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Improving the voltage sag and voltage swell of power distribution with the integration of ultra-capacitor and dynamic voltage restorer using RBF network

MSc Thesis for the Partial Fulfillment of

Master of Science in Electrical Automation and Control Technology Management

By,

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Advisor,

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In partial fulfillment for the Degree

MASTER OF SCIENCE IN ELECTRICAL AUTOMATION AND CONTROL TECHNOLOGY MANAGEMENT

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DECLARATION

Here by I declare that, this written thesis on “Improving the voltage sag and voltage swell of power distribution with the integration of ultra-capacitor and dynamic voltage restorer using RBF network” is my original work. And it has not been presented as a thesis in any other university for the provision of an academic degree, diploma, or certificate. All sources of materials that are used for this thesis are fully acknowledged through citation.

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Place: Addis Ababa

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This thesis work has been submitted for examination with my approval as a TVTI advisor.

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Thesis on

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*By***,**

Mahider Maseresha (MTR/635/13)

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ABSTRACT

Power Quality (PQ) problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipment's. The voltage sag and swell are the most frequent PQ problems that mainly occur in the distribution systems that causes for frequent tripping of circuit breaker, failure of drive systems, shutdown for domestic and industrial equipment. The Dynamic Voltage Restorer (DVR) connected in series has magnificent dynamic capabilities and is a flexible solution for PQ problems. Ultra-Capacitors/UCAP has ideal characteristics such as high power and low energy density essential for improving the voltage sag and swell. In this thesis, voltage sag and voltage swell problem are improved by using the method of integration of Ultra Capacitor and Dynamic Voltage Restorer device and Radial Basis Function network. Here, UCAP is used as energy storage as it provides excessive power in a short time interval. Integrated DVR into Ultra Capacitor via bidirectional DC-DC converter which supports in presenting a rigid dc-link voltage and helps in compensating temporary voltage sag and voltage swell. The integrated UCAP-DVR is implemented at low voltage side of distribution transformer. RBF Controller was used in DVR for power quality enhancement. The simulation results have been carried out by MATLAB/Simulink. In the proposed system the voltage sag is compensated from 0.304 p. u to 1p.u and the voltage swell is compensated from 1.125p.u to 1p.u.

Keywords: Dynamic Voltage Restorer, Ultra-capacitor, DC-DC converter, sag, swell, power quality, RBF controller.

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LIST OF ABBREVIATION

APF	Active Power Filter
BESS	Battery Energy Storage System
C	Capacitance
DC	Direct Current
DLG	Double Line to Ground
DSC	Distribution Series Capacitors
DSTATCOM	Distribution Static Synchronous Compensators
DVR	Dynamic Voltage Restorer
EEP	Ethiopian Electric Power
EPR	Equivalent Parallel Resistor
ESR	Equivalent Series Resistor
FACTS	Flexible AC Transmission System
GTO	Gate Turns of Thyristors
IEC	International Electro Technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Integrated Gate Bipolar Transistor
IGCT	Integrated Gate Commutated Thyristor
LL	Line to Line
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PCC	Point of Common Coupling
PQ	Power Quality
PWM	Pulse Width Modulation
R	Resistance
RBF	Radial Base Function
SA	Surge Arrestors
SEMI	Semiconductor Equipment and Material International
SETC	Static Electronic Tap Changers

SLG	Single Line to Ground
SMESS	Supper Conducting Magnetic Energy Storage System
SSFCL	Solid State Fault Current Limiter
SSTS	Solid-State Transfer Switch
SVC	Static Var Compensator
TSC	Thyristor Switched Capacitor
UCAP	Ultra Capacitor
UPFC	Unified Power Flow Controller
UPS	Uninterrupted Power Supply
VDVR	Voltage of DVR
VL	Load Voltage
VSC	Voltage Source Converter
VSI	Voltage Source Inverter

CHAPTER ONE

INTRODUCTION

1.1 Background

Electric power is more essential for modern life and important for increasing the development in industrial applications and in any other aspects, so the power quality issues is the main idea to improve human life living status. Power disturbance include a wide range of disruption like voltage sags and voltage swell, interruptions, harmonics distortion, flicker and impulse transients. Voltage swell is characterized as the increments in real-time maximum voltage and current at the power frequency over periods ranging between 1/2 a cycle to 1 minute, with typical scales ranging from 1.11 to 1.18 Pico-amperes (p.u.) [1].
Due to their rarity and greater impact on the electrical power grid, voltage spikes are less of an issue in distribution systems than voltage drops. Since Uninterruptible power supply (UPS) energy storage capacity becomes too expensive for high-power loads, the DVR may be a more cost- effective alternative. Power quality can be improved using active power conditioners (APCs) and active voltage conditioners (AVCs) utilizing a dynamic voltage resistor and the radial base function/ RBF to improve the quality of the power [1][2].

An rms voltage or current variation from 10% to 90% of the minimal value and lasting from 0.5 cycles to 1 minute is defined as voltage sag. The main cause for voltage sag is an imbalance voltage and currents when damage the fuses or trip breakers in the voltage sag conditions excess current generated by a short circuit or fault some place in the system are the most common source of voltage problems. Radial basis function (RBF) networks recently have a rapid development in control techniques and successful applications. Various theoretical investigations and practical industrial applications of neural network radial basis functions demonstrate promising results for function approximation and control system design in the context of solving the control issues of complex nonlinear systems in the presence of various types of uncertainties [3] [4].

