work of (Babaei & Kangarlu, 2010) [18] with the use of unidirectional switches instead of bi-directional switches. The performance of the DVR has been tested by both experimental and computer simulation and satisfactory results were obtained.

In [4], Sajid Ali, Yogesh K Chauhan and Bhavnesh Kumar, they used two techniques to improve the quality of electrical energy. The first technique is to connect compensation devices such as the dynamic voltage restorer in a series with the source voltage and the second is the CPD connecting in parallel with the source voltage. There are many energy quality problems of them There are many energy quality problems and these problems are (swells, sag, harmonics, transients, notching, flicker). These problems are major problems for the quality of energy and there are several ways to improve quality has been selected DVR device as the best solution to quality problems and also to compensate for disturbances in electrical networks and the most important of these problems (sag, swell) voltage. These problems are major problems for the quality of energy There are many ways to improve quality The DVR device has been chosen as the best solution to quality problems and also to compensate for disturbances in electrical networks and the most important of these bulge problems. The DVR is characterized by a quick response to inject or absorb the appropriate voltage without any difficulties as well as to avoid the stability of the electrical system either of the main features of the device. It is less expensive compared with other protective devices.

T AppalaNaidu [19]. Modern power systems currently have large circuits that include many load sources connected to each other through transmission lines and distribution networks but the important thing about this is the power quality and reliability of power supply in the load centers. In most countries power generation has been generated and developed to be reliable, but we cannot guarantee that the quality of the power supply is reliable due to the diffusion of electrical transmission and distribution networks. There are also natural and nonlinear loads such as motors that require high electrical current. So, DVR is one of the best CPDs used for this task. The DVR compensates the (sag, swell, harmonic and unbalanced) voltages. A DVR is connected in a series with the supply voltage at the PCC. The DVR is always on standby for any emergency occurring in electrical networks.

In [20], N. Pavan Kumar and Yash Pal, Power quality has become a major issue in transmission and distribution systems and there are many problems affecting it such as (swell, sag) and other destabilizations that affect are on the quality of the sinusoidal to the supply voltage and thus distort the load voltage and damage sensitive devices. There are many solutions for power quality such as CPD and flexible AC transmission devices (FACTS). These devices can be classified into two parts (shunt and series), series voltage compensators such as DVR and shunt voltage compensators such as DSTATCOM, it is designed to improve the quality of the power supply. In this scientific paper, to restore the load voltage to its normal state, a DVR device is connected between the supply voltage and sensitive load in the cases linear and non-linear load, theory is a simple algorithm based on the synchronous reference frame theory (SRFT) is used to generate reference voltages to control a three-phase battery and three wire DVR to compensate for linear loads of various faults.

M.Sharanya1, M.Sharanya1and Dr M.Sasikala3 [5]. There are many power problems, the most important of which are (unbalance, spike, noise fluctuation, swells, sag, harmonic, transient, interruption) voltages. These problems can be mitigated using CPD. CPDs include various electronic control units and are used in medium and low distribution assembly. DVR is a device of voltage compensation dangling and also has the ability to absorb the overvoltage and correction of the power factor and has the ability to process harmonics and the features of the DVR device small size and inexpensive and its ability to processing the distortions of voltages. The method of operation of the device through the injection or absorption voltages and connected to a series with the source voltage to restore the quality of power. In this study, active filters were used to control the harmonics and return the current to normal state. These distortions occurred due to nonlinear loads. However, the use Active filters (AF) increases the cost. Hybrid filters are made up of a mixture of active and passive filters and are used to reduce harmonics and have great advantages over the treatment of harmonic distortions.

Shailesh M. Deshmukh1, Bharti Dewani2 [21]. In most industries, we need high-quality electrical power and with the increase of sensitive loads increases the problems of power quality and the quality of the current and voltage task for the factories, public utilities and consumers and that protection the consumers equipment is an important economic and that any difference in voltage will causes very heavy consequences for customers and there are a lot of problems. the most important problems (sag, swells) these problems must be solved and can adopt various remedial measures to reduce these problems or compensate the problem of electrical oscillation of the most important problems of this problem particularly affects industrial facilities and even if was electric oscillation small periods but they are installment for production stopped for long periods and to the processing these problems, we chose the DVR device because we consider it distinctive devices to solve all power quality problems and in this study the device consists of several parts (voltage source inverter, active filter, energy storage protection and control system, linking transformer injection with voltage source).

A. Khoshkbar Sadigh, Student Member and K. M. Smedley [22]. Sensitive loads such as auto factories, medical equipment, paper mills and semiconductor factories all these factories are affected by the power supply disruptions. Therefore, the demand for energy quality has become a pressing issue for electric power supplier's companies. Voltage fluctuation is very dangerous in distribution networks on the quality of electric power and thus result in losses in material and moral to the consumer. Several countries have sought solutions to solve problems of electrical power quality and access to problem-free and high-quality capacity from these countries is Canada. In

1991, the Royal Canadian Institute conducted more than one site to obtain high-quality energy. It was discovered that electrical voltage fluctuation is one of the most common problems in electric networks. It is the result of sudden load changes. Therefore, a DVR device was chosen as a very efficient device to control these problems. we can Connected the DVR on any voltage source and be high responsive for any disturbance in voltage. In this study, DVR has two main parts of control to identify and detect the reference. The first part is sag, swell voltages and is detected sag, swell by way of electrical grid analysis. There are several different ways to detect disorders including (peak, rms. dq0 components, negative sequence, positive) measurement. The second part is to determine the source of the reference signal and the reference signal depends on the type of energy storage and ability to support the active power and voltage the lost there are several ways to compensate voltage lost these ways (persag, energy minimized, in-phase and hybrid compensation) methods.

Prasad A. Raut and Manohar N. Kalgunde [23]. Ideally, electric power companies have committed them to providing their customers with a continuous flow of electrical power without any distortions and disturbances. Therefore, DVR has been chosen as an ideal device for repairing deformities and disturbances of the electrical power system (EPS). The DVR consists of two main parts: the first part is the power circuit and the second is the control circuit. There are many necessary standards that must be controlled they are frequency, magnitude, phase shift and these standards can control them by using a DVR device by injecting or absorbing the damaged part. In this study was used sinusoidal pulse width modulation switching technique to control on AC output voltage this control be by comparison between sinusoidal reference signal to get the pulse per half cycle with a triangular carrier wave. The aim of the control scheme is to maintain the volume of constant voltages at any point in the sensitive load and simulators using MATLAB program.

In [24], Rakeshwri Pal and Dr. Sushma Gupta used the PI controller to control on work of the DVR, which has been working on the maintenance at the level of load voltage sensitive within the limit allowed through the injection of effective and ineffective in the system during the period of error or the entry of loads of non-Linear network. In this study, batteries were used to compensate or repair the voltages level in case of the load. The working principle of the device depends on the correlation between the required voltages and the load voltage in the case of deformation. On the other hand, the DVR is based on the relative value and shape of the wave and the injection of a wave on its base to ensure the nappy in the form of a sensitive wave. In this paper, simulations were carried out in two stages: the first was without a DVR with a three-phase line with each other for 0.1 second and the voltage wave was distorted at the end of the load. The second simulation was with the connection of the DVR with the network and the application of the same error at the first time, and this time the voltages were restored at the end of the load (96%) and through the results of this simulation, it was found that the DVR is a good regulator of voltages.

CHAPTER THREE

POWER QUALITY WITH DVR DEVICE

3.1 Introduction

This chapter a general review of power quality is provided, which includes, the importance of having a power quality, types of PQ disturbances, their causes, effects and solutions to PQ problems. Then a review of the DVR and related research work carried out on the DVR is presented.

3.2 Power Quality Definition

The principle of electrical power quality can be explained in a number of ways, but here it is generally understood that the consumer obtains high-quality of electrical energy without any distortions. This means that the voltages are constant in value and frequency.

Depending on whether electricity is consumed or supplied, term power quality can be again being viewed in two different perspectives. From the supply point of view, it is can be referred as the ability of the generator to generate electricity at 60 or 50 hertz (Hz) with the little or no variation, while of the transmission and distribution point of view, it refers to the ability of the voltage staying within an acceptable range with an increase or decrease of five percent (5%).

Researchers like Roger Dugan, Wayne Beaty and Mark McGranaghan [25], they define power quality as any deviation in frequency, current and voltage that would result in malfunction or failure of end user or utility equipment.

In general, the concept of electrical power quality means an assessment of electrical energy as a product based on specific indicators. These indicators are methods or basic means which we can assess the efficiency of electrical power networks starting from transport networks and ending for distribution networks for end consumers.

Electrical power quality the optimum performance of the electrical equipment and devices at consumers, electrical power quality is related to the shape of the wave, which is determined by the following factors (amplitude, frequency, harmonics, symmetry of 3- phases system, voltage regularity).

Any change in any of the precedent factors will result in the effect and change in the sinusoidal wave shape of the voltage source while the principle of electrical power quality is achieved if all values are within the permitted standard limits.

3.2.1 Need for Power Quality

There are many factors that triggered the need to prevent and to solve power quality problems. These include the deregulation of the power industry, Increased use of hardware that generates problems in the quality of electrical power, increased use of sensitive equipment and the increased in PS interconnectedness. All of the factors listed have an impact on the ability of utility companies to compete with each other, to keep existing customers and get new ones at the same time.

It is also a well-known experience that poor power quality has a negative effect on system and equipment. Therefore, to some extent, the success of the consumers or the end user in his or her business depends on the utility company, because the utility company can cause the end user disruption in his day to day productions. Therefore, the need to continuously assess a supreme quality of power is of utmost important in order to avoid such effects [25].

3.3 Power Quality Problems Types

In order to resolve all the problems and fluctuations of the electric power, it is necessary to understand and identify the types of fluctuations that occur in the electrical grid. For the describe and understand the different types of power quality problems (PQPs) are shown table 3.1, with a summary of their symptom, effects and cause. Power quality problems are easy to determine by varying the nature of the basic components of the sine wave, sine wave for the voltage, current and frequency [26].

3.3.1 Causes of Power Quality Problems

Some typical actions or disturbances on the electrical power systems (EPS) which cause power quality problems are listed below:

1. Operation of non-linear loads.
2. Malfunction or damage in cables and transformers electrical.
3. Lightning and natural phenomena.
4. Start-up or switching of large loads e.g. motors.
5. Energization of transformer and capacitor bank.
6. Wrong maneuvers (Connection) in distribution substations.

Although all the disturbance mentioned above are of concern in the context of power quality, but still there is no doubt that the most problematic issue is the occurrence of faults, which is the main concern of this work. In the occurrence of fault, there will be a voltage variation at different points of the system which differs in both magnitude and duration, depending on how far is the point from the fault location, the procedure of fault clearing and the system impedances [26].

Table 3.1: Summary of power quality disturbances with description, causes and consequences.

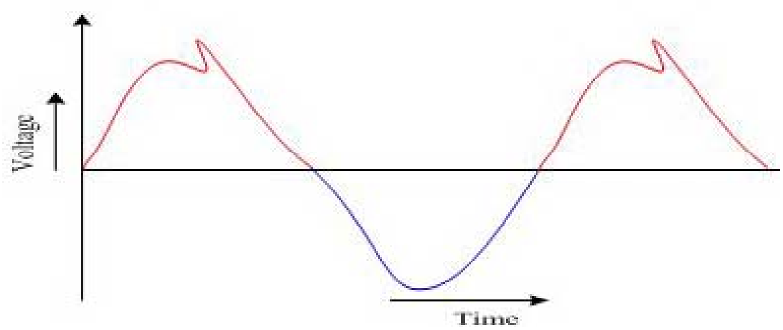
Type of Disturbance	**Example Wave Shape**
1. Transient	
Impulsive transient	
Description: It sudden high peak events that raise the current or voltage levels in either a negative or a positive direction.	
Causes: The switching of inductive loads, lightning, utility fault clearing, poor grounding, Electrostatics Discharge (ESD).	
Consequences: Possible damage, system halts, loss of data.	

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

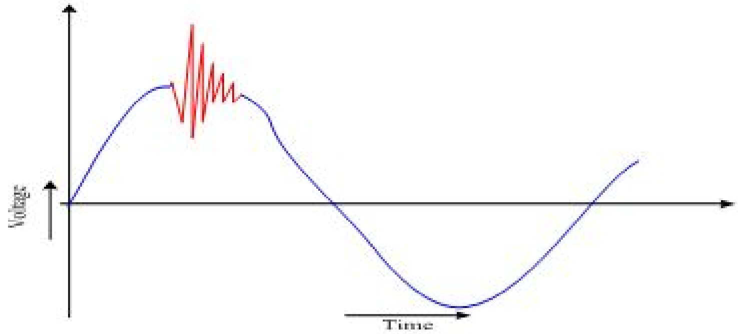
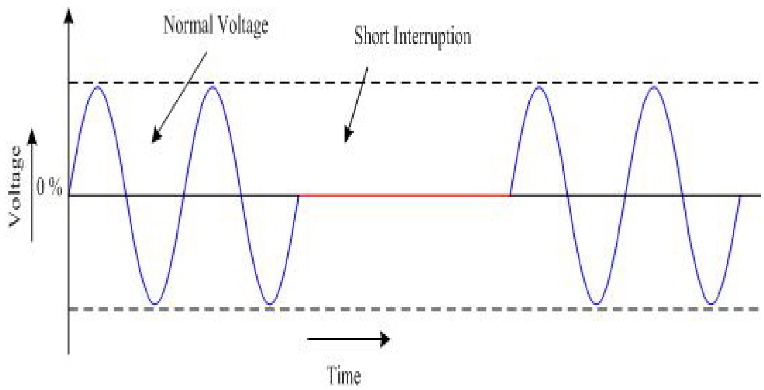
Type of Disturbance	Example Wave Shape
Oscillatory transient	
Description: It is a sudden change in the steady-state condition of a signal's current, voltage, or both, at both the negative and positive signal limits, oscillating at the natural system frequency	
Causes: Switching of inductive or capacitive loads	
Consequences: Possible damage, system halts, loss of data.	
2. Interruptions	
Very-short interruptions	
Description: Total interruption of electrical supply for a duration from few ms to two seconds.	
Causes: Circuit breaker tripping, switching, component failures, utility faults.	
Consequences: Loss of information, tripping of protection devices, Stoppage of sensitive equipment, malfunction of data processing equipment.	

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

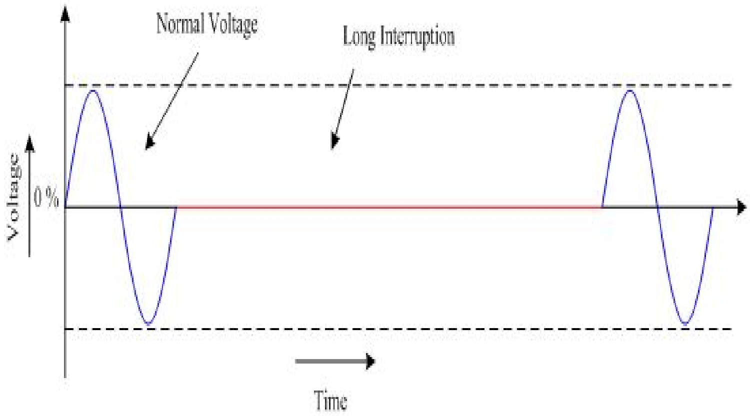
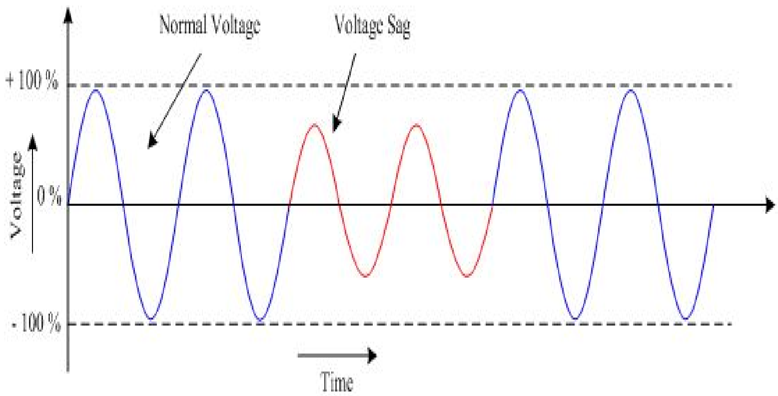
<table>
<tr><th>Type of Disturbance</th><th>Example Wave Shape</th></tr>
<tr><td>Long- interruptions</td><td>
</td></tr>
<tr><td colspan="2">Description: Total interruption of electrical supply for the duration (Instantaneous 0.5 cycles to 30 cycles, Momentary 30 cycles to two seconds, Temporary two seconds to two minutes, Sustained greater than two minutes)</td></tr>
<tr><td colspan="2">Causes: Circuit breaker tripping, switching, component failures, utility faults.</td></tr>
<tr><td colspan="2">Consequences: Stoppage of all equipment.</td></tr>
<tr><td colspan="2">3. Sag / Undervoltage</td></tr>
<tr><td>Sag or dip</td><td>
</td></tr>
<tr><td colspan="2">Description: A decrease of the normal voltage level between (10 and 90) % of the nominal RMS voltage at the power frequency, for durations from 0.5 cycle to one minute.</td></tr>
<tr><td colspan="2">Causes: faults, Startup loads.</td></tr>
<tr><td colspan="2">Consequences: Loss of data, system halts, shut down.</td></tr>
</table>

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

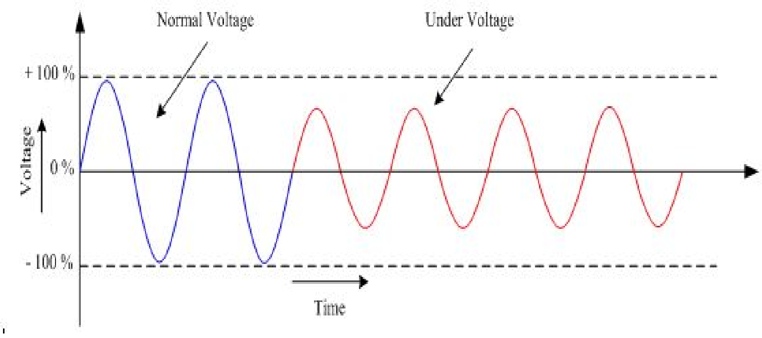
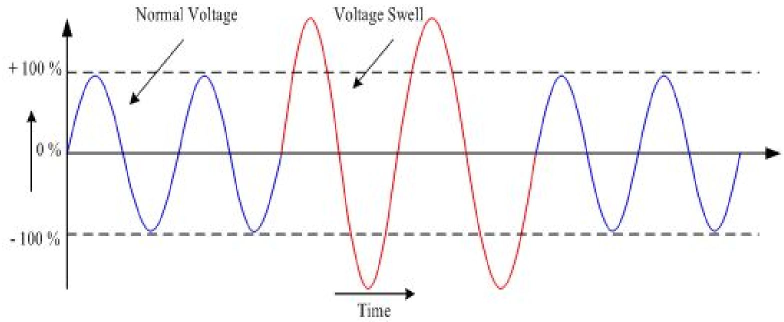
Type of Disturbance	Example Wave Shape
Undervoltage	
Description: It is the result of long-term problems that create sag (Low of the supply voltage < -10% for a long time).	
Causes: load changes, Utility faults.	
Consequences: Loss of data, system halts, shut down.	
4. Swell / Overvoltage	
Swell	
Description: increase in RMS voltage for a duration of 0.5 cycle to one minute).	
Causes: Utility faults, load changes.	
Consequences: Equipment damage/reduced life, nuisance tripping.	

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

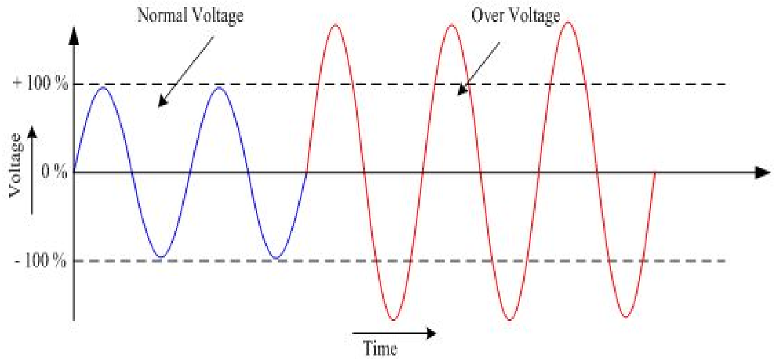
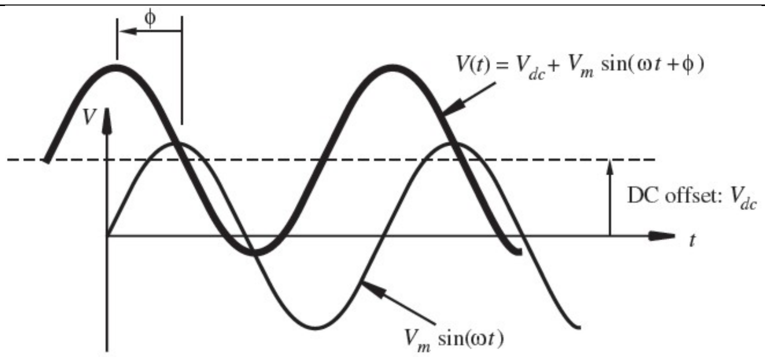
<table>
<tr><th>Type of Disturbance</th><th>Example Wave Shape</th></tr>
<tr><td>Overvoltage</td><td>
</td></tr>
<tr><td colspan="2">Description: Increase of supply voltage (> 6%) for a long time.</td></tr>
<tr><td colspan="2">Causes: Utility faults, load changes.</td></tr>
<tr><td colspan="2">Consequences: Equipment damage/reduced life</td></tr>
<tr><td colspan="2">5. Waveform distortion</td></tr>
<tr><td>DC offset</td><td>
</td></tr>
<tr><td colspan="2">Description: It can be induced into an AC distribution system, due to the failure of rectifiers within the AC to DC conversion technologies.</td></tr>
<tr><td colspan="2">Causes: Power supplies, Faulty rectifiers.</td></tr>
<tr><td colspan="2">Consequences: Ground fault current, transformers heated, nuisance tripping.</td></tr>
</table>

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

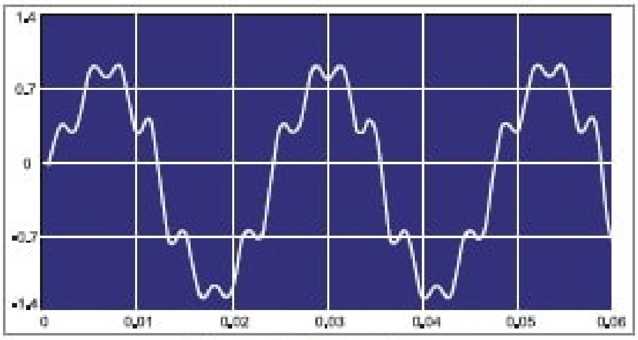
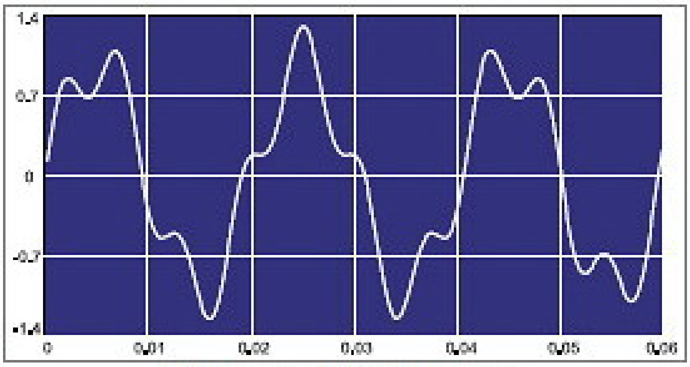
Type of Disturbance	**Example Wave Shape**
Harmonics	
Description: Harmonic distortion (HD) is the corruption of the fundamental sine wave at frequencies that are multiples of the fundamental (180 Hz is the third harmonic of a 60 Hz fundamental frequency;; 3 × 60 = 180).	
Causes: Electronic loads (nonlinear loads).	
Consequences: System halts, transformers heated.	
Interharmonics	
Description: It is a type of waveform distortion (WD) that is usually the result of a signal imposed on the supply voltage (Vs) by electrical equipments such as static frequency converters, arcing devices and induction motors.	
Causes: Faulty equipment, control signals, arcing devices, induction motors, frequency converters.	
Consequences: Heating, light flicker, communication interference.	

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

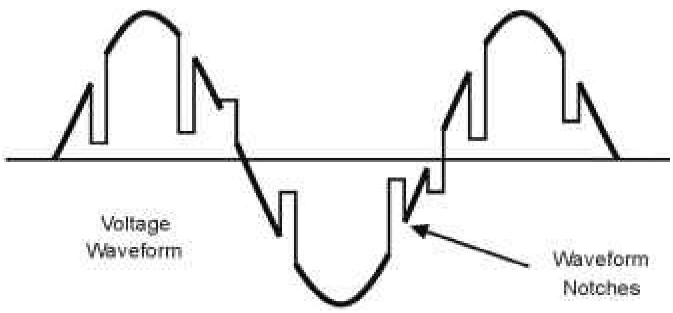
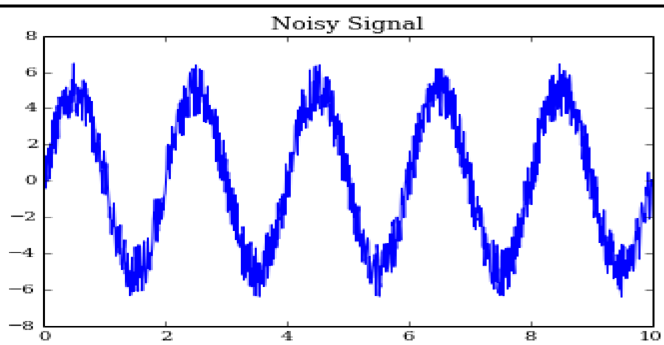
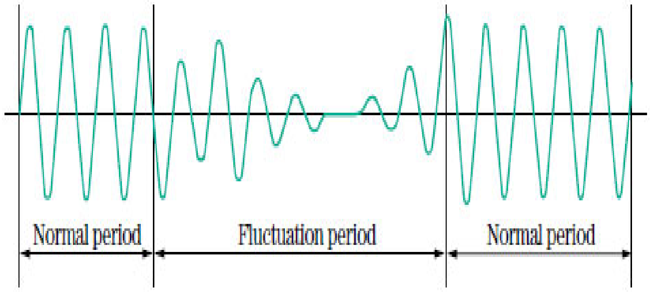
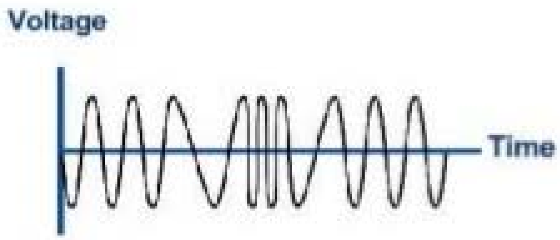
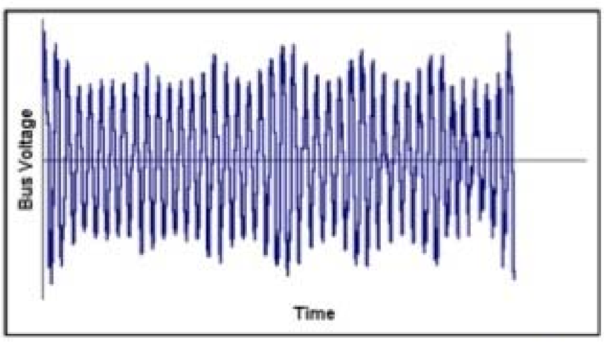
Type of Disturbance	Example Wave Shape
Notching	
Description: It is a periodic voltage disturbance caused by electronic devices, such as light dimmers, variable speed drives and arc welders under normal operation.	
Causes: Arc welders, Variable speed drives, light dimmers.	
Consequences: Data loss, system halts.	
Noise	
Description: Noise is unwanted current or voltage superimposed on the power system current or voltage waveform.	
Causes: Faulty equipment, transmitters (radio), proximity to EMI/RFI source, ineffective grounding.	
Consequences: Data loss, System halts.	

Table 3.1 (Continued): Summary of power quality disturbances with description, causes and consequences.

<table>
<tr><th>Type of Disturbance</th><th>Example Wave Shape</th></tr>
<tr><td>6.Voltage fluctuations</td><td>
</td></tr>
<tr><td colspan="2">Description: Voltage fluctuation is a series of random voltage changes or a systematic variation of the voltage waveform, of small dimensions, namely (95 to 105) % of nominals at a low frequency, generally below 25 Hz.</td></tr>
<tr><td colspan="2">Causes: Faulty equipment, transmitters (radio), proximity to EMI/RFI source, ineffective grounding.</td></tr>
<tr><td colspan="2">Consequences: Data loss, System halts.</td></tr>
<tr><td>7. Frequency Variations</td><td>
</td></tr>
<tr><td colspan="2">Description: It is deviation of the power system fundamental frequency from it specified nominal value (e.g., 50 or 60 Hz).</td></tr>
<tr><td colspan="2">Causes: Intermittent operation of load equipment.</td></tr>
<tr><td colspan="2">Consequences: Light flicker, system halts.</td></tr>
<tr><td>8. Voltage flicker</td><td>
</td></tr>
<tr><td colspan="2">Description: It is a series of systematic voltage fluctuation.</td></tr>
<tr><td colspan="2">Causes: Large cyclic loads such as welders, induction arc furnaces and motor when cycled.</td></tr>
<tr><td colspan="2">Consequences: Irritating lighting flicker and control reset.</td></tr>
</table>

Distribution systems are radially operated, for this reason, in the occurrence of a fault the systems are subjected to sustained interruption. On the other hand, faults that occur in transmission systems do not cause sustained interruption, because transmission systems are meshed. In such system, the electric power flow is transferred to another path when the faults occur with the help of the protection system. Nevertheless, the fault in both distribution and transmission system can be very critical to certain processes/customers.

In overhead line systems, the majority of the fault in distribution and transmission systems are caused by natural phenomena, especially lightning [27]. Thunderstorms and wind are also of severe disturbances in both high and medium voltage networks. And sometimes, trees adjacent to tower or line causes voltage interruptions and sags in the network.

3.3.2 Effects of PQ Problems

The impact of PQ Problems to the consumer and the utilities are many and varied. However, the majority of these problems affect the consumer equipment than the utility [28]. Motor overheating, flickering lights, computers shutting down and tripping off of adjustable speed drives are the common symptoms of PQPs [9]. The following are some of the effects of power quality problems for consumer equipment [29];

1. Cause computer and computer controlled equipment to freeze and lose data. And most of these problems are caused by voltage variations because computers are sensitive equipment.
2. Discharge lamps like compact fluorescent lamps (CFLs) and fluorescent lamps are also affected, because these devices are susceptible to voltage sags as they require high voltage to initiate discharge during starting.
3. Telephones nearby will also experience noise induced by adjacent electrical equipment.
4. Induction motors and other industrial equipment, especially in industries like the refineries and textile industries are quickly exposed to the voltage dip because almost all the motors are connected to each other and also the other electrical components in the electrical system (ES). In the present the voltage sag, if any of the components in the electrical system is affected by voltage

sag and its dips in the process, the whole plant can be affected and sometimes lead to shut down of the plant.

5. Others effects of power quality problem include erroneous result by meters in the presence of harmonics and sometimes loss of data and mal-operation of data processing equipment.

3.3.3 Solutions to Power Quality Problems

Various methods of preventing and solving power quality problems had been reported in many literatures such as [25, 29]. The solutions in the literature include:

1. Reducing the effects of PQ problems on sensitive equipment.
2. Use of custom power devices (CPD) and power conditioning equipment (PCE).
3. By analyzing the symptoms of the problem and determining its cause, after that must solve this problem.

In this section only the first two approach of solving and preventing PQ problems would be discussed. Nevertheless, one of the main objectives of this thesis is design a DVR, which is regarded as PCE with emphasis on the mitigation or solving voltage sag and swell problems.

3.3.3.1 By reducing the effects of disturbance on sensitive equipment

This type of solutions can only be done in the manufacturing process of sensitive electrical equipment such computers, data process etc. In this approach to solving power quality problems, can the manufacturer that manufactures sensitive electrical equipment that reduces or limits the effect of PQPs by designing the electrical equipment to be less sensitive to any changes in voltage.

For example, the manufacture can desensitize the equipment manufactured to solve power quality problems. The undervoltage relay can also be adjusted or the device like capacitors can be added to sensitive equipment to provide energy storage when the voltage sags.

3.3.3.2 By installing power conditioning equipment

Another solution to PQ problems is the used of custom power devices (CPDs) which serves as a power quality mitigation equipment. These devices either can either eliminate or reduce the effect of PQ problems.

Example of these power conditioning equipment are uninterruptible power supplies (UPSs), static var compensator (SVC), super conducting magnetic energy storage (SMES), active power filters (APF), Dynamic voltage restorer (DVR), distribution static synchronous compensators (DSTATCOM) etc. which is implemented in this project work.

Nevertheless, sometime reducing or eliminating the causes of power quality disturbances is also another solution. These can be done by reducing or eliminating all the possible action that may likely cause disturbances into the power system network.

3.4 Dynamic Voltage Restorer

A DVR is a power electronic device for voltage correction [30, 31], it is connected in series with the feeder of sensitive loads between the load buses and the incoming supply [32], as shown in figure 3.1. DVR was first installed in Westinghouse in 1996 [33]. And since then, because of the growing number of sensitive loads worldwide, many installations have been taken place and with a wide spread of research in the control philosophies of DVR [31]. Nowadays, commercial solutions are found within the range of MVA and installed in the industries to support the entire factory one of the most important these solutions is DVR.

A modern PWM inverter that is capable on the generating accurate high-quality voltage waveforms form the heart of CPDs like DVR. And a proper design of the control scheme enables the DVR to injection three-phase controllable voltages of required phase angles and amplitudes to maintain the load bus voltage in the desired waveform during voltage swells, harmonics, sags in the distribution grid voltage [13, 34]. The DVR has three operating modes;

1. Standby: (also termed as short-circuit operation mode) when the voltage injected has zero magnitudes.
2. Boost/injection: when the DVR injects a required voltage of appropriate magnitude and phase to restore the pre-fault load bus voltage.

3. Protection mode: In this mode, the bypass switch can be used as a protection device to protect DVR from the overcurrent in the load side due to short circuit on the load or overcurrent.

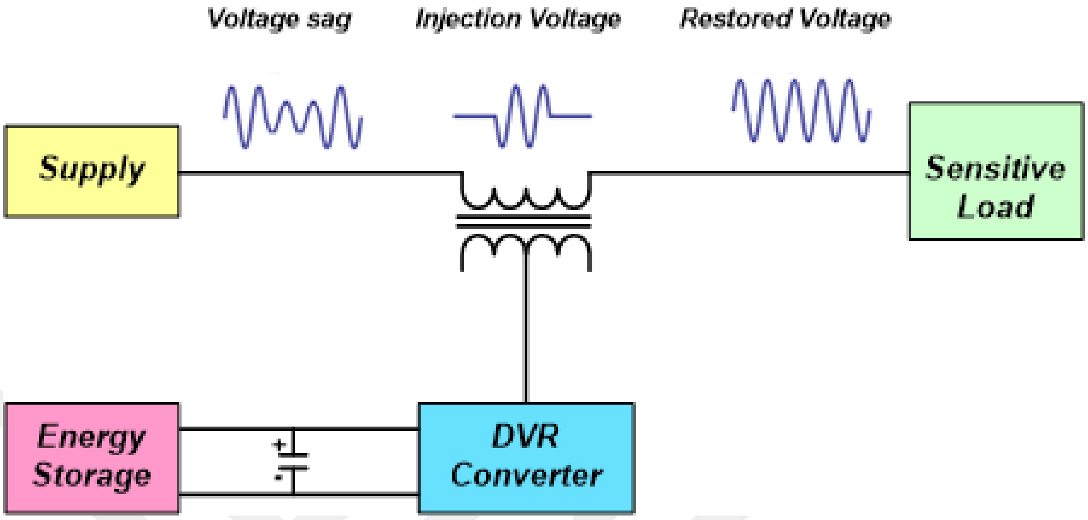


Figure 3.1: Schematic diagram for DVR [35].