Most people agree that sag and swell is the most significant quality issue in power systems today. They can cause sensitive equipment to fail to perform their proper function. For industrial, commercial, and residential applications, power quality is the most critical. so that solving the voltage sag/swells is an important issue[5] [6].

Since voltage sag and swell conditions are extremely dangerous, numerous studies have been conducted to prevent them. For the most effective way, specialized power devices are recommended like UPS, UCAP, IGBT, PMW, D-STATCOM and Transformer[7].

It is shown to be universal approximator, these networks are simpler to create and train than other neural networks due to their fixed, simple three-layer topology. RBF networks can respond well to patterns that are utilized for training a generalization perspective. RBF networks have a high threshold for input noise, which improves the stability of the systems they are designed. Therefore, due to this reason RBF network is a solution for nonlinear controller design. To mitigate voltage control performance by designing DVR as the country standard parameters using RBF network is an essential for controlling the disturbances of voltage sags/swells [9].

1.2 Statement of the Problem

Power quality problem is defined as any problem that causes voltage or frequency deviation in the power supply and my result failure or maloperation of network. Some of the power quality problems are overvoltage, surges, spikes, and transients, frequency variation, under voltage, sags, blackouts, noise and harmonics. To improve the power quality, various methods have been implemented individually. However, until now each of the methods are not efficient enough to solve power quality problems. In this thesis work, designing integration of ultra-capacitor, dynamic voltage restorer and by Radial Basis Function is proposed to solve the power quality problem. Due to the continuous growth of electric load and transfer of high regional power through a large interconnected network, the quality of power system may reduce and leads to a complex operation.

1.3 Objectives

1.3.1 General objectives

- To improve power quality by reducing the voltage sag and voltage swell of power distribution using the integration of ultra-capacitor and dynamic voltage restorer by Radial Basis Function.

1.3.2 Specific Objectives

- To Design UCAP-DVR for load voltage compensation.
- To simulate the results of proposed system using MATLAB/Simulink
- To compare the results according their p.u values

1.4 Significance of the Study

The quality of power system increase downtime and reduce productivity in industries and customers. Solving the problem of voltage sag and swell to deliver reliable and quality power supplies for customers by using DVR integrating with UCAP using RBF network were designed in this study. Therefore, the result from this study has a great importance on solving power quality problem. Additionally, the finding of this study helps in policy formulation and development of a framework for critical technology, skill and raw material/input requirement.

1.5 Scope of the thesis

The scope of this thesis work mainly focuses on designing an integration of Ultra Capacitor and DVR by RBF network methods for power distribution level, to simulate the proposed system result using MATLAB/Simulink and to compare the performance of each of the considered power quality improving methods based on p.u values.

1.6 Limitation of the thesis

Due to the complexity power quality problems, in this thesis, only voltage sag and swell are considered. To solve the power quality problems, the designing of the integration of Ultra Capacitor with DVR by Radial Basis Function/RBF network methods is used. However, it does not include some intelligent optimization techniques.

1.7 Outline of the Thesis

This thesis work is splitting into six sections.

Chapter1: This chapter is an introduction part which includes background, Objective, significance, statement of the problem, limitation and scope of the research.

Chapter2: this chapter mainly includes the related works to the proposed power quality improving methods. **Chapter3**: This chapter explains about theoretical background and modeling of PQ improvement techniques. **Chapter4:** This chapter focused on designing and modeled a simulation of the look and Analysis of an RBF controller with DVR and U-capacitor for mitigation of voltage sag and swell in three-phase network design, other research per this thesis, and therefore the controller design utilized in this thesis. **Chapter 5**: This chapter summarizes the simulation results and discussion. **Chapter6**: This chapter includes deduction for all the works done in this paper and recommends some uncovered power quality improvement techniques for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Power quality is most significant quality issue in power systems today. Many researchers are present a lot of power quality problems in their investigations. In this paper, some of the power quality problems and improving mechanisms with control devices are discussed briefly.

Power disturbance is an incident that manifests as an abnormal voltage, current or frequency resulting in the failure of end use of equipment's. In recent years the notion of power quality in utility side has gotten dire attention. Because of the continuous growth of the transfer of high regional power and electric load via a huge interconnected network, the power system security reduces productivity and leads to a complicated operation. It creates with a broad range of disturbances such as flicker, voltage swells, harmonics, voltage sags, interruptions and another distortion.

According to IEEE 1159:1995, sag and swell are the most significant issues in the distribution system. Swell is the increments in real-time maximum voltage and current at the power frequency over periods ranging between 1/2 a cycle to 1 minute, with typical scales ranging from 1.11 to 1.18 Pico-amperes (p.u.) [8].