3.4.1 Power Circuit of DVR

The DVR consists of five main parts that are shown in figure 3.2. Namely, Voltage injection transformer, line filter, energy storage device, voltage source inverter and bypass switch. The functions of each of these parts are described as follows;

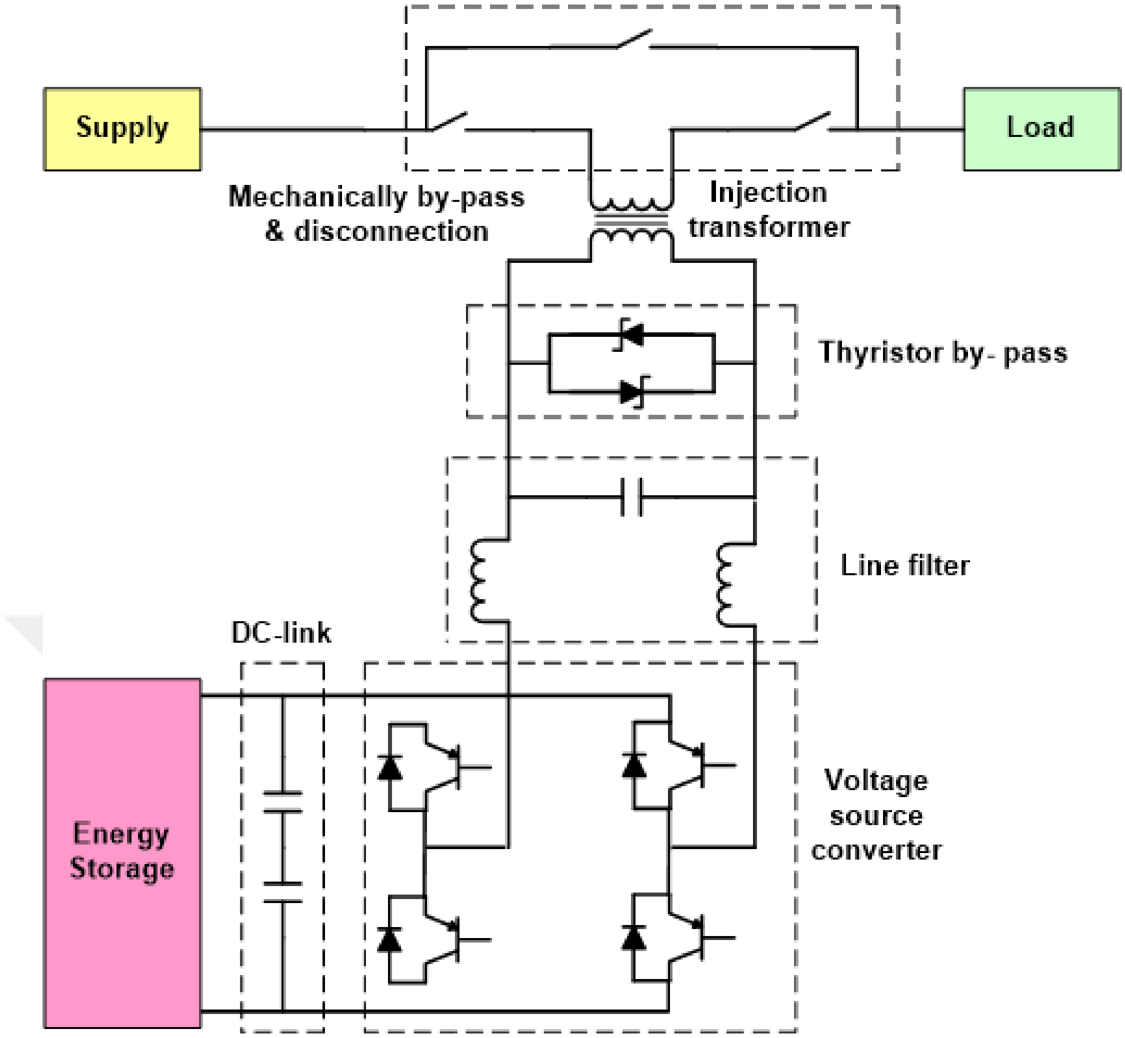


Figure 3.2: Main configuration of DVR [35].

3.4.1.1 Series voltage injection transformer

A three-single-phase transformer are connected in series with the distribution feeder to couple the voltage source convertor (VSC) (at the low voltage level) to the higher distribution voltage level. The three-single transformers can be connected with the star/open star winding or delta/open star winding. The latter does not permit the injection of the zero-sequence voltage. The choice of the injection transformer winding depends on the connections of the step-down transformer that feeds the load. If a Δ-Y connected transformer is used, there is no need to compensate the zero sequence voltages. However if a Y-Y connection with neutral grounding is used, the zero sequence voltage may have to be compensated [36].

3.4.1.2 Energy storage

During disturbances of voltage in the power system network, DVR needs real power to compensate or to mitigate the disturbances. For the DVR with energy storage topology, a storage element or a direct current (DC) link is required by the VSC to produce an AC voltage which is to be injected into the grid when there is a voltage disturbance in the network [37].

3.4.1.3 Voltage source inverter

The inverter systems in the DVR are to convert the direct current (DC) voltage supplied from the storage element to alternating current (AC) voltage source which is being injected into the system via the injection transformer during voltage disturbances [38]. The rating of the VSI is relatively low in voltage and high in the current of the presence of step up injection transformer.

3.4.1.4 Bypass switch

In the occurrence of fault in the power system network, fault in the downstream might flow to the inverter circuit of the dynamic voltage restorer. To avoid this to happen a bypass switch is incorporated in the inverter circuit to bypass the path for load current during faults, service and overload [38].

3.4.1.5 Line Filter

Line filter is included in the DVR system in order to reduce the switching harmonics generated by the PWM VSC. The filtering scheme can be placed either on the high voltage side or in the inverter side. The filtering use in this thesis is placed in the inverter side. This is because all the higher order harmonics components that is generated by the VSI would be at least eliminated from the system [39].

3.4.2 DVR Operating Modes

Basically, the DVR can operate in modes, namely: Standby mode, protection mode, boost or injection mode**.** A detail description of the modes in the following section [33, 40].

3.4.2.1 Protection mode

In this mode, the bypass switch can be used as a protection device to protect DVR from the overcurrent in the load side due to short circuit on the load or overcurrent. The DVR can be protected by the action of the bypass switches by supplying another path for current.

During short circuit or in the presence of large inrush current, If the current on the load side exceeded the permitted limit, the bypass switches (S1 and S2) will open to isolate the DVR from the main system and supplying an alternative path for the current to flow through Switch S3 (closed) [39], as shown in figure 3.3.

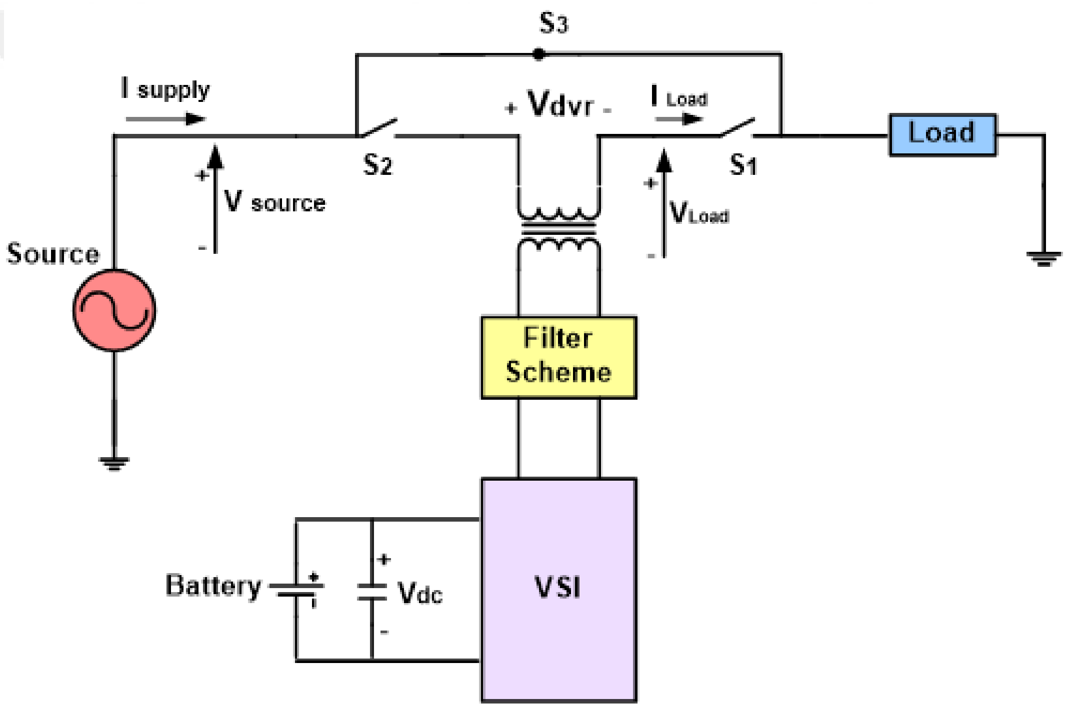


Figure 3.3: The configuration of DVR in protection mode, [39].

3.4.2.2 Standby mode: (V_{DVR}=0)

In standby mode, the low voltage winding of the transformer is shorted through the inverted. Such that switching of a semiconductor does not occur and the full load current will pass through the secondary. The DVR will be most the time in standby mode [41], as shown in figure 3.4.

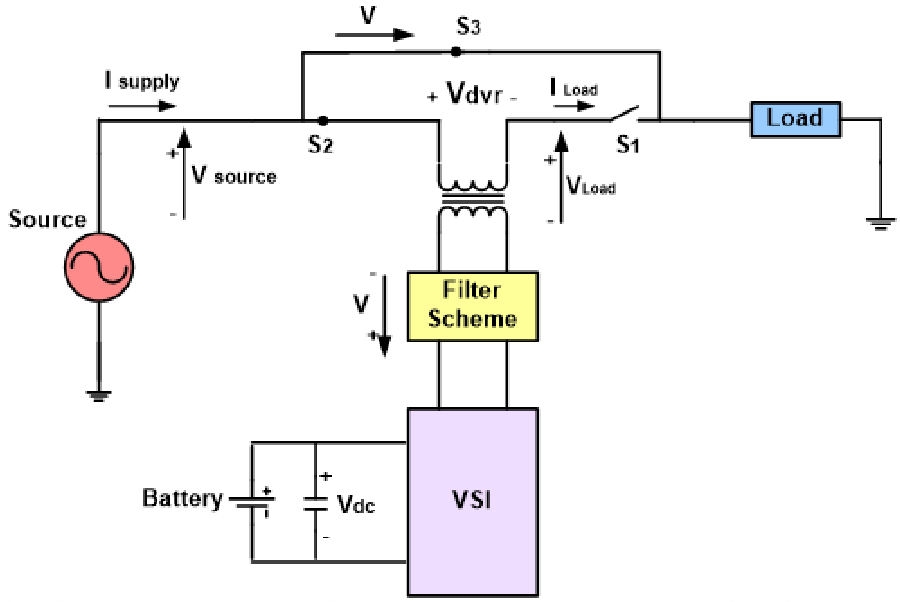


Figure 3.4: The configuration of DVR in standby mode [41].

3.4.2.3 Injection/ Boost mode: (V_{DVR}>0)

In this mode, if there any disturbance in electrical distribution networks such as harmonics, swell and sag, a DVR starts injecting three-phase controllable voltages of required phase angles and amplitudes via the boost transformer to maintain the load voltage in the desired waveform during voltage swell, harmonics and sag in the grid voltage [39], as shown in figure 3.5.

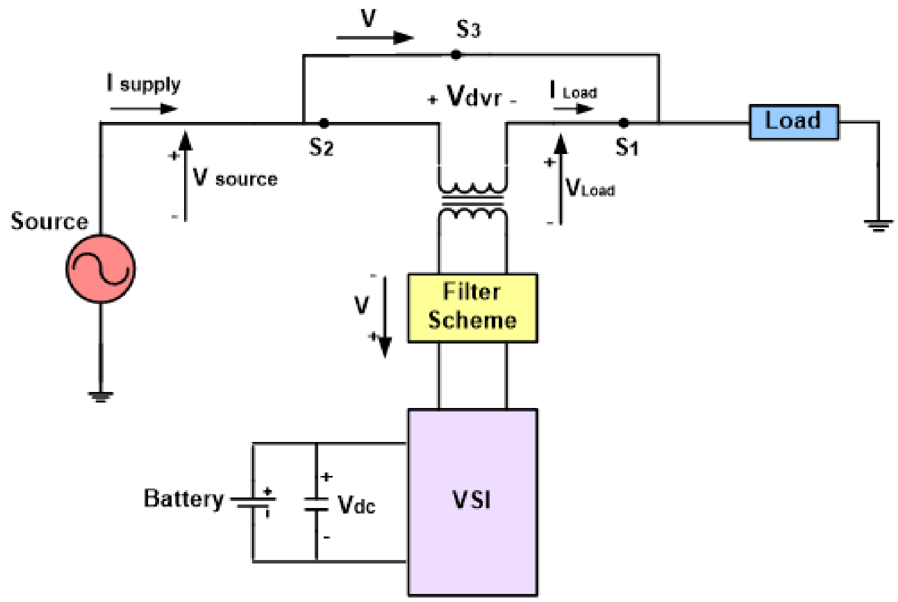


Figure 3.5: The configuration of DVR in Injection mode [41].

3.5 DVR Load Voltage Controllers

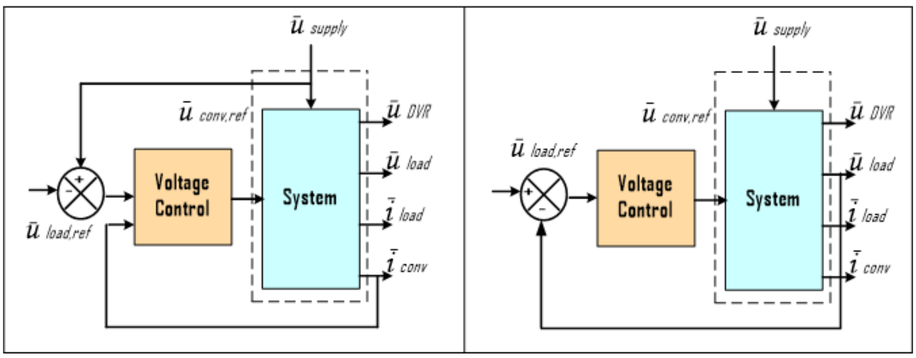
The control system in DVR is very important, as it detects the starting time, the depth and the end of disturbances, voltage references generation, steady and transient state of the injected voltage and protection of the system during disturbances by an appropriate detection algorithm which working in the real time.

The control must be vigorous to withstand to different types of disturbance from both the load side and supply side. In literature such as in [33, 37], various DVR device voltage controllers have been tested and described. These controllers are:

1. Feedforward voltage controller and
2. Feedback voltage controller and
3. Multi variable controller

The feedforward controller, for example, is described in [33, 40], as the dominant DVR voltage control method because of its robustness and very simplicity. In this control technique, the load voltage is not sensed and the voltage to be injected is calculated based on the difference between the pre-sag and during sags voltage. The principle of operation of the feedforward controller is illustrated in figure 3.6 (a).

In the feedback control, the load voltages are measured and are used as feedback loop. This technique faster and has a more correct response, only that the voltage controller is very complex in nature and it depends on the load connected. The principle in feedback controller is shown in figure 3.6 (b) with the load voltage used as the feedback signals. In this technique, the controller current is not used, because voltage controller handles the voltage drop in the line filter. But still the supply voltage is measured in order to detect the disturbance.



(a) (b)

Figure 3.6: (a) Feedforward control and (b) Feedback control.

In [37], multi variable is used with an inner current loop to control the current in the filter capacitor and an outer voltage loop to control the DVR voltage. It is reported as a fast method and very robust.

3.6 DVR System Topology

Various DVRs topologies have been proposed in the past by different researchers. The topologies of DVR with the storage element and with no energy storage element have been discussed in [37]. In some scheme, the DVR is equipped with energy storage element (supercapacitor, battery, etc.) to supply real power to the system in other to compensate voltage imbalance or to obtained required compensation power during voltage disturbance [42, 43]. The topologies with energy storage base have the advantage of injecting the stored energy to the faulted supply. The energy storage element is costly and this partially limits its application. Moreover, the energy storage elements have limited capacity and sometimes the device may fail to operate or malfunction in the occurrence of long-term disturbances. On the other hand, due to the absence of storage element, the DVRs with no storage element have less weight, less cost, less volume and can mitigate voltage disturbances for a long interval of time due to the energy required to compensate is obtained directly from the faulty network [15]. Nowadays various types of energy storage are integrated into the DVR available in the market, this include [44, 45];

1. Photovoltaic
2. Flywheels
3. Magnetic energy storage
4. Lead acid and batteries
5. Super-capacitor

CHAPTER FOUR

METHODOLOGY

4.1 Introduction

'In this chapter, a detailed discussion of the method used in the modeling process of the Dynamic Voltage Restorer system and other components associated with it is described. It includes the modeling of a three-phase radial network that can be used to test the performance of the DVR system, the design of the DVR and it controller and which includes;

1. Design a three-phase electrical network in an area selected from Iraqi electrical networks for power quality analysis.
2. To design a suitable controller for a DVR device, which allows the device to work in normal and abnormal conditions.
3. Design of a DVR and link it to the grid of three-phase from the Iraqi distribution grids to compensate and mitigate the various types of power quality problems that occur in this grid

4.2 Modeling of Three-Phase Supply System

The supply system in this thesis is modeled as an ideal three phases, with a voltage supply of 132 KV, 50Hz frequency. The length of the transmission line is 70 km and then step down to 33 KV by a three-phase transformer (Three windings). Then a transmission line with a length of 9 km 33 KV after that step down to 11 KV by a three-phase transformer (Three windings) and to feed two transmission lines as shown in figure 4.5.

Through testing the capability of the proposed DVR system in improving the voltage quality during power quality disturbance for different types of event, a short circuit fault is injected like voltage sag to get on a wave free of any distortion in the load terminal as in figure 4.6. These short circuit faults considered are a single line to ground (L-G) fault, line to line (L-L) fault, double line to ground (DL-G) fault, three-phases fault and three-phase to ground (3P-G) fault all through some of the resistances fault (0.8Ω and 2Ω). The DVR device has been tested on these values of the fault resistances. These faults will equally create three-phase voltage sag, single-line voltage sags, double-line voltage sags, three-phases voltage sags, swells, interruption, harmonics and voltage unbalance in Iraqi networks.

4.3 Modelling of the Loads

In order to test the performance of DVR device and potential problems, both linear load and nonlinear are to be considered as shown in figure (4.5 and 4.7) respectively. For the linear load, the load used are inductive/resistive/capacitive loads, while nonlinear load is modeled using diode rectifier with a 6-pulse connected to an inductor.

4.4 Power Circuit of the DVR Device

The power circuit of DVR consists of four (4) components as shown in figure 4.1, namely: injection transformer, filter, series converter, energy storage. The modeling of each of these components is described in the following section in details.

As shown in figure 4.1, for each phase of the line, a two-winding linear transformer is used, with a voltage ratio of 11/700 kV. The winding of the linear transformer to the converter is designated as the secondary while the winding connected to the supply side is designated as the primary.

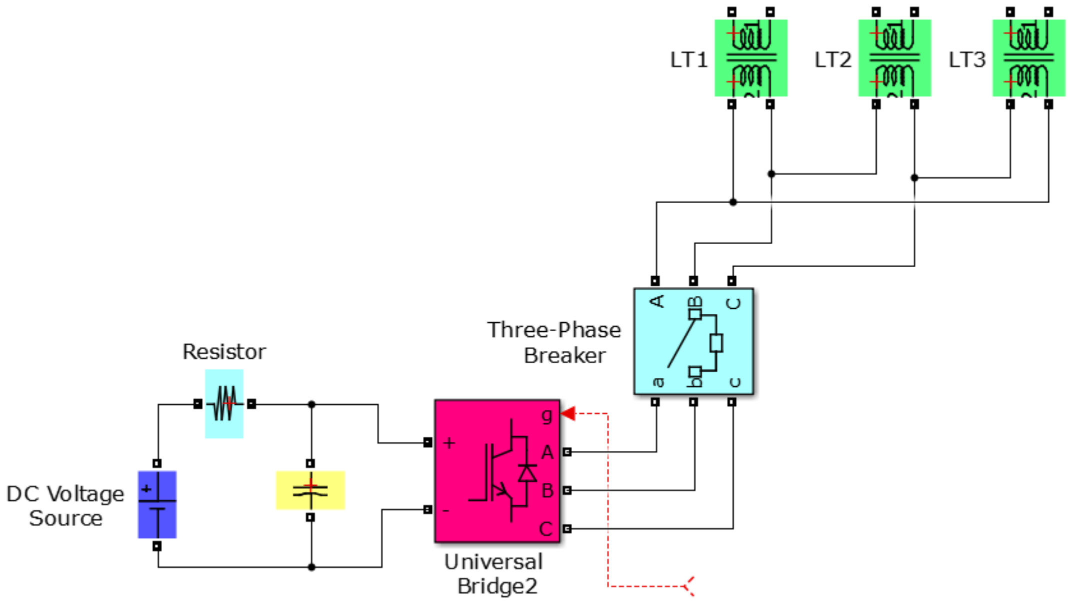


Figure 4.1: Simulink diagram of DVR device power circuit.

A regulated constant DC supply source is used as the storage element and a three-single phase universal bridge PWM inverters are used in the series converter circuit as shown in figure 4.1. The VSI is relatively high in current and low in voltage due to the presence of a step-up injection transformer. The parameter of the system is provided in Table 4.1.

Table 4.1: System parameters.

No	System Quantities	Standards
1	Load 1 = Load 2	**P**=30kW, **Q_L**= 100VAR **Q_C** =100VAR
2	Transmission line Parameter	**L**=0.0005E-3 **R**=1Ω
3	Specification of Inverter	3arms IGBT based, 6 pulses, Sample Time=5μs, Carrier frequency=1080Hz
4	PI Controller	Sample time = 50μs, **K_p** = 0.5, **K_I** = 50
5	DC Link Voltage	110V

4.5 Calculation of Voltage injected by DVR

In figure 4.2, the left side circuit of the DVR represents the equivalent Thevenin circuit of the electrical network. When voltage unbalances occur, DVR injects the desired voltage through an injection transformer to maintain a constant voltage profile. Z_{th} is the equivalent system impedance whose value depends on the fault type;

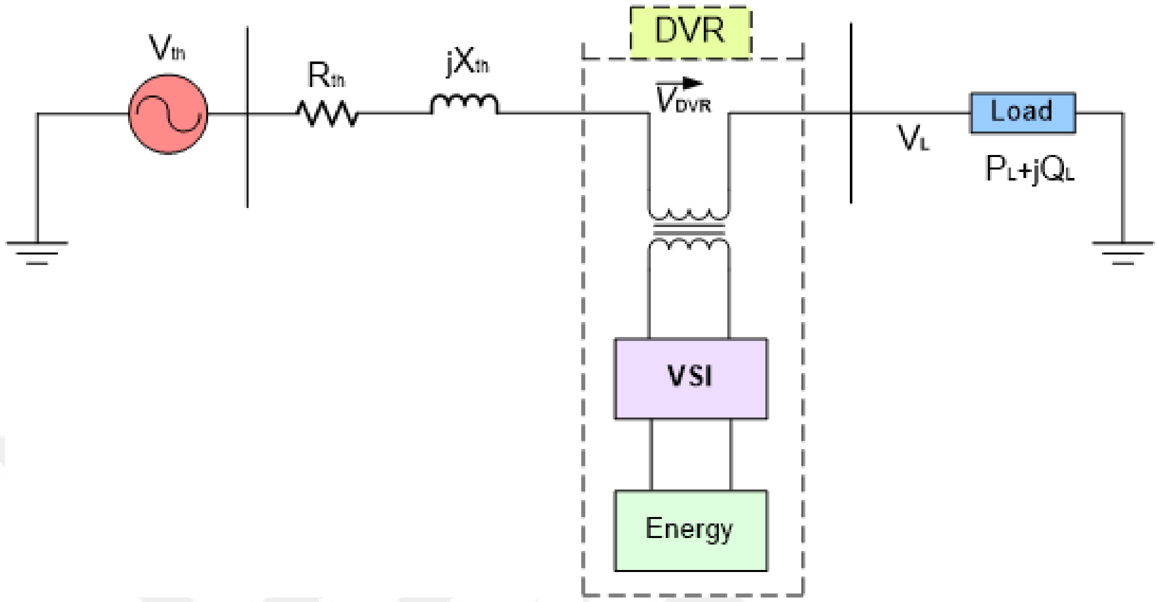


Figure 4.2: Schematic diagram of DVR device.

The series voltage injected of the DVR can be written as,

$$V_L = V_{th} - Z_{th} I_L + V_{DVR} \tag{4.1}$$

$$V_{DVR} + V_{th} = V_L + Z_{th} I_L \tag{4.2}$$

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \tag{4.3}$$

$$Z_{th} = R_{th} + jX_{th} \tag{4.4}$$

Where;

V_{th} = Equivalent Thevenin voltage of the system

V_L = Load voltage

Z_{th} = Equivalent Thevenin impedance of the system

I_L = Load current and

$$I_L = \left[\frac{P_L + jQ_L}{V_L} \right] \tag{4.5}$$

Taking I_L = as reference, equation (4.3) can be rephrase as

$$V_{DVR}\angle\alpha = V_L\angle 0^0 + Z_{th}I_L\angle(\beta-\phi) - V_{th}\angle\delta \tag{4.6}$$

Where, α = angle of V_{DVR}

β = angle of system impedance Z_{th}

δ = angle of system voltage V_{th}

ϕ = Load power angle and

$$\phi = \tan^{-1}\left(\frac{Q_L}{P_L}\right) \tag{4.7}$$

The complex power injected by DVR is

$$S_{DVR} = V_{DVR}I_L \tag{4.8}$$

4.6 Compensation Techniques

There are two different strategies are normally used for swell/sag compensation which is as follows;

a) Pre-sag compensation method

b) In-phase compensation method

4.6.1 Pre-Sag Compensation Method

In this compensation technique, the magnitude and the phase angle both are compensated. The DVR injected voltage is the difference between the sag and pre-sag voltage and restores the voltage magnitude and the phase angle to the nominal pre-sag condition as shown in figure 4.3.

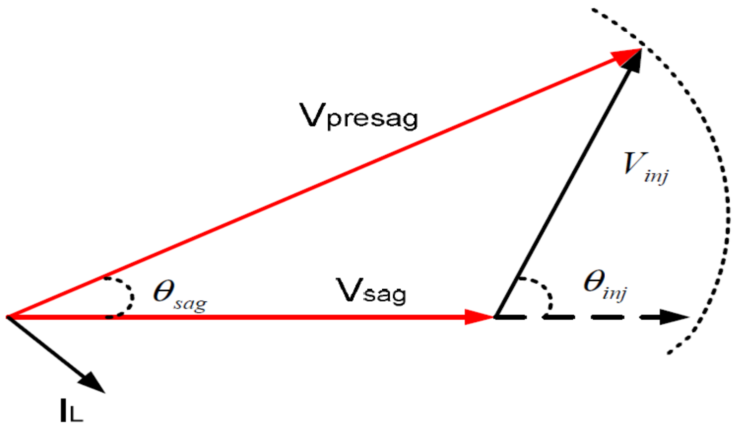


Figure 4.3: Pre- sag compensation technique.

The voltage V_{inj} and phase angle θ_{inj} to be compensated can be calculated as given by this equation;

$$V_{inj} = \sqrt{V_{sag}^2 + V_{presag}^2 - 2V_{sag}V_{presag}\cos\theta_{sag}} \tag{4.9}$$

Another method to calculate the V_{inj} by using this equation;

$$|V_{inj}| = |V_{presag}| - |V_{sag}| \tag{4.10}$$

$$\theta_{inj} = \tan^{-1}\frac{V_{presag}\sin\theta_{presag}}{V_{presag}\cos\theta_{presag} - V_{sag}\cos\theta_{sag}} \tag{4.11}$$

$$V_{inj} = V_{presag} - V_{sag} \tag{4.12}$$

4.6.2 In-Phase Compensation Method

This method is very helpful over the pre-sag method because it can compensate any kind of voltage sag regardless of unbalanced voltage drop or unbalanced phase jump. In this compensation technique, only the voltage magnitude is compensated. V_{DVR} is in-phase with the left-hand side voltage of DVR as shown in the figure. The injected voltage is in-phase with supply voltage, as shown in figure 4.4.

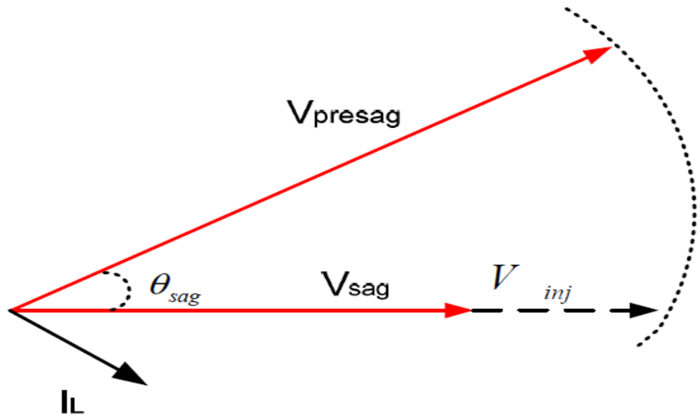


Figure 4.4: In-phase compensation technique.

This method is very simple for implementation and very fast to calculating the DVR compensation voltage, which is calculated by this equation;

$$V_{dvr} = V_{inj} \angle \theta_{inj} \quad (4.13)$$

$$|V_{inj}| = |V_{presag}| - |V_{sag}| \quad (4.14)$$

$$\theta_{inj} = \theta_{sag} \quad (4.15)$$

$$V_{inj} = V_{presag} - V_{sag} \quad (4.16)$$

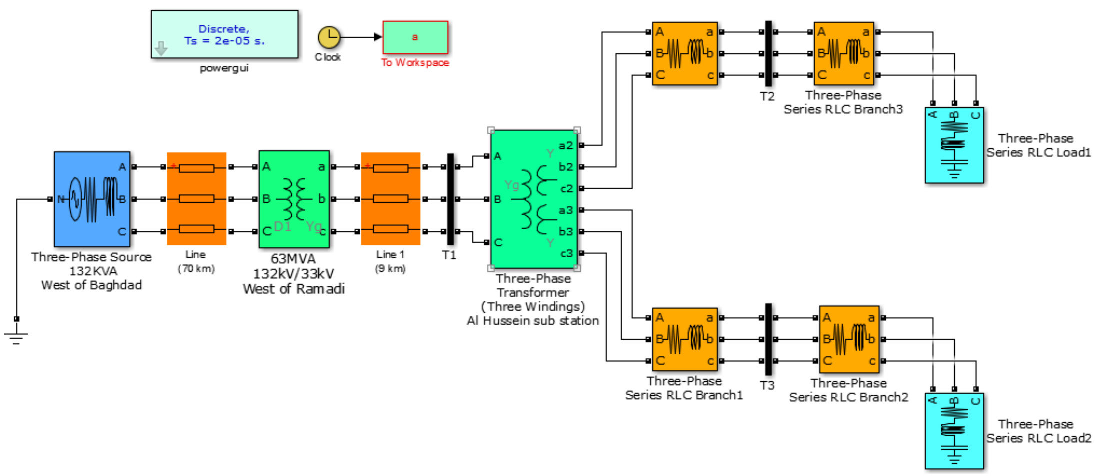


Figure 4.5: Simulink block diagram of the 3-phase supply system with linear load connected.

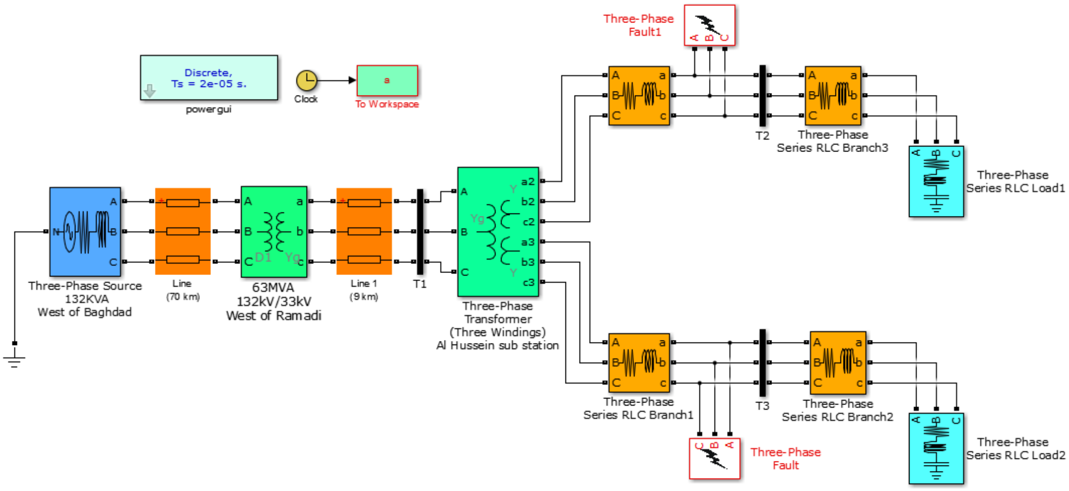


Figure 4.6: Simulink block diagram of the 3-phase supply system with faults in both the two transmission lines.

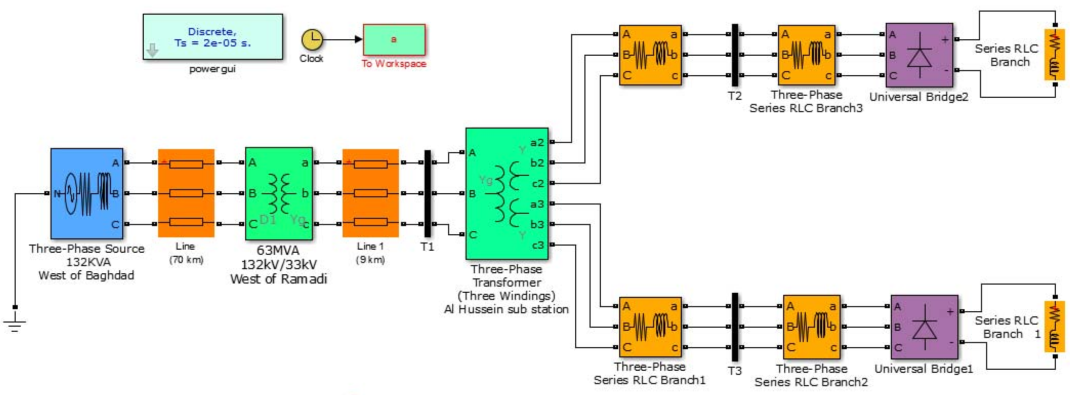


Figure 4.7: Simulink block diagram of the three-phase supply system with nonlinear load connected.

4.7 Proposed Control Philosophy for the DVR

The configuration of the proposed design is depicted in figure 4.10 linear loads and figure 4.11 nonlinear loads. During voltage disturbance, the DVR detects the power quality disturbances by sensing the load voltage and passed it through a discrete sequence analyzer as shown in figure 4.8. The sequence analyzer now compares the magnitude of the load voltage and the reference voltage (V_{ref}). The errors obtain due to the comparison of the reference voltage and the load voltage is processed by a Proportional Integral (PI) controller, which is just after the sequence analyser also depicted in figure 4.8.

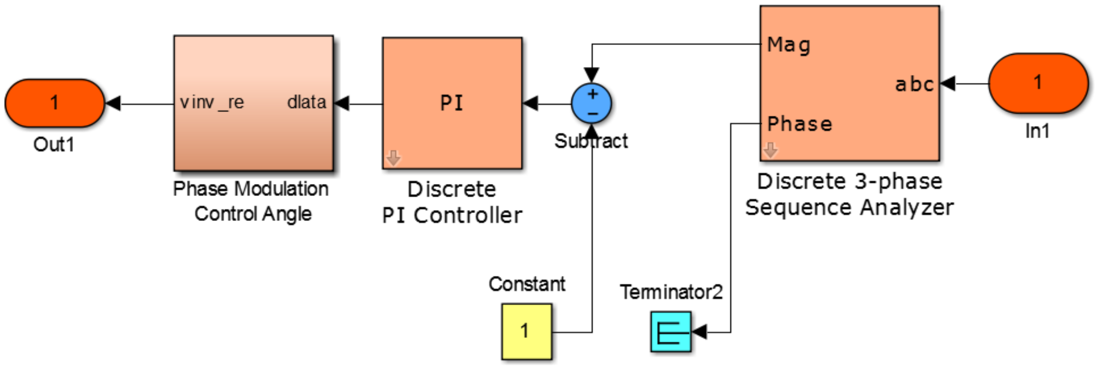


Figure 4.8: Simulation model of DVR controller.