Kaur and Sandeep, 2020, states simulation and Analysis for Mitigating Voltage Sags and Swells, in the paper, Voltage sag problem is the most frequently occurring and detrimental power quality problems, in this work, the main objectives are to assuage voltage sag problem using proposed Distribution Static Compensator (DSTATCOM), The simulation results clearly demonstrate a DSTATCOM's effectiveness in reducing voltage sags and swells, as well as its quick dynamic response. Sag is a reduction from 0.1 to 0.9 p. u in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 minute. It is a temporary voltage drop below a specific threshold at some point in the electrical system, a rms voltage variation from 10% to 90% of the minimal value and lasting from 0.5 cycles to 1 minute. Additionally, The duration values are divided into three groups by the IEEE 1159: immediate, transient, and temporary [1]

Bindu, P 2013 proposed voltage dip and swell mitigation using dynamic voltage restorer (DVR) system, in this paper power disturbance is one of the main issues addressed is used as objectives of this research work, in this work the controller schemes and mechanisms of mitigation using DVR system.

The simulation result of performance of DVR in enhancing power quality system is discussed [1].

Instrumentation Engineering, in 2014 proposed mitigation of voltage swells to improve power disturbance of distribution system using a custom power device (DVR), the paper states that the way to improve the quality of the electricity delivered to the customers. In this work DVR unique power devices solve alleviate undesired voltage that originate on the supply side of the power system. The simulation result presents customer serves power quality applications for a better performance using easy and modern design controllers of RBF [2].

Sudharani, S. and Godwin Immanuel, D.2021, *(et.al)* propose Mitigation of voltage sag and swell by dynamic voltage restorer using fuzzy based particle swarm control, in this paper Reliability of distributed system is measured with the power quality (PQ) that gains more interest of investigators and turned to be huge concern in commercial and industrial purposes. The simulation results validate that this controller offers an economical solution for industrial requirements by offering compensation problems in a shorter time span in this work, which focuses on improving the design of the dynamic voltage restorer (DVR) to improve power quality as one of the main objectives [3].

Burungale, 2017, proposed DSTATCOM Performance for Voltage Sag, in this paper, the control mode acts as a voltage stabilizer while also adjusting for voltage variation, imbalance, and reactive power. In this work objectives of VSC based DSTATCOM and can be extended to multilevel inverter based DSTATCOM to reduce the harmonic content in current, the simulation result of a DSTATCOM are presented [4].

It is always brought on by a sudden drop in load on a circuit with a loose or malfunctioning neutral connection and a broken or subpar voltage regulator [9].

Maluk and Chandra, 2017 states that voltage dip usually accredited as one of the most significant power quality disruptions. It is a brief drop in rms voltage from normal voltage that occurs in a few milliseconds to seconds. The voltage sag is defined as a momentary reduction in voltage at a point in the electrical system below a threshold with the rms fluctuation of a magnitude between 10% and 90% of the normal voltage and duration between 0.5 cycles and one minute. The most common causes of voltage sag include rural location far from power supply, of heavy loads switching, an imbalanced load on a three-phase system, long distance from a distribution transformer with interposed loads, grid systems that are unreliable, equipment’s that is not appropriate for local supply, motor starting and short circuit. Recently, practically there are various types of devices. Such as series supply capacitors, video recorder, distribution static synchronous compensators, surge arresters, superconducting magnetic energy systems, solid state switches, static electronic tap switches, solid state fault current limiter, switched thyristor capacitors, active power filters, static variation compensator and uninterruptible power supplies. Many scientists have done various researches to minimize the problem with the above devices and this research was done through the integration of ultra-capacitor with DVR to improve the power quality problem. G. RAMESWARA REDDY, Associate Professor, KBR College of Engineering, Nalgonda, India, in 2015, conducted a study for "Improving Power Quality of Distribution Network Using Ultra-Capacitor Integrated Power Conditioner". In addition, the method of PWM is used. The distribution feeder is connected in series with the DVR system, which provides the power system network in the critical load [10].

There are three methods of sag compensation method while using dvr system. such as: in pre –sag compensation, phase advance method and compensation method [11].

A. Pre –Sag Compensation Method

According to Ali moghassemi and sanjeevikumar 2020, revealed that the difference between the pre-sagged and post-sagged voltages will be injected by the DVR. It restores the voltage magnitude and phase angle to their pre-sag values. The advantage of this approach is that it restores the voltage at the site of connection to the same level as before the sag while maintaining the same voltage phase shift.

B. In-Phase Compensation

Regardless of the load current or the pre-fault voltage, the added DVR voltage is in phase with the measured supply voltage. The benefit of this approach is that the injected DVR voltage is minimal for constant load voltage.

C. Phase Advance Method

The source voltage and the injection voltage are in phase. The phase advanced approach's injection voltage magnitude is larger than that of the other approaches for this method. Voltage waveform breaks, erroneous zero crossing, and load power swing can all be caused by voltage phase shift.

Thus, the phase advance mechanism should be altered to a load that is tolerant of phase jumps, or the transition delay should be increased when the phase angle is shifted from pre-fault to advance angle.

J.Moody and C.Darken at the end of 1980s presented a bout a “types of NN which is called Radial Basis Function (RBF)”. Firstly, Broomhead and Lowe were exploiting the use of radial basis functions in the design of neural networks. These neural network have a special functions regarding on their characteristic feature on response of decreases, or increases, monotonically with distance from a center point [12].

As Dash, Panigrahi, and Panda 2006, recognized the disturbance waveform. The distance-based activation function used in the hidden nodes of radial basis function networks enables the detection of outliers during estimation and requires less training time. The medium and low voltage **t**o protect high power application from voltage dip in the operation of DVR system installed. When the control unit detects sag, it can inject missing voltage into the supply through an injection transformer. During compensation, active power is injected into the distribution via the sag correction approach. Actually, DVR requires energy storage for long-term sags. DVR compensatory voltage can be achieved in three ways [14].

Ming, 2005, (*et.al*) proposed that Simulink model on various samples illustrate that the PID controller obtained by using these RBF neural network gives satisfactory results. The typical operating point of a conventional PID controller makes it difficult for it to perform well in other operating conditions. RBF network are powerful computational tools widely used in pattern recognition, system modeling, and identification. The RBF network forms a special architecture of the neural network, which is characterized by several main advantages: the simplicity of its structure, faster learning algorithms, and better approximation capabilities. Many researchers have been working over the last decade to create more effective training methods and applications due to the RBF neural network's popularity [13].

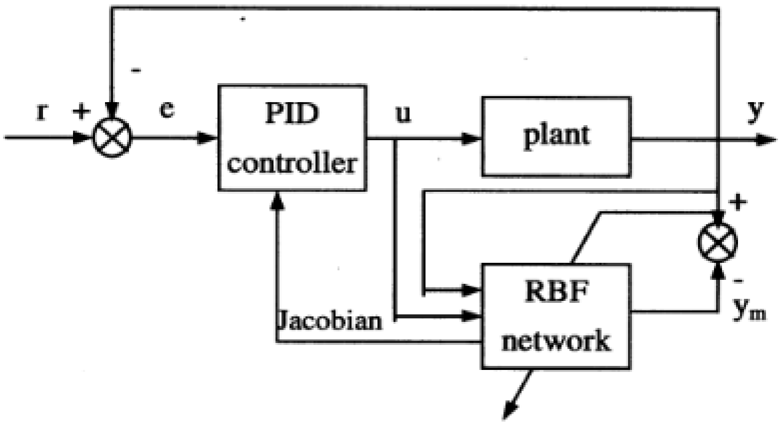

Figure 2. 1 Design of adaptive PID controller based on RBFNN [13].

*Source Ming, 2005, (*et.al*)* [15]

D-STATCOM (Distributed Static Compensator), Devices provide high speed and reactive power regulation to eliminate voltage sag and swell issues and to provide stability or harmonic suppression. It is essentially a power gadget that distributes reliable power quality. It is a device that, in addition to power quality distribution with the aid of simulation software, offers voltage sag mitigation, voltage stability, harmonics management, correction, and an increase in power factor% to minimize voltage flicker it is a power electrical equipment that is extremely effective and efficient and is utilized in power distribution networks. In order to reduce the sag and swell interruption, it injects a current into the system[14].

Reactive power can be controlled by D-STATCOM at fast speed to provide voltage stabilization. It shields the distribution system from voltage sag, which is brought on by abrupt changes in reactive current demand. It offers load balancing during transients, power factor correction, and lead and power to active system stability. Reactive power is controlled at a high rate of speed to provide voltage stabilization. It shields the distribution system from voltage sag, which is brought on by abrupt changes in reactive current demand. It offers load balancing during transients, power factor correction, and lead and power to active system stability [14].

Ibrahim, S B in 2018 proposed Voltage Quality Enhancement in Distribution System Using Artificial Neural Network (Ann) Based Dynamic Voltage Restorer, in this paper provide smart triggering pulses for the DVR to mitigate and to provide compensation against voltage sags and swells is objectives, in this work proposed problem for any application, which need urgent attention for their compensation. The simulation result is DVR with ANN control is applied to protect a sensitive load under voltage disturbance conditions [15].

According to International Journal of modeling and optimization, 2012, there are four primary categories of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). The MOSFET features quick switching speeds and a high on-resistance requirement. It can operate at frequencies higher than 20 kHz [18].

Yao, Fengjun, 2020 (et.al) revealed that RBF Neural Network Based Virtual Synchronous Generator Control with Improved Frequency Stability, in this paper, analyzed from the mechanical operating conditions and adaptive inertia control system based on RBF neural network is proposed. In this work to evaluate performance to analyze control system is used as objectives of the work, the simulation result shows the strategy overcomes the shortcomings of traditional virtual synchronous generators. The gadget can only be used in applications with a few hundred volts due to the rising resistance with voltage. The GTO is a latching device that can be turned off by a negative pulse of current to its gate [16][17].

Chu, 2018, (et.al) proposed that Dynamic overall proportional integral derivative(PID) sliding mode control using radial basis function neural compensator for three-phase active power filter, in this paper, to improve the process of robustness and inhibition of the steady state error, accelerating the system response is objectives, The simulation results confirm the developed RBFNN dynamic global PID sliding mode controller's exceptional performance in three different scenarios, and some comparisons are done simultaneously to highlight the superior qualities of the raised control approach [18]

He lei, 2019 (et al) presented that ultra-capacitor is used as energy storage device as it has high power density. It stores energy through charge separation and thus need for chemicals are reduced. The benefit of adopting UCAP is that it has a long lifespan and numerous charge and discharge cycles. The decision on the number of UCAPs depends on variables like the terminal voltage of the UCAP, DC-link voltage, and distribution grid voltage. Ultra-capacitors (UCAP) are ideal for mitigating voltage sag and swell since they have desirable properties including high power and low energy density [19].