The Proportional Integral (PI) controller now drives and controlled the plant with the sum of error obtained (difference with the load voltage sensed and the reference voltage) and the integral value. The input of the PI controller is an actuating which is the error (the difference between reference V_{ref} and the terminal voltage). Such kind of error is processed by the PI controller and gives an output of angle δ.

The modulated angle **δ** from the output of the PI controller is applied to the PWM generators in phase A as presented in equation 4.17, while the angle of phase B and C are shifted by 120º and 240° as presented in equation 4.18 and 4.19, respectively. Therefore, in this PI controller, only voltage the voltage magnitude is taken as feedback parameter in the control scheme.

$$V_a = \sin(\omega t + \delta) \quad (4.17)$$

$$V_b = \sin(\omega t + \delta + 2\pi/3) \quad (4.18)$$

$$V_c = \sin(\omega t + \delta + 4\pi/3) \quad (4.19)$$

The sinusoidal signal $V_{control}$ is phase modulated by means of the angle δ as shown in figure 4.9. And the modulated three phase voltages are given equation 4.17, 4.18 and 4.19 respectively.

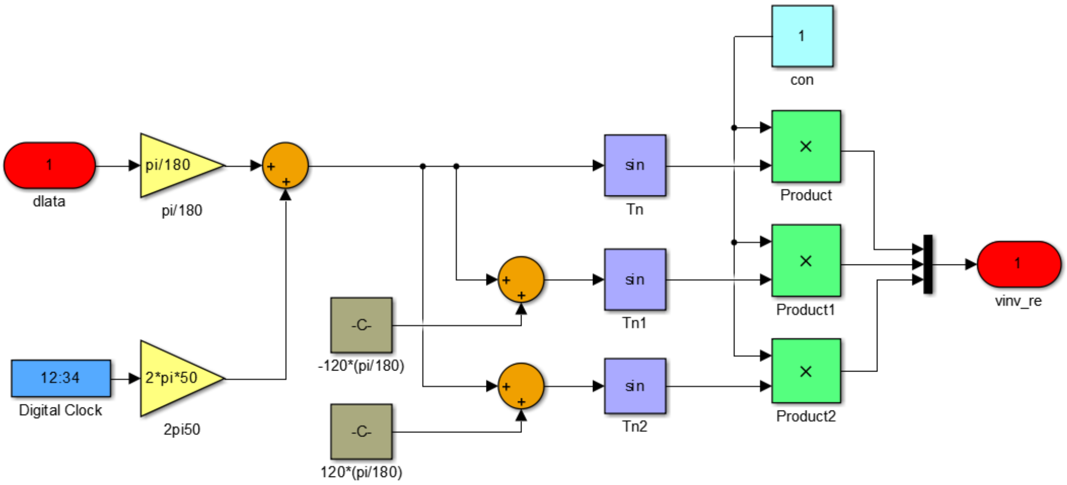


Figure 4.9: Phase modulation of the control angle δ.

To generate the required switching single for the VSC valve by the PWM generator, the sinusoidal signal $V_{control}$ is then compared against a triangular signal. The frequency modulation index (M_f) of the carrier signal and the amplitude modulation index (M_a) are the main parameters required for the sinusoidal PWM scheme. And, in order to obtain the highest fundamental voltage component at the output of the controller, the amplitude modulation index (M_a) is kept fixed at 1P.U.

$$M_a = \frac{V_{control}}{V_{tri}} = 1P.U \tag{4.20}$$

Where;

$V_{control}$ = The peak amplitude of the signal.

V_{tri} = The peak amplitude of the triangular signal.

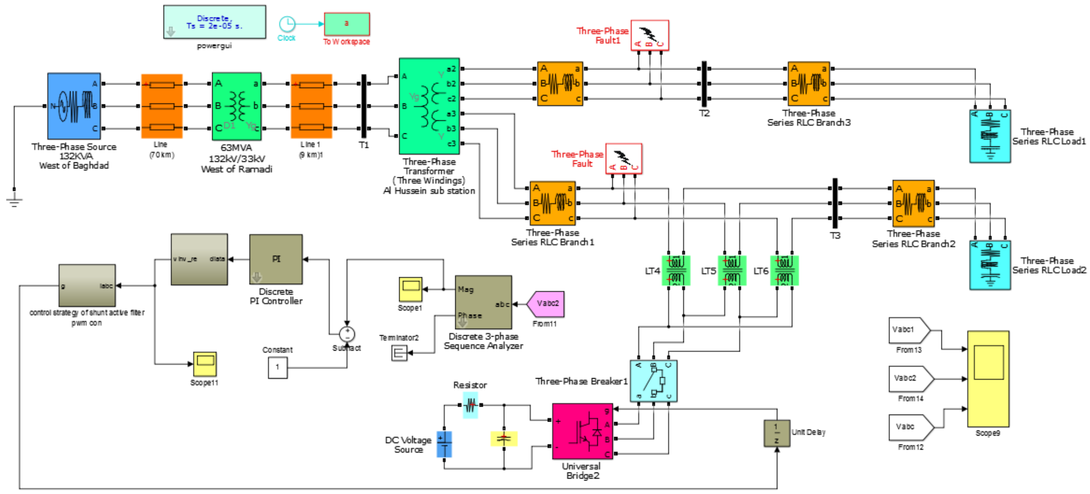


Figure 4.10: MATLAB/Simulink configuration of the proposed DVR design mode with linear load connection.

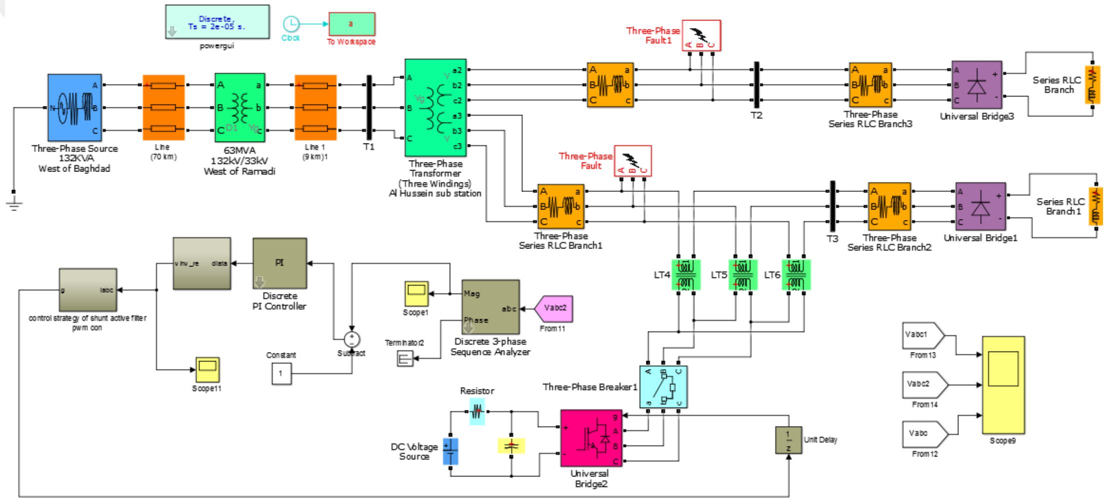


Figure 4.11: MATLAB/Simulink configuration of the proposed DVR design mode with nonlinear load connection.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter, several simulations are carried out to verify the performance of the DVR designed for different types of disturbance and been tested under different load conditions so as to fully investigate it performance.

Simulation is carried out for network with linear load connected and for a network with nonlinear load connected. All the results obtained have been discussed in detail. The system runs at 50 Hz frequency and sample time is chosen to be 80 ms The total period of simulation in each case is 0.2s.

5.2 Simulation of Electrical Grid With Linear Loads

The first case presented is the simulation of the three-phase radial network in the absence of faults in the system, and in this case, the three phase voltages are in balance condition and the waveform is a pure sinusoidal sine wave and the DVR system is said to be in a standby mode. As shown in figure 5.1. Power quality problems are detected by sensing the voltage at the point of common coupling (PPC) during fault period.

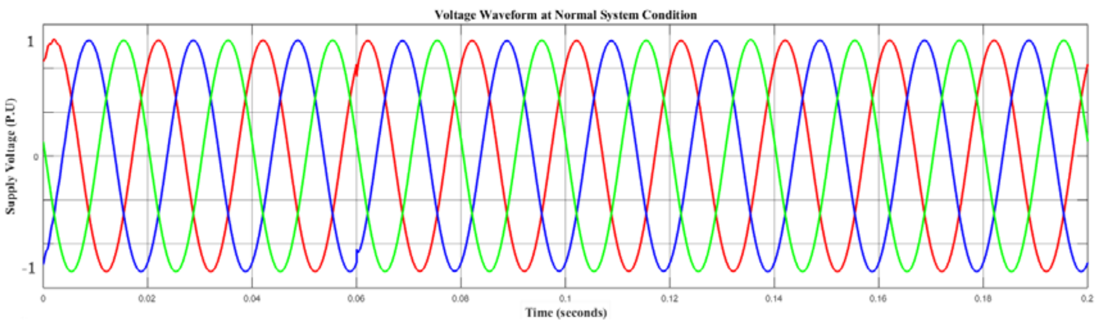


Figure 5.1: Voltage waveform at the normal system condition (without fault).

Simulation is again carried out in the presence of a three-phase fault, double line to ground fault and single line to ground fault via a fault resistance of 0.8Ω which initiate 75% voltage sag in the supply voltage for all the three types of fault as shown in figures 5.2, 5.3 and 5.4 parts (a) respectively.

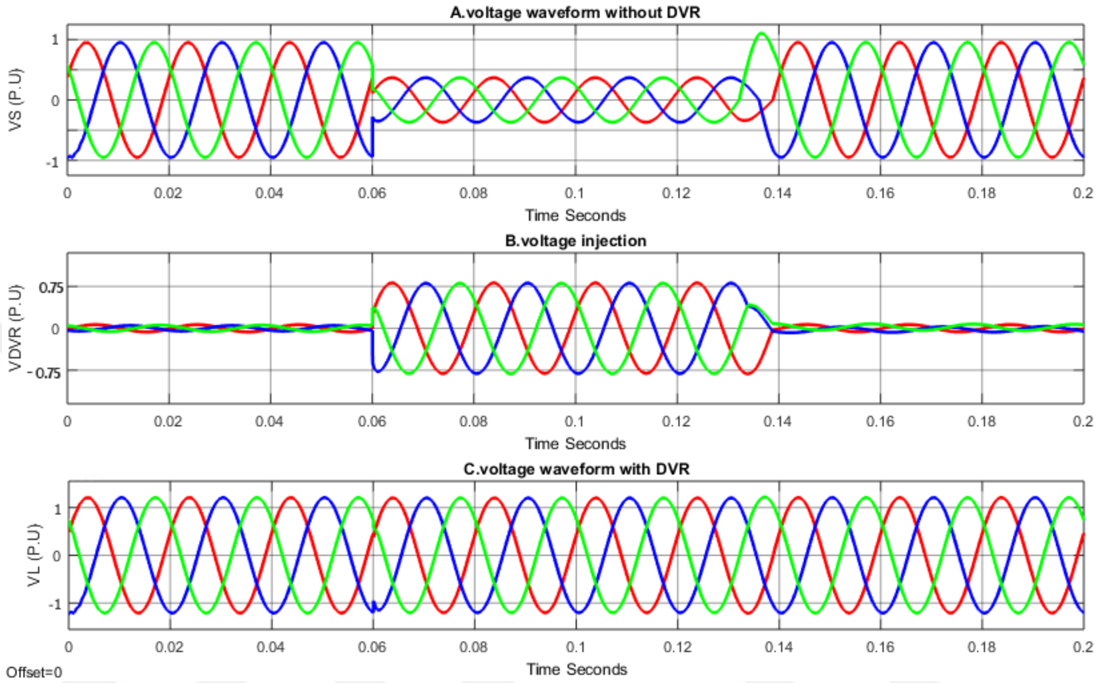


Figure 5.2: Three phase voltage sags.

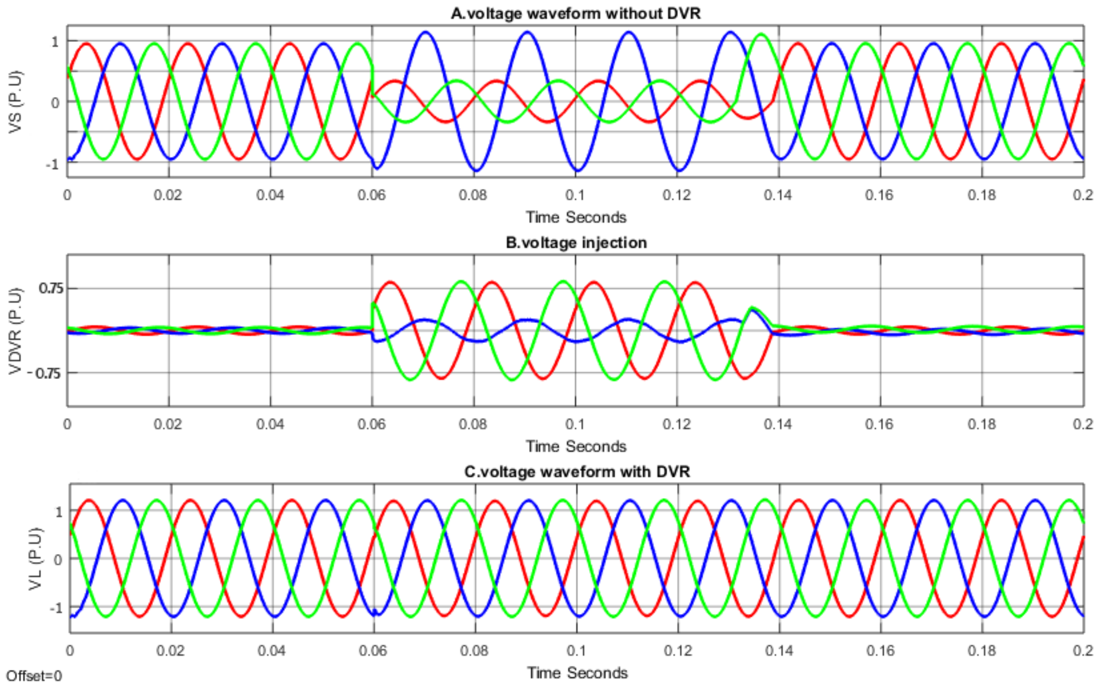


Figure 5.3: Double phase voltage sags and phase voltage swell.

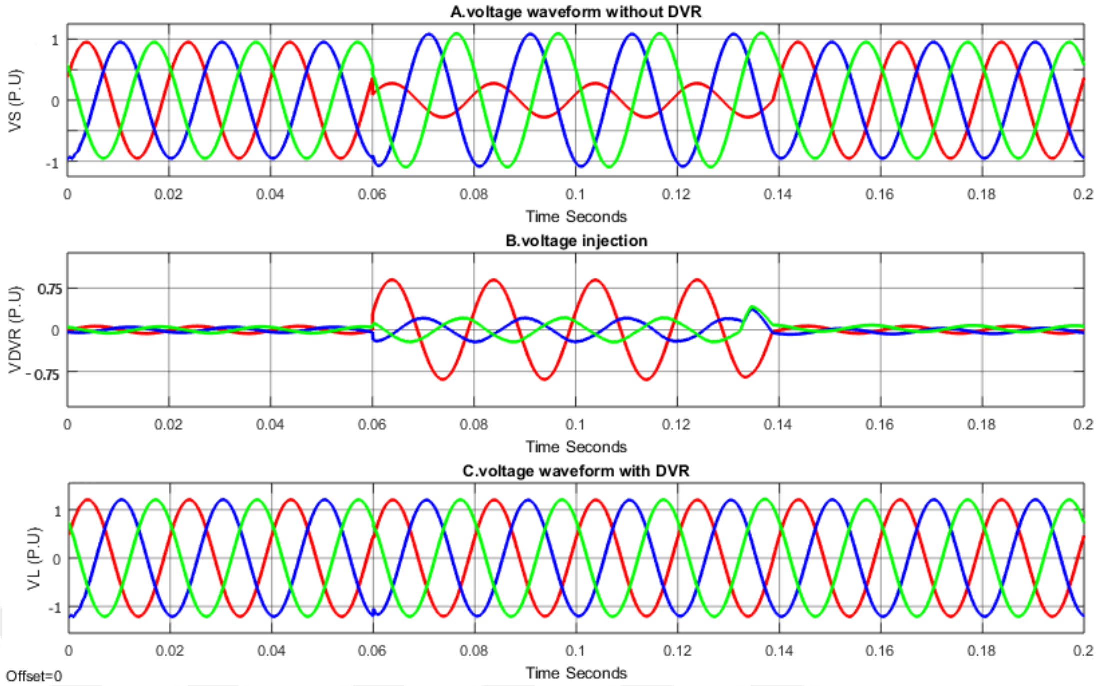


Figure 5.4: Phase voltage sag and double phase voltage swell.

In all the cases shown in figures 5.2, 5.3 and 5.4, part (a) voltage sag was introduced at time 0.06 seconds and it is kept up to 0.14 seconds with voltage sag duration of 80 ms Figures 5.2, 5.3, 5.4 parts (b) show the voltage injected to mitigate the missing supply. While figures 5.2, 5.3 and 5.4 parts (c) show the resultant load voltage after compensation.

It is clearly seen from the result presented in figures 5.2, 5.3 and 5.4, that after compensation, the load voltage returns to its normal 1 P.U as shown in figure 5.1. This is an indication that the control scheme design for the DVR is good since it can serve the purpose for which it is designed.