The bidirectional DC-DC converter used to integrate the DVR into the ultra-capacitor aids in presenting a rigid DC-link voltage and also assists in adjusting for transient voltage sag and swell. To present a rigid DC-link voltage and to compensate for transient voltage sag and swell, A bidirectional DC-DC converter that integrates the DVR inside an ultra-capacitor helps present a robust dc-link voltage and compensate for transient voltage sags and swells [20].

The GTO is best suited for high voltage applications. The GTO's shortcomings include the inability of GTO-based devices to satisfy a DVR's dynamic needs. Compared to the MOSFET and GTO, the IGBT is thought to be a more recent invention. In essence, it is a three terminal controlled switch that combines the GTO's high voltage capabilities with the MOSFET's quick switching speeds. This combination produces a medium speed-controlled switch that can handle the medium power range. The IGCT is a recent compact device with improved performance and durability, the IGCT enables the construction of VSC with extremely high-power ratings. The highly advanced converter architecture with IGCTs allows the DVR to correct for sag and swell to a greater extent than previous DVRs employing traditional devices [21][22].

Parwal, 2019, (et.al) states voltage control devices like IGBTs which are voltage-controlled devices and a gate charge is required to flip the IGBT rapidly. It should switch the IGBT from off to on as quickly as possible to reduce time spent in the linear semiconductor area and hence switching losses [23].

According to Maluk and Chandra (2017), the importance of IGBT are minimal power loss and quick switching. The gating signal from PWM is pumped into the IGBT to actuate the inverter [10].

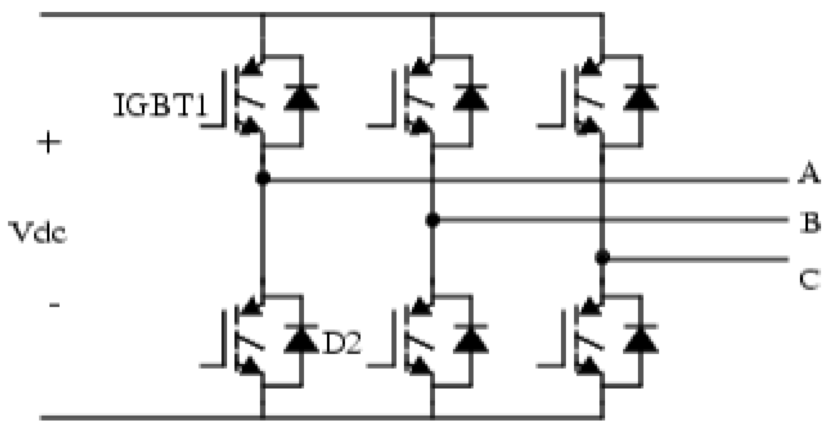

Figure 2.2 IGBT layout [10]

2.2 Standards Linked with Voltage Sags

Voltage sag standards are meant to be used as reference papers detailing each equipment and schemes in a power system. Both producers and consumers employ these standards to meet greater power quality requirements. Manufacturers create items that fulfill the standards of a standard, and purchasers demand that the product meet the standard. IEEE and SEMI power quality standards are the most widely used [24][9].

2.2.1 IEEE Standard

The technical committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board create IEEE standards. The IEEE standards related to voltage sags are listed below. IEEE 446-1995, "IEEE recommended practice for emergency and standby power systems for industrial and commercial applications range of sensibility loads"

The standard goes through the impact of voltage sags on sensitive equipment, motor starting, and so on. It demonstrates the ideas and examples of how systems should be built to minimize voltage sags and other power quality issues when the backup system is operational [24].

IEEE 493-1990, "Recommended practice for the design of reliable industrial and commercial power systems" The standard suggests several strategies for predicting voltage sag characteristics such as amplitude, duration, and frequency. Voltage sags are primarily of relevance in three areas. The various regions are summarized as follows:

- Estimating voltage sag magnitude by calculating voltage drop at critical load using network impedance, fault impedance, and fault location.
- The length of the voltage sag can be estimated by evaluating protective equipment and fault clearance time.
- An assessment of the frequency of occurrence may be produced depend on trustworthy data for the knowledge and neighborhood of the system parameters.

IEEE 1100-1999, "IEEE recommended practice for powering and grounding Electronic equipment".

IEEE 1159-1995, "IEEE recommended practice for monitoring electric power quality". The goal of this standard is to explain how to appropriately interpret and monitor electromagnetic events. It offers distinct definitions for each sort of disruption. IEEE 1250-1995, "IEEE guide for service to equipment sensitive to momentary voltage disturbances" [9].

2.2.2 SEMI International Standards

The SEMI International Standards Program is a service accessible by Semiconductor Equipment and Materials International (SEMI). Its mission is to give standards and suggestions to the semiconductor and flat panel display sectors in order to increase productivity and business.