Nevertheless, the double phase sags and single-phase sags shown in figures 5.3 and 5.4 are both classified as unbalanced voltage sags. This occurs when one phase or two phases of a three voltage drops down to about 30%, while the other phases remaining swells up as clearly shown in figures 5.3 and 5.4.

In figures 5.5, 5.6 and 5.7 the simulation is again carried out in the presence of a three-phase fault, double line to ground fault and single line to ground fault via a fault resistance of 2Ω which initiate 50% voltage sag in the supply voltage for all the three types of fault as shown in figures 5.5, 5.6 and 5.7 parts (a) respectively.

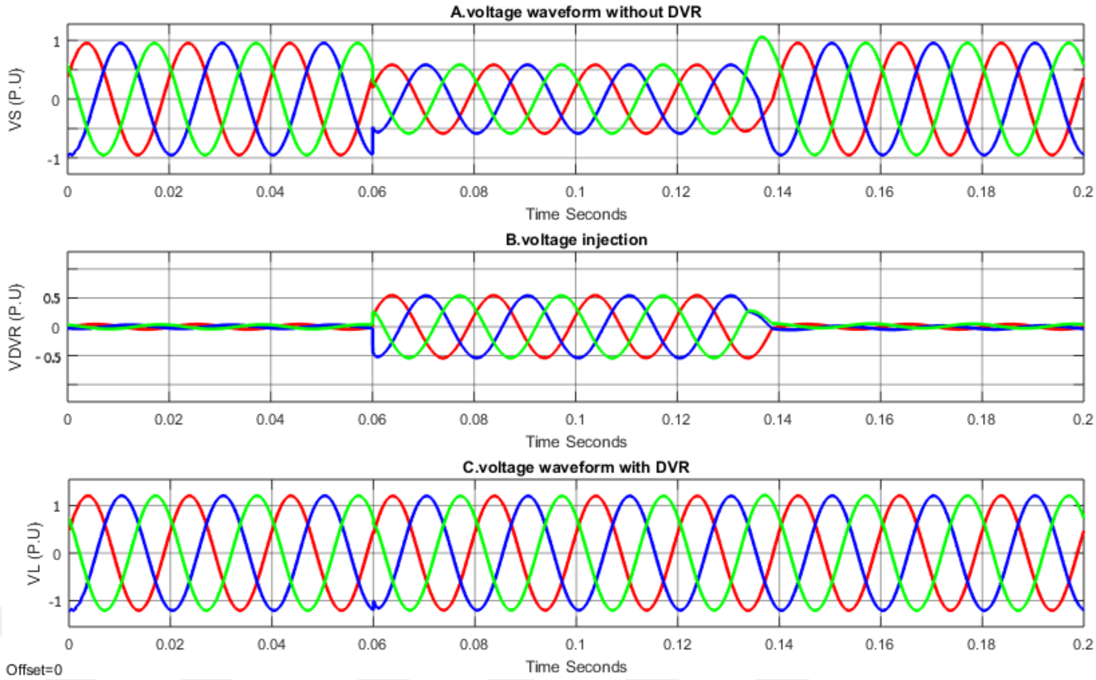


Figure 5.5: Three phase voltage sags.

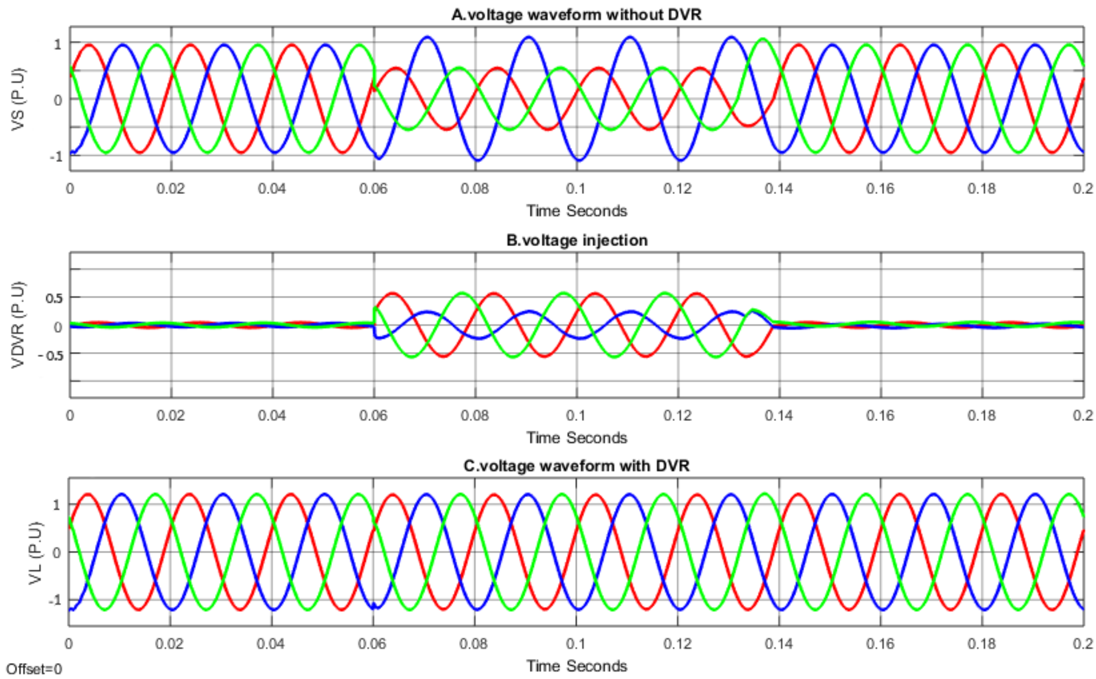


Figure 5.6: Double phase voltage sags and phase voltage swell.

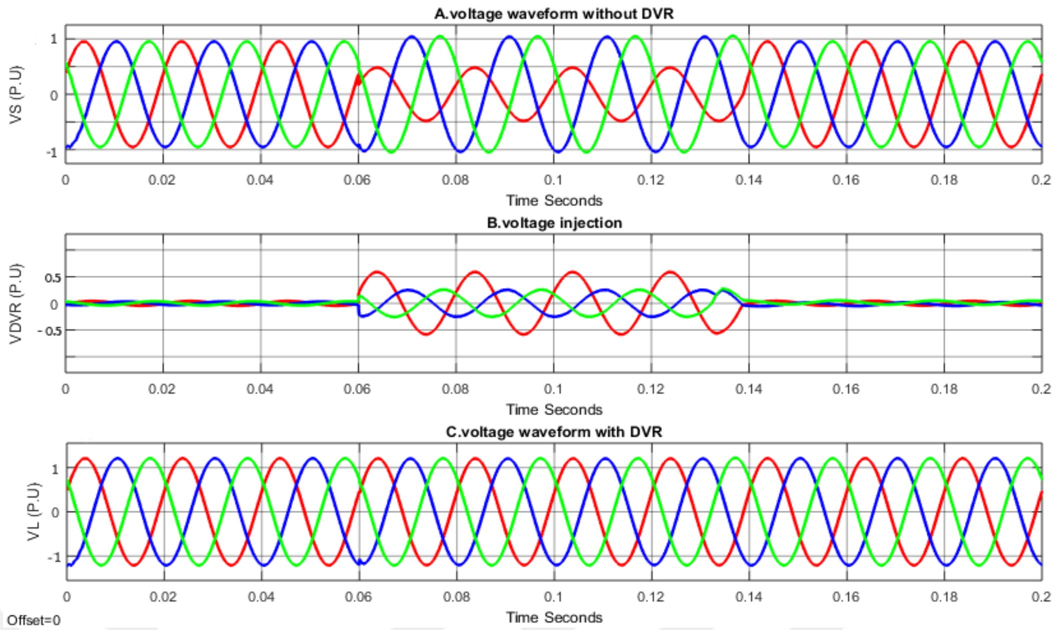


Figure 5.7: Phase voltage sag and double phase voltage swell.

In this case, as shown in figures 5.5, 5.6 and 5.7 parts (a) voltage sag was introduced at a time from 0.06 seconds to 0.14 seconds with voltage sag duration of 80 ms Figures 5.5, 5.6, 5.7 parts (b) shows the voltage injected to mitigate the missing part of the supply voltage. While figures 5.5, 5.6 and 5.7 parts (c) show the resultant load voltage after compensation.

It is seen from the results presented in figures 5.5, 5.6 and 5.7, that after compensation, the load voltage returns to its normal 1 P.U as shown in figure 5.1. This is an indication that the control scheme design for the DVR is good since it can serve the purpose for which it is designed.

With that, the double phase sags and single-phase sags shown in figures 5.6 and 5.7 are both classified as unbalanced voltage sags. This occurs when one phase or two phases of a three voltage drops down to about 30%, while the other phases remaining swells up as clearly shown in figures 5.6 and 5.7.

Figures 5.8, 5.9 and 5.10 shows the operation and performance of the DVR during interruption in the system, i.e. that is a complete loss of supply also with a duration of 80 ms, from 0.06 seconds to 0.14 seconds. Simulation is again carried out in the presence of 3-phase interruption, DL-G interruption and L-G interruption via a fault resistance of 0.01Ω. voltage for all the three types of fault as shown in figures 5.8, 5.9 and 5.10 parts (a) respectively. Figures 5.8, 5.9 and 5.10 parts (b) shows the shape of the voltage injection wave of the DVR. Figures 5.8, 5.9 and 5.10 parts (c) shows the voltage waveform with the DVR at the sensitive load's side (after compensation).

It is seen from the results presented in figures 5.8, 5.9 and 5.10, that after compensation, the load voltage returns to its normal 1 P.U as shown in figure 5.1.

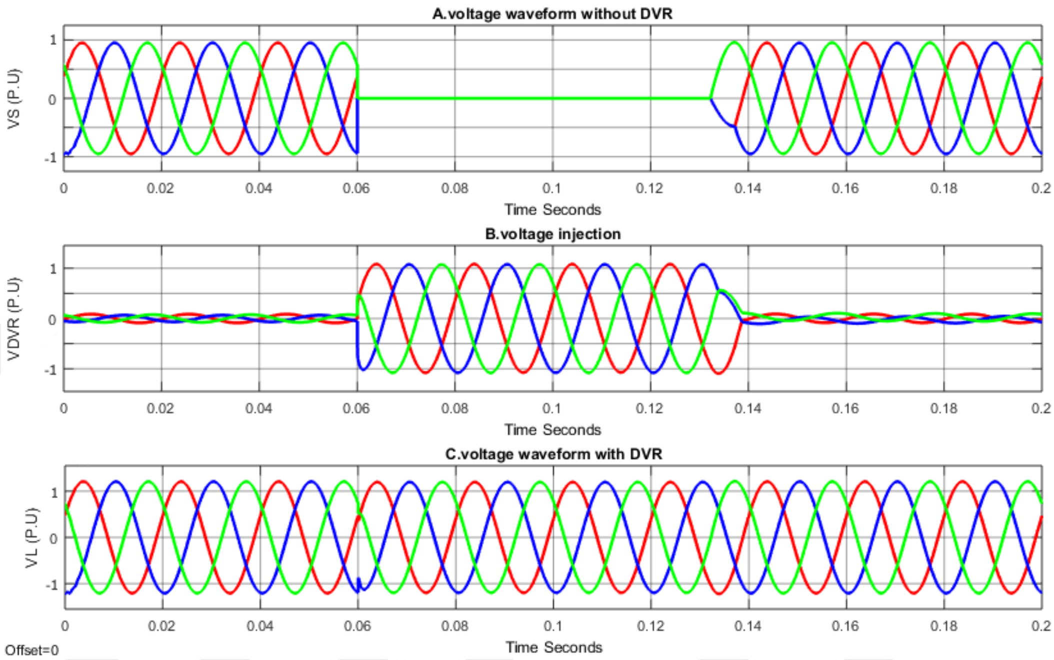


Figure 5.8: Three phase voltage interruption.

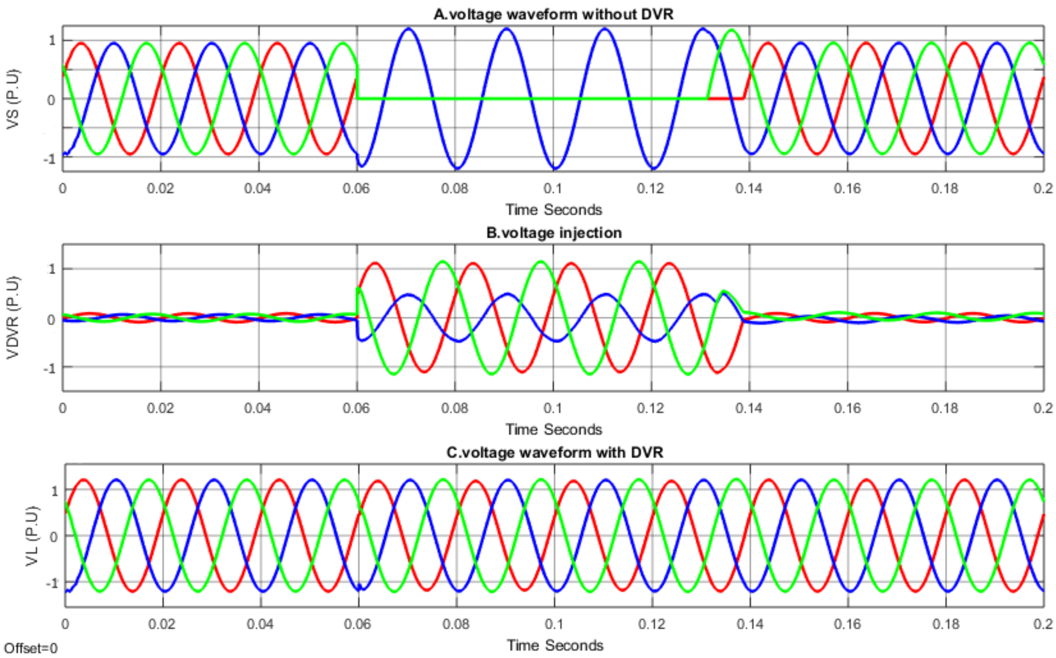


Figure 5.9: Double phase voltage interruption and phase voltage swell.

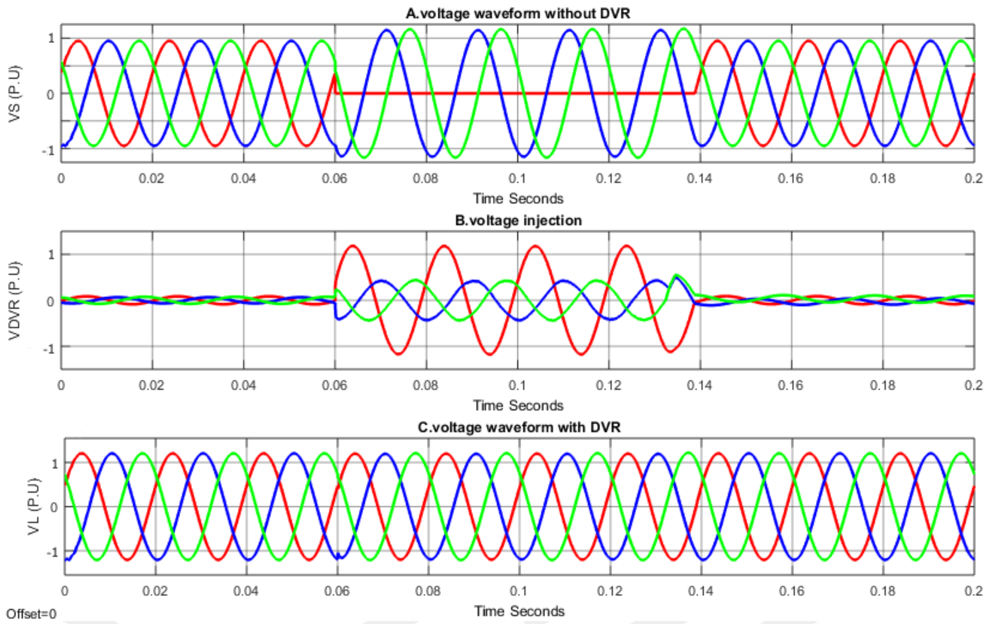


Figure 5.10: Phase voltage interruption and double phase voltage swell.

Figure 5.11 shows the operation and performance of the DVR during line-line (L-L) in the system, i.e. that is a loss two-phases of Three-phases voltage supply (Vs) also with a duration of 80 ms. Also in figure 5.11part (a) shows the supply voltage with a line-line (L-L) interruption for the period from 0.06 to 0.14 milliseconds, part (b) shows shape voltage injection waves of the DVR, part (c) shows the voltage waveform with the DVR at the voltage loads (after compensation).

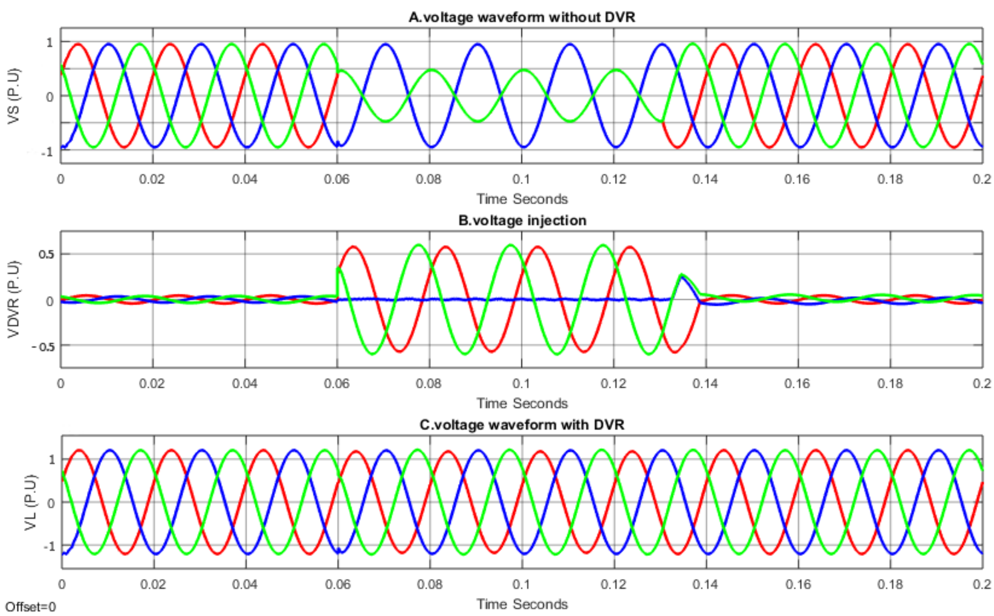


Figure 5.11: Phase-Phase voltage fault.

It is also important to determine the response of the DC link current and voltage during the starting of the fault to its end. This is very important because the DVR depends only on the DC voltage, as the injection voltage during sag is obtained from it. And in some cases, if the DC link voltage continues to decrease without in the presence of sag, the load voltage cannot be fully maintained.

The response of the DC-link voltage with respect to the three types of sags namely three phase sags, double phase sags and single-phase sags can be seen is in figures 5.12, 5.13 and 5.14. As can be seen in all the three-sag scenario, before the occurrence of sag, the DC-link voltage is fully charged the rated supply voltage. But at time 0.60s to 0.14s which is the beginning and ending of sag, power is taken solely from the DC-link capacitor.

As can be seen in figures 5.12, 5.13 and 5.14, the decay of power in the DC-link voltage is higher during three phase and double phase when compared to single phase sag. This is because three-phase sags and double phase sags are more severe than single phase sags. For the single-phase sag, only a small amount of power is absorbed as shown in figure 5.14.

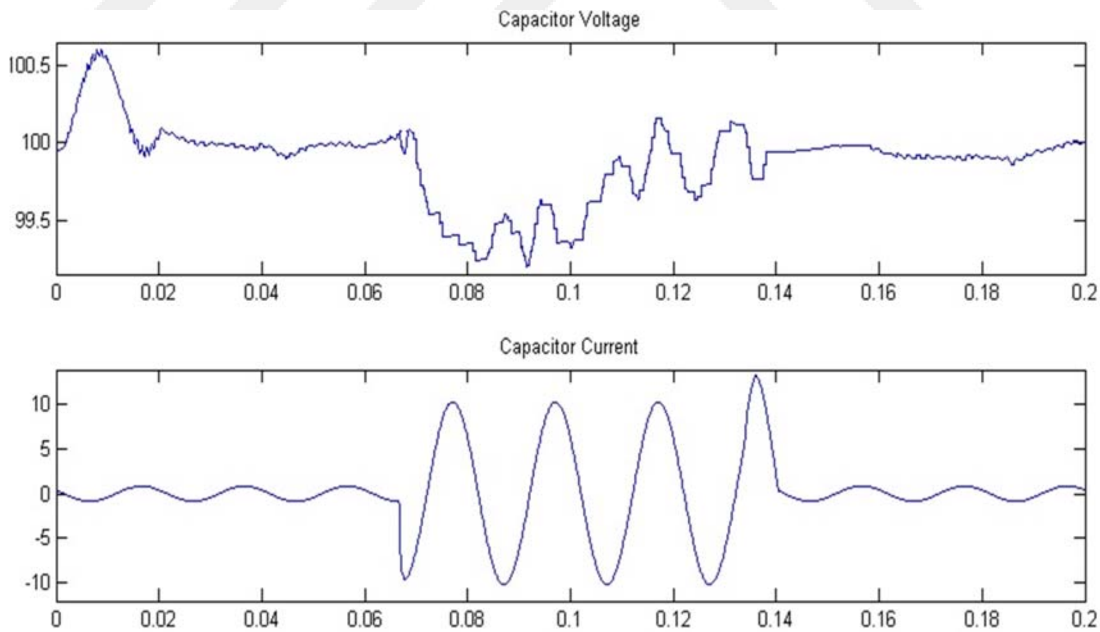


Figure 5.12: DC link current and voltage during 3-phase voltage sag.

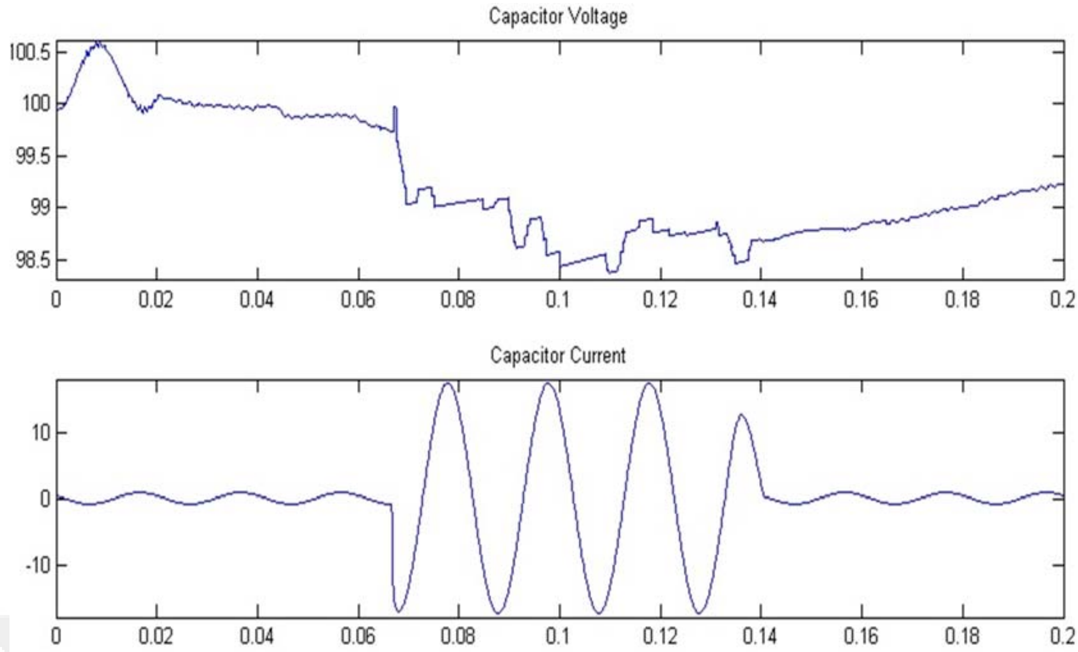


Figure 5.13: DC link current and voltage during double line (DL) voltage sag.

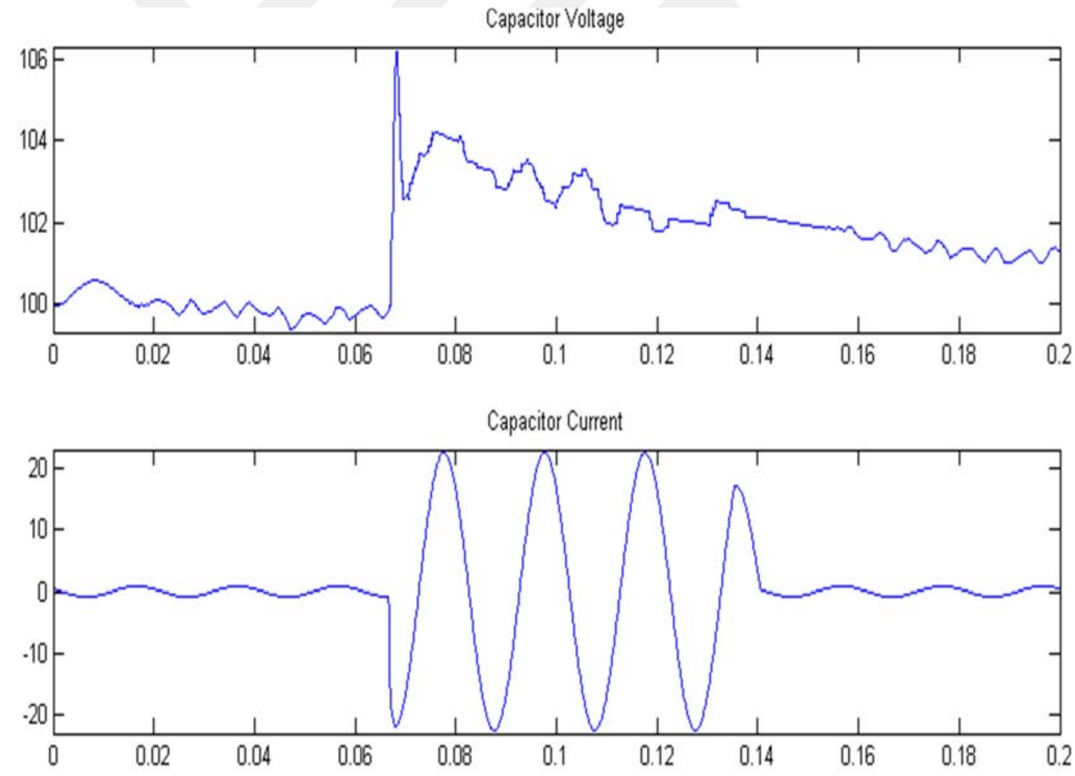


Figure 5.14: DC link current and voltage during single line (SL) voltage sag.

Fast Fourier Transform (FFT) analysis of the output voltage at the connected load has been done without and with a capacitor as shown in figures 5.15, 4.16 and 5.17.

In the figures 5.15, 5.16 and 5.17 shows the Total Harmonic Distortion (THD) for the voltage in the case of three-phase to ground (3P-G) fault, double line to ground (DL-G) fault and phase to ground (L-G) fault are 9.97%, 9,87% and 10.0% respectively. But when a DVR is placed in each of the cases, the THD value decreases to 2.81%, 2.51% and 2.10% respectively. Thus, as can be seen in each of the cases, the harmonic voltage is significantly reduced.

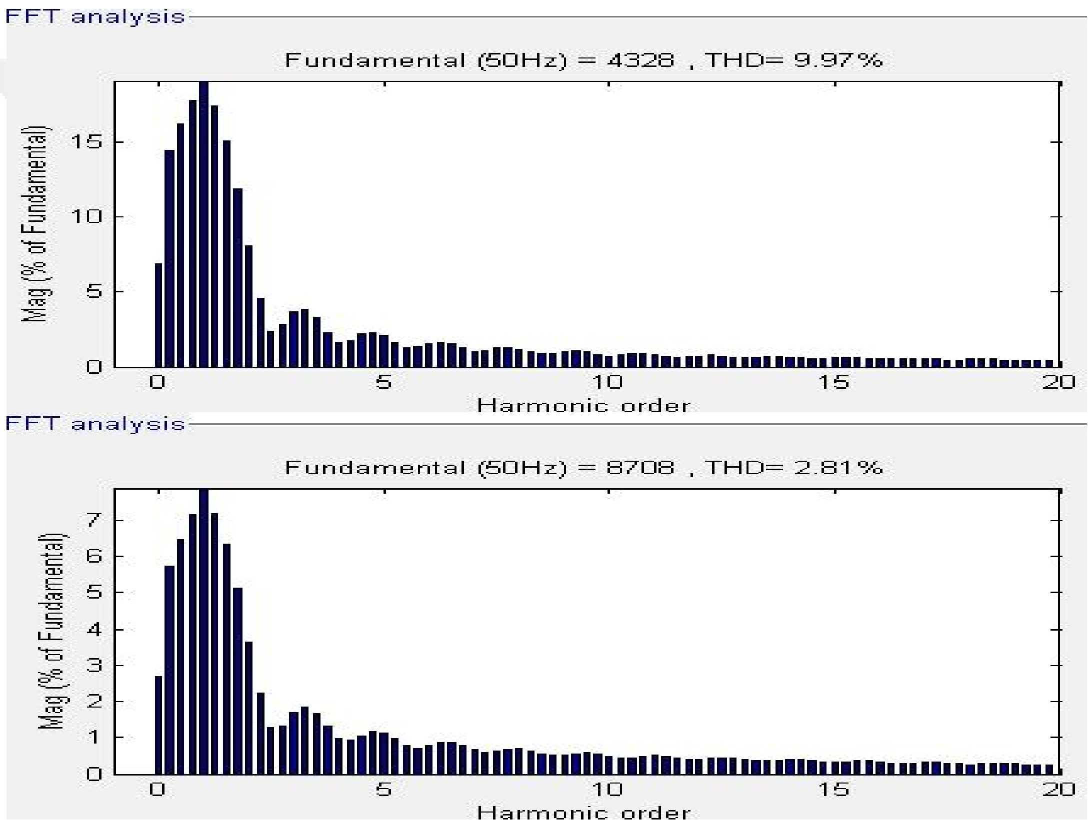


Figure 5.15: Harmonic voltage without and with DVR during 3-phase voltage sag.

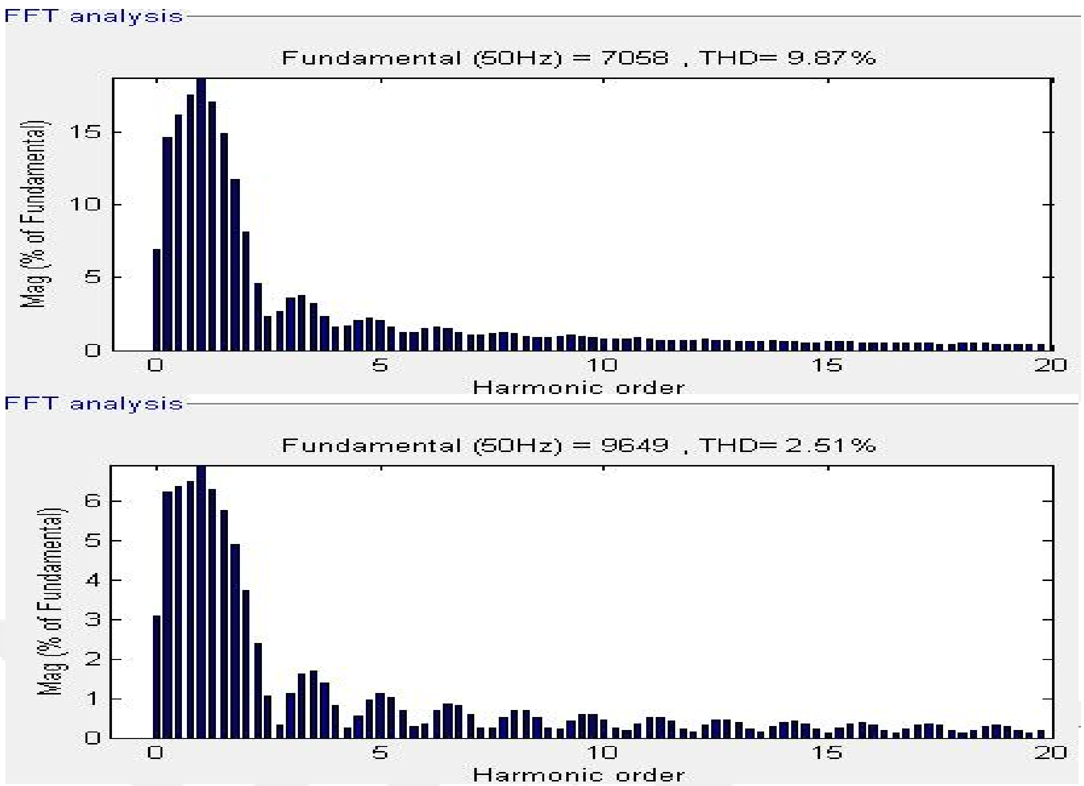


Figure 5.16: Harmonic voltage without and with DVR during double phase voltage sag.

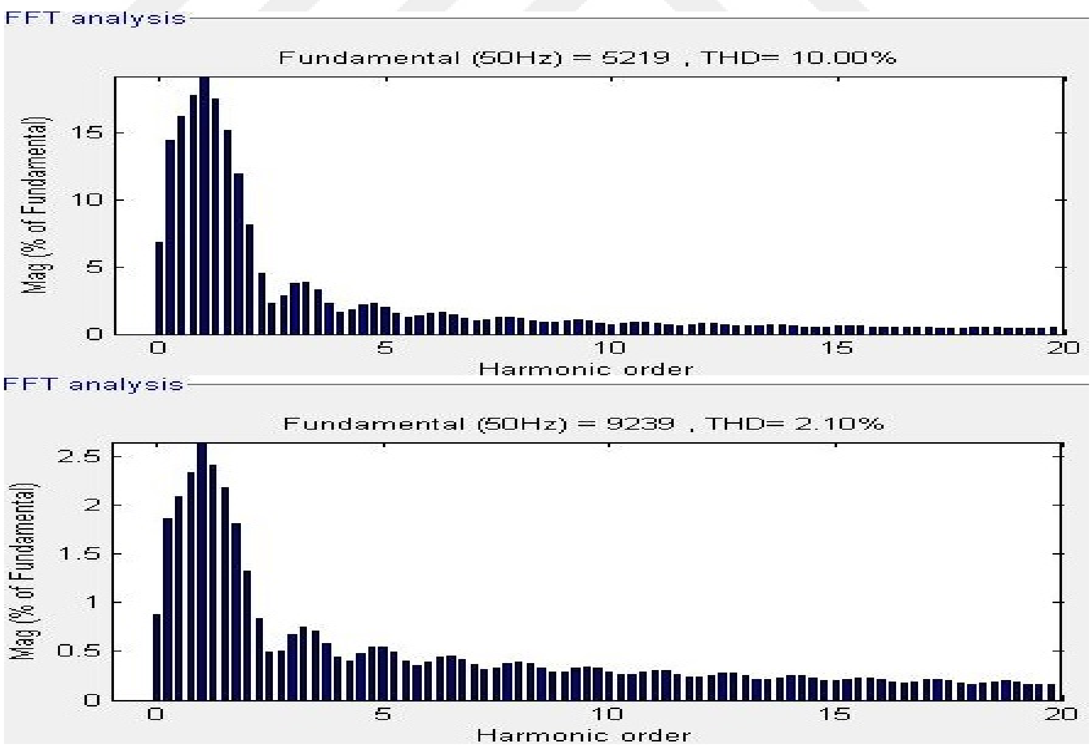


Figure 5.17: Harmonic voltage without and with DVR during single phase voltage sag.

5.3 Simulation of Radial Network with Non-Linear Load Connected

In this section, the capability of the DVR in resolving harmonics problems is tested and verified. The radial network model of figure 5.12 with a non-linear load was used in the testing. The non-linear load is used in this case instead of linear load just create harmonics in the system.

The simulation results obtained shows that the supply voltage is not a pure sinusoidal as shown in figure 5.18 part (a). This is because of the presence of a nonlinear load connected which causes harmonic and distort the supply voltage. While figure 5.18 part (b) shows the shape of the voltage injection wave of the DVR and figure 5.18 part (c) shows the voltage waveform with the DVR at the sensitive load's side (after compensation).