The standards are voluntary technological agreements between the maker of the equipment and the end user. The standards guarantee that goods and services are compatible. When it comes to voltage sags, two standards handle the issue for the equipment. SEMI F47-0200, "Specification for semiconductor processing equipment voltage sag and swell protection"

The standard covers voltage sag protection requirements for semiconductor processing equipment. It solely describes voltage sags with durations ranging from 50ms to 1s [25].

SEMI F42-0999, "Test method for semiconductor processing equipment voltage sag immunity" This standard defines a test method for validating semiconductor processing equipment against specifications and determining its susceptibility. To measure the susceptibility of semiconductor processing equipment, it also describes test apparatus, test setup, test procedure, and ultimately how to report and interpret the results [26].

2.3 Summary of Literature Review

Electric power disturbance is most significant issue in developed country as well as in developing country. Many scholars proposed different alternatives to improve the reliability and the quality of electricity delivered to the consumer. They also state the most significant quality issue in power systems are voltage sag and swell. These can affect sensitive equipment and cause it to fail. For industrial, commercial, and residential applications, power quality is the most critical so that to solve the voltage sag/swells is an important issue. Such specialized power devices are recommended like UPFC, DSTATCOM, STATCOM, and TCSC. SVC, DVR, UPS and DSC.

Dynamic Voltage Restorer is the most effective tool for reinstating voltage perfection in the most effective way. This is a series compensator powered by a power electronic converter that can keep sensitive loads from any supply disturbances. The maximum voltage injection capability affects the DVR voltage capabilities.

The integration of UCAP based DVR is required. The ultra-capacitor and DVR coupled through two-directional DC to DC converter. It is used to accomplish a precise and fast response of the DVR. UCAPs have the appropriate features for efficient adjustment of PQ issues such voltage dip and swell researching the high quality of power in disseminated power generation due to their high-power density and low energy density.

Due to the absence of moving components, no need for freezing or heating, and no internal chemical changes as a result of their operation, ultra-capacitors have a wide range of potential applications that make them unbeatable in many fields. Additionally, they are exceedingly effective and long-lasting and do not require regular repairs despite having a shorter lifespan owing to deep cycling.

In general, disturbance analyzers, voltage recorders, and other devices retain the aforementioned power disturbances. However, with the development of computer technology, it is now possible to construct equipment for power quality monitoring and analysis that is better, faster, and more precise.

2.4 Research Gap

Related to power quality improvement, different researches have been done by many researchers. From each of the reviewed literatures, the following main gaps are identified.

- Only single PQ improvement mechanisms are used. But the desired power quality cannot be satisfied using single method.
- No more power quality problems are considered Other than the Voltage sag and swell
- No intelligent optimization techniques are used to compute the controller tuning parameters.

Based on the identified gaps, in this thesis, it is proposed that the integration of different controllers is considered and their performance is evaluated based on the p.u values.

CHAPTER THREE

MODELING

3. 1 Mathematical Modeling of DVR in a Distribution System

DVR is a series compensator powered by a power converter that can keep sensitive loads from any supply disturbances. This device can generate and severally controllable real and reactive power at its ac output terminal. This device principally consists of a control system and an energy storage unit, with a *VSC* joined in series with grid through a boosting injection transformer. Figure 3.1 illustrates the generalized *DVR* model and the way it is linked to the grid [20].

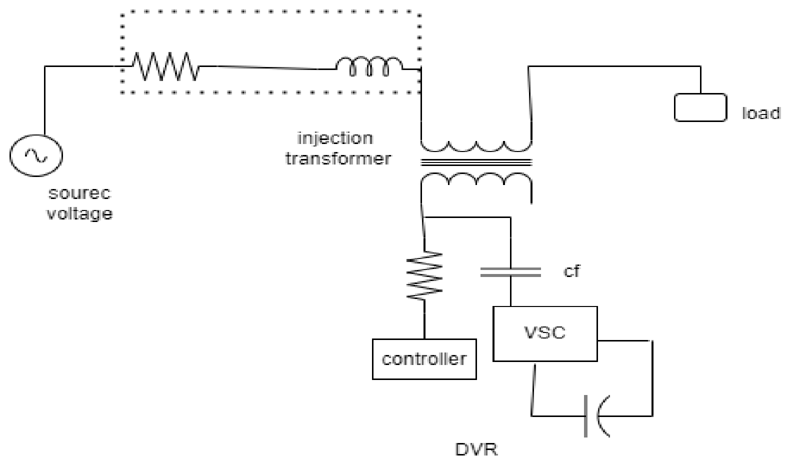

Figure 3. 1 Generalized single line model of *DVR* [27].