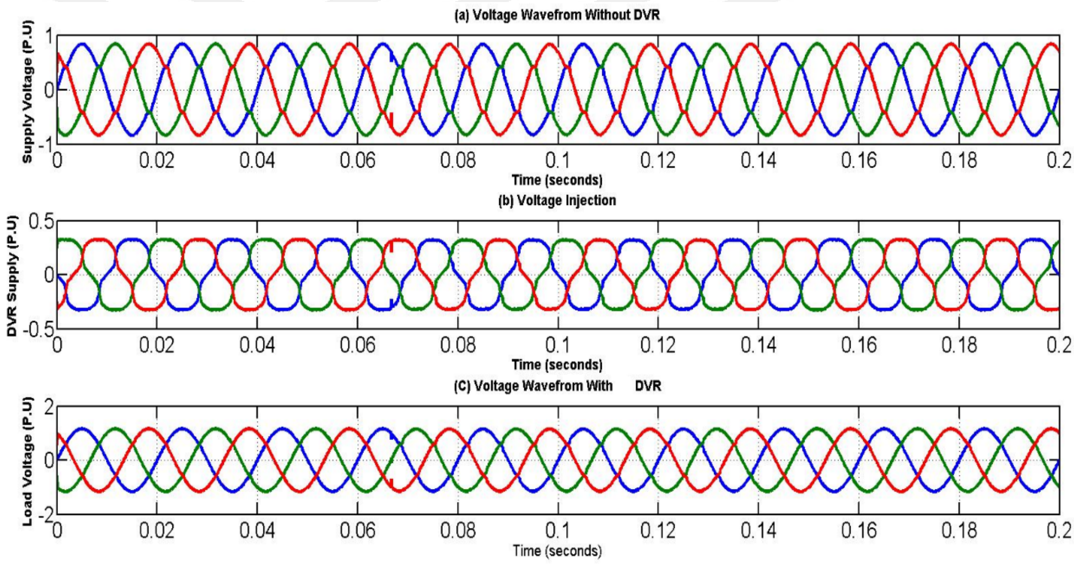


Figure 5.18: Three-phases distorted (harmonics).

Figure 5.19 shows the operation and performance of the DVR in the presence of harmonics and 3-phase voltage sag in the network for the period from 0.06 to 0.14 milliseconds. Figure 5.19 part (a) shows the supply voltage with three-phase voltage sag with wave distortions (harmonics), part (b) shows the shape of the voltage injection wave of the DVR and part (c) shows the voltage waveform with the DVR at the sensitive load's side (after compensation).

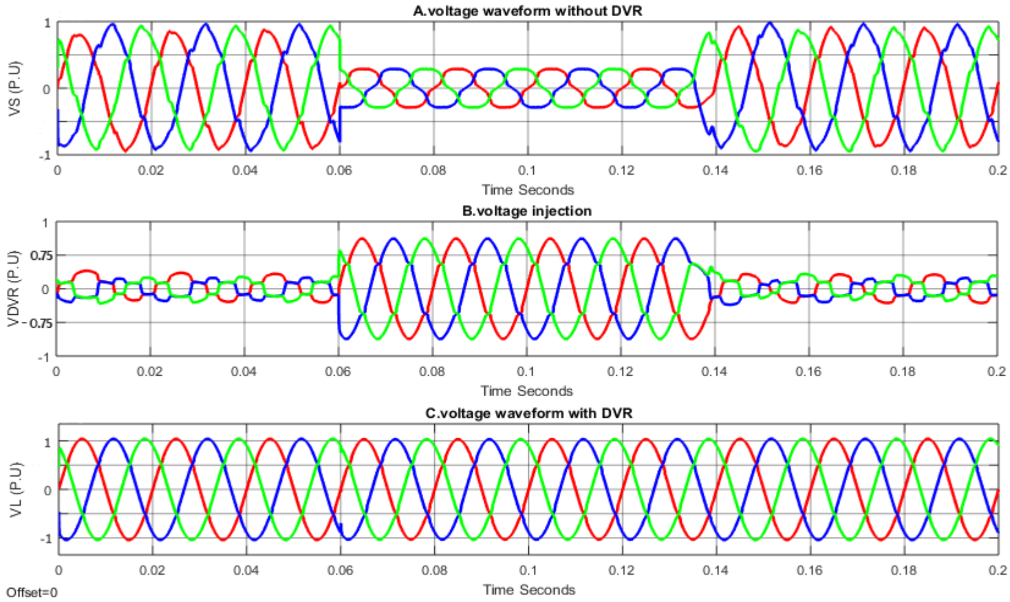


Figure 5.19: Three-phases sag with harmonics.

Figure 5.20 shows the operation and performance of the DVR in the presence of harmonics and 3-phase voltage interruption in the network for the period from 0.06 to 0.14 milliseconds. Figure 5.20 part (a) shows the supply voltage with three-phase voltage interruption with wave distortions (harmonics). Part (b) shows the shape of the voltage injection wave of the DVR. Part (c) shows the voltage waveform with the DVR at the sensitive load's side (after compensation). and also in figure 5.20 shows the capability of the DVR in compensation and mitigating harmonics.

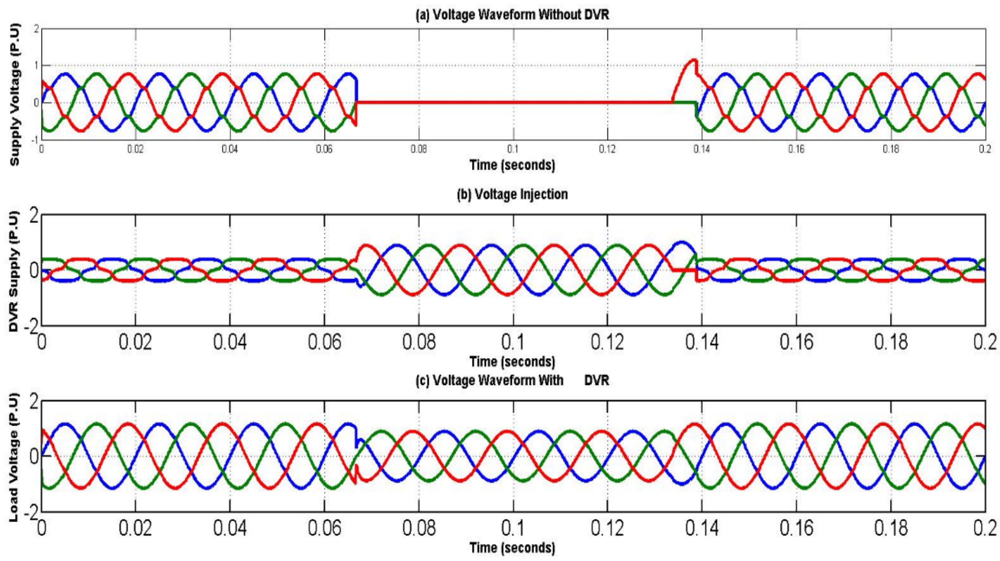


Figure 5. 20: Three-phases interruptions with harmonics.

CHAPTER SIX

CONCLUSION AND FUTURE WORKS

6.1 Conclusion

Power is an issue that is becoming increasingly important to consumers of electricity at all levels of usage. The used of nonlinear load and sensitive loads are nowadays common in both domestic environment and in the industry, because of these reasons, a heightened awareness developing worldwide. The occurrences on the electricity supply network that are considered normal before by the utility companies and the end user are considered as a problem for the users of more sensitive loads.

In this thesis, a simple, cost-effective and fast response custom power device called dynamic voltage restorer was proposed to solve power quality problems in a medium voltage radial network. The DVR was modeled and simulated using MATLAB/Simulink. The DVR was designed to improve voltage disturbances in a radial network. And from the results obtained, it can be concluded that DVR is a multipurpose device, since it has the capability of mitigating various types of disturbances unlike other power conditioning devices. In addition to that, it can effectively handle both balanced and unbalanced fault conditions without having any difficulties in injecting the appropriate missing component to correct supply voltage so as to keep the load voltage constant. Another important factor observed is that the capacity for power compensation depend on the rating of the DC storage. Therefore, the storage capacity should be carefully selected when designing so as to avoid failure of the DVR system.

Thus, it is a clear indication that by introducing DVR into a power system network it can help in improving voltage quality. Hopefully, this thesis would be of benefit to others who are keen on modeling of dynamic voltage restorer for mitigation of power quality problems.

6.2 Future works

With the increase uses of modern electronic devices (sensitive loads) in the factories to increase the efficiency of production as well as in the homes of customers. Therefore, in the future works must consider the following:

A DVR device must be developed to compensate all power quality disturbances that occur in electrical networks with the use of a new controller should be the fastest response from PI controller.

A DVR must be used on a large scale to keep sensitive devices from damage and minimize financial and moral losses.

REFERENCES

1. Prakash, Y. and S. Sankar. Power quality improvement using DVR in power system. in Power and Energy Systems Conference: Towards Sustainable Energy, 2014. 2014. IEEE.

2. Bukar, A.L., An Improvement of Voltage Quality in Low Voltage Distribution System Dynamic Voltage Restorer. 2015, Universiti Teknologi Malaysia.

3. Hazarika, S., et al., Application of dynamic voltage restorer in electrical distribution system for voltage sag compensation. Int J Eng Sci, 2013. 2(7): p. 30-8.

4. Ali, S., Y.K. Chauhan, and B. Kumar. Study & performance of DVR for voltage quality enhancement. in Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on. 2013. IEEE.

5. Sharanya, M., B. Basavaraja, and M. Sasikala. Voltage quality improvement and harmonic mitigation using custom power devices: DVR and hybrid filters. in Microelectronics and Electronics (PrimeAsia), 2013 IEEE Asia Pacific Conference on Postgraduate Research in. 2013. IEEE.

6. Benachaiba, C. and B. Ferdi, Voltage quality improvement using DVR. Electrical Power Quality and Utilisation. Journal, 2008. 14: p. 39-46.

7. Dua, G.S. and R. Kaur. Enhancement of Power Quality in distribution network using DVR. in India Conference (INDICON), 2015 Annual IEEE. 2015. IEEE.

8. Kim, S., H.-G. Kim, and H. Cha, Dynamic Voltage Restorer Using Switching Cell Structured Multilevel AC–AC Converter. IEEE Transactions on Power Electronics, 2017. 32(11): p. 8406-8418.

9. Bollen, M.H., Understanding power quality problems. Piscataway, NJ, USA: IEEE, 2000. 1: p. 1-35.

10. Ghosh, A. and G. Ledwich. Structures and control of a dynamic voltage regulator (DVR). in Power Engineering Society Winter Meeting, 2001. IEEE. 2001. IEEE.

11. Li, B., S. Choi, and D. Vilathgamuwa, Design considerations on the line-side filter used in the dynamic voltage restorer. IEE Proceedings-Generation, Transmission and Distribution, 2001. 148(1): p. 1-7.

12. McKay, S.L., Researching second language classrooms. 2006: Routledge.

13. Babaei, E. and M.F. Kangarlu, Sensitive load voltage compensation against voltage sags/swells and harmonics in the grid voltage and limit downstream fault currents using DVR. Electric Power Systems Research, 2012. 83(1): p. 80-90.

14. Babaei, E., M.F. Kangarlu, and M. Sabahi, Compensation of voltage disturbances in distribution systems using single-phase dynamic voltage restorer. Electric Power Systems Research, 2010. 80(12): p. 1413-1420.

15. Babaei, E., M.F. Kangarlu, and M. Sabahi, Mitigation of voltage disturbances using dynamic voltage restorer based on direct converters. Power Delivery, IEEE Transactions on, 2010. 25(4): p. 2676-2683.

16. Babaei, E. and M.F. Kangarlu, A New Topology for Dynamic Voltage Restorers without dc Link. IEEE Symposium on Industrial Electronics and Applications 2009.

17. Babaei, E. and M.F. Kangarlu. A new topology for dynamic voltage restorers without dc link. in Industrial Electronics & Applications, 2009. ISIEA 2009. IEEE Symposium on. 2009. IEEE.

18. Babaei, E. and M.F. Kangarlu, Voltage quality improvement by a dynamic voltage restorer based on a direct three-phase converter with fictitious DC link. Generation, Transmission & Distribution, IET, 2011. 5(8): p. 814-823.

19. AppalaNaidu, T. The Role Of Dynamic Voltage Restorer (DVR) in improving power quality. in Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), 2016 2nd International Conference on. 2016. IEEE.

20. Kumar, N.P. and Y. Pal. Performance evaluation of three-phase, three wire DVR for power quality improvement. in Engineering and Systems (SCES), 2014 Students Conference on. 2014. IEEE.

21. Deshmukh, S.M. and B. Dewani, Overview of Dynamic Voltage Restorer (DVR) for Power Quality Improvement. International Journal of Engineering Research and Applications, 2012. 2(6): p. 1372-1377.

22. Sadigh, A.K. and K. Smedley. Review of voltage compensation methods in dynamic voltage restorer (DVR). in Power and Energy Society General Meeting, 2012 IEEE. 2012. IEEE.

23. Raut, P.A. and M.N. Kalgunde. An overview and design of Dynamic Voltage Restorer to improve power quality in microgrid. in Energy Systems and Applications, 2015 International Conference on. 2015. IEEE.

24. Pal, R. and S. Gupta. Simulation of dynamic voltage restorer (DVR) to mitigate voltage sag during three-phase fault. in Electrical Power and Energy Systems (ICEPES), International Conference on. 2016. IEEE.

25. Kennedy, B.W., Power quality primer. 2000: McGraw Hill.

26. De Almeida, A., L. Moreira, and J. Delgado. Power quality problems and new solutions. in International conference on renewable energies and power quality. 2003.

27. Bollen, M.H., Understanding power quality problems. Vol. 3. 2000: IEEE press New York.

28. Goswami, A., C. Gupta, and G. Singh, Minimization of voltage sag induced financial losses in distribution systems using FACTS devices. Electric Power Systems Research, 2011. 81(3): p. 767-774.

29. Ipinnimo, O., et al., A review of voltage dip mitigation techniques with distributed generation in electricity networks. Electric Power Systems Research, 2013. 103: p. 28-36.

30. Brumsickle, W.E., et al., Dynamic sag correctors: cost-effective industrial power line conditioning. Industry Applications, IEEE Transactions on, 2001. 37(1): p. 212-217.

31. Praveen, J., et al. Review of dynamic voltage restorer for power quality improvement. in Industrial Electronics Society, 2004. IECON 2004. 30th Annual Conference of IEEE. 2004. IEEE.

32. Ghosh, A. and G. Ledwich, Compensation of distribution system voltage using DVR. Power Delivery, IEEE Transactions on, 2002. 17(4): p. 1030-1036.

33. Rosli Omar, N.A. Rahim, and M. Sulaiman, Dynamic Voltage Restorer Application for Power Quality Improvement in Electrical Distribution System: An Overview. Australian Journal of Basic and Applied Sciences, 2011.

34. Jurado, F. and F. Hidalgo. Neural network control for dynamic voltage restorer. in IECON 02 [Industrial Electronics Society, IEEE 2002 28th Annual Conference of the]. 2002. IEEE.

35. Nielsen, J.G. and F. Blaabjerg, A detailed comparison of system topologies for dynamic voltage restorers. Industry Applications, IEEE Transactions on, 2005. 41(5): p. 1272-1280.

36. Zhan, C., et al., Dynamic voltage restorer based on voltage-space-vector PWM control. Industry Applications, IEEE Transactions on, 2001. 37(6): p. 1855-1863.

37. Nielsen, J.G., et al., Control and testing of a dynamic voltage restorer (DVR) at medium voltage level. Power Electronics, IEEE Transactions on, 2004. 19(3): p. 806-813.

38. Kumar, S.R. and S.S. Nagaraju, Simulation of DSTATCOM and DVR in Power Systems. ARPN Journal of Engineering and Applied Sciences, 2007. 2(3): p. 7-13.

39. Mohammed, S.A., et al., Dynamic Voltage Restorer (DVR) System for Compensation of Voltage Sags, State-of-the-Art Review. International Journal of Computational Engineering Research, 2013. 3(1): p. 177-183.

40. Nielsen, J.G., Design and control of a dynamic voltage restorer. 2002: Videnbasen for Aalborg UniversitetVBN, Aalborg UniversitetAalborg University, Det Teknisk-Naturvidenskabelige FakultetThe Faculty of Engineering and Science, Institut for EnergiteknikDepartment of Energy Technology.

41. Vaishali, N., K. APRAMEYA, and D. UBDTCE, Power Quality Enhancement Using DVR in Distribution System.

42. Omar, R. and N. Rahim, Voltage unbalanced compensation using dynamic voltage restorer based on supercapacitor. International Journal of Electrical Power & Energy Systems, 2012. 43(1): p. 573-581.

43. Ramasamy, M. and S. Thangavel, Experimental verification of PV based Dynamic Voltage Restorer (PV-DVR) with significant energy conservation. International Journal of Electrical Power & Energy Systems, 2013. 49: p. 296-307.

44. Marei, M.I., A.B. Eltantawy, and A.A. El-Sattar, An energy optimized control scheme for a transformerless DVR. Electric Power Systems Research, 2012. 83(1): p. 110-118.

45. Ghosh, A., A.K. Jindal, and A. Joshi, Design of a capacitor-supported dynamic voltage restorer (DVR) for unbalanced and distorted loads. Power Delivery, IEEE Transactions on, 2004. 19(1): p. 405-413.

CURRICULUM VITAE

PERSONAL INFORMATION

Name, Surname : Amir Hameed Abed

Date and place of Birth : Iraq – 20.10.1981

Marital Status : Married

Phone : 00905367812125 – 009647809684481

Email : amir_eng30@yahoo.com

Occupation : Employee in the Iraqi Ministry of Electricity

EDUCATION

Undergraduate: University of Technology - Baghdad, College of Engineering, Department of Electrical and Electronic Engineering.

LANGUAGE

English, Turkish

PUBLISHED PAPERS

[1] Amir Abed, Javad Rahebi, Ali Farzamnia, "Improvement For Power Quality By Using Dynamic Voltage Restorer In Electrical Distribution Networks", *IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS)*, University Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia on 21 October 2017.

[2] Amir Abed, Javad Rahebi, Husham Sajir, Ali Farzamnia, "Protection Of Sensitive Loads From Voltages Fluctuations In Iraqi Grids By DVR Device", *IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS)*, University Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia on 21 October 2017.