Source: Muhammad *et al. 2022.* Power Quality Improvement

Figure 3.2 illustrates the *DVR* equivalent circuit diagram, where V_L represents load voltage and *V* source represents source voltage, so the voltage inserted by DVR, V_{dvr} can be written as:

$$V_L = V_{source} + V_{dvr} \tag{3.1}$$

c_{fc} And Lfc are the filter parameter as illustrated in Figure 3. 2 The filter capacitor current i_{fc} can be determined as:

$$i_{fc} = C_{fc} \frac{dV_{dvr}}{dt} \tag{3.2}$$

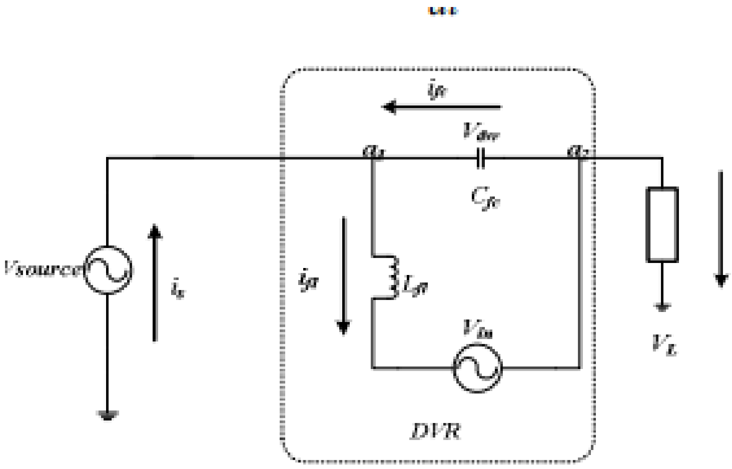

Figure 3. 2 Equivalent circuit diagram of *DVR* [5].

Source: Muhammad *et al. 2022.* Power Quality Improvement

$$is - ifi + c = 0 \tag{3.3}$$

Equation (3.3) determine the source current, while i*fc* and *ifl* are determining the capacitor current and filter inductor respectively. Now, putting the value of *ifc* in (3.3), gives (3.4) and then i get (3.5) after simplification.

$$i_s - i_{fl} + c_{fc}\frac{dV_{dvr}}{dt} = 0 \tag{3.4}$$

$$\frac{dV_{dvr}}{dt} = \frac{(i_{fl} - i_s)}{c_{fc}} \tag{3.5}$$

In equation (3.5), I obtain the first state equation of *DVR* and *KVL* is applied to the second state equation, as shown in Figure 3.2 at closed loop. So.

$$V_{dvr} + V_{fl} - V_{in} = 0 \tag{3.6}$$

Where

- ✓ V_{in} is the output *AC* voltage of *VSC*
- ✓ V_{dvr} Is the DVR injected voltage, and $V_{fl}$is the voltage across the inductor, given in (3.7). By putting equation (3.7) in equation (3.6), I was get equation (3.8), and, after simplification, I was get equation (3.9).

$$V_{fl} = L_{fl}\, {di_{fl}}/_{dt} \qquad (3.7)$$

$$V_{dvr} + L_{fl}\, {di_{fl}}/_{dt} + V_{in} = 0 \qquad (3.8)$$

$$di_{fl} = \frac{(V_{in} - V_{dvr})}{Lf} \qquad (3.9)$$

Therefore, the state space model of the series connected DVR is illustrate in equation (10)

$$\frac{\mathrm{d}}{\mathrm{dt}} \begin{bmatrix} i_{fl} \\ V_{dvr} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{\mathrm{L}_{fl}} \\ \frac{1}{C_{fc}} & 0 \end{bmatrix} \begin{bmatrix} i_{lf} \\ V_{dvr} \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{L_{fl}} \\ \frac{-1}{C_{fc}} & 0 \end{bmatrix} \begin{bmatrix} i_{s} \\ V_{in} \end{bmatrix} \qquad (3.10)$$

Where is and V_{in} are the input variables while V_{dvr} and i_{fl} are the state variables.

3.2 DVR Structure

Voltage source inverters (VSI) can realize the voltage sources in DVR structure through capacitor filter and inductor – capacitor filter realization. The three VSI are connected to a single DC storage capacitor in the capacitor storage. Each switch in this scenario is an anti-parallel diode and a power semiconductor device. The transformer and a capacitor filter are connected to each VSI through the network. Inverter isolation is also provided by the transformers, which also lower the voltage requirements of the inverters. This keeps the dc storage capacitor from shorting out via switches in separate inverters. The capacitor filter is linked across the secondary of the transformer in the DVR configuration. This keeps switching frequency harmonics out of the system. The main disadvantage of the method is that the direct connection of VSI to the transformer primary produces in transformer losses. The high frequency flux fluctuation increases transformer iron losses significantly. To avoid this, as illustrated in Figure 3.3, a switch frequency LC filter (LCf) is installed in the transformer primary. The transformer's secondary is directly linked to the feeder. This can also minimize switch frequency harmonics, particularly on the transformer's primary side.

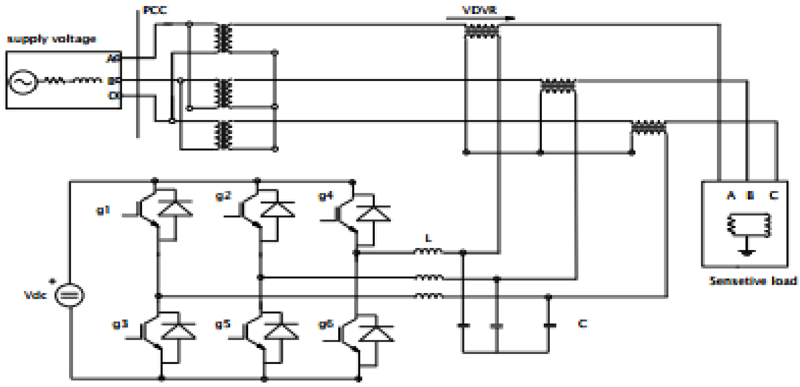

Figure 3.3 DVR structure and location [27].

3.3 The Basic Components of a DVR

DVRs can be used in both medium and low voltage applications. Figure 3.4 shows conventional circuit configuration of the DVR. It is basically containing of the following parts:

3.3.1 Series Voltage Injection/booster Transformers

This kind of transformer restricts noise coupling from the main to secondary sides as well as transient energy. In most cases, the injection transformer's HV side is linked in series to the distribution system and the low voltage side of the DVR's power circuit can be connected there. Its main function is to couple the injected compensating voltages produced by VSC to the incoming supply voltage and plugged the DVR to the distribution system using transforms and high-voltage windings. This isolates the load from the system and raises the voltage supplied by the filtered VSI output to the desired level (VSC and control mechanism). The transformer winding ratio is generally maintained at the predetermined value based on the voltage required at the secondary side of the transformer basically it is maintained at supply voltage to enable DVR to account for entire voltage sag. The primary side current was increase with a greater transformer winding ratio, which was negatively impact the operation of the linked power electronic equipment in the VSI. Buck boost transformers are a kind of transformers designed to lower (buck) or increase (boost) line voltage by 5-20% and they are small single /three phase transformers.

An appropriate three phase buck boost transformer size in KVA is represented by:

$$\text{Three phase KVA} = \frac{Load\ voltage\ x\ load\ current\ \ \sqrt{3}}{1000} \qquad (3.11)$$

From table 3.1 the maximum load current requirement for feeder number (7) is 77A and the actual load voltage is 415 V.

$$\text{Three phase KVA} = \frac{415V\ x\ 77A\ x\sqrt{3}}{1000} = 55.34\ \text{KVA}$$

Maximum ampere rating of the over current device = full load input Amps x 125 %

Line fuse =77A X 125 % =96.5A

In a three-phase system, the basis values are typically power and voltage. The base power is three phase power in KVA, and the base voltage is phase to phase in KV. The system's base impedance may be determined by using the base voltage and base power values as follows:

$$\text{Zb} = \frac{KV^2}{KVA}\ \text{ohm} \qquad (3.12)$$

But according to IEEE 142-1993 standard 75KVA 3-Ø transformer has 2.42, 2.1 and 3.2 % of resistance (%R), reactance (%X) and impedance (% Z) respectively.

Short circuit rms amperes at transformer terminals are calculated by per unit method.

$$X_{trans} = (0.021)\ (\frac{75\ KVA}{75KVA}) = 0.021\ \text{p.u}$$

$$R_{trans} = (0.0242)\ (\frac{75\ KVA}{75KVA}) = 0,\ 0242\ \text{p.u}$$

$$Z_{trans} = \sqrt{(X\ trans)^2 + (R\ trans\ )^2} = \sqrt{(0.021)^2 + (0.0241)^2} = 0.032\ \text{p.u}$$

$$I_{sc} = \frac{KVA}{\sqrt{3}\,XVL{-}LXZ} = \frac{75KVA}{\sqrt{3}\,X\ 15V\ X\ 0.032}\quad 3260.6\ \text{A}$$

The greatest common type of fault is the single line to ground fault and the impedance fault is calculated as

$$V_A = I_A \text{X}\ Z_F$$

$$Z_f = \frac{240\ v}{3260.6\ A} = 0.0736\text{p.u}$$

$$V_{sag} = \frac{VAX\ Zfault}{Zfault+\ Zsupply} = \frac{240\ X\ 0.073}{0.073+0.032\Omega} = 168\ .2\text{V}$$

$$V_{missing} = \text{V Pre sag} - \text{V sag} = 240\ \text{V} - 168\text{V} = 72\text{V}$$

From 15KV/0.415KV, 75KVA, 3 - Ø of feeder transformer we can calculate the reactance and resistance of transformer in per unit as follows

X_{source} = $\frac{75\ KVA}{25MVA}$ = 0.003p.u

X_{trans}= (0.021) ($\frac{75\ KVA}{75kVA}$) = 0.021p.u

X_{total} = (0.003 + 0.021) p.u = 0.024p.u

R_{trans} = (0.0242) ($\frac{75\ KVA}{75kVA}$) = 0.0242p.u

Z = $\sqrt{(X\ total)^2 + (R\ trans\ )^2}$ =$\sqrt{(0.024)^2 + (0.0242)^2}$ = 0.034 p. u

I_{sc} = $\frac{KVA}{\sqrt{3}\,XVL-LXZ}$ = $\frac{75KVA}{\sqrt{3}\,X4\ 15V\ X\ 0.0324}$ = 3061.37A

Z_f = $\frac{240v}{3061.376A}$ = 0.078 p.u

V_{sag} = $\frac{VX\ Zfault}{Zfault+\ Zsupply}$ = = 167.14V

V_{sag} = V_{presag}– $V_{missing}$

$V_{missing}$ = V_{presag} – V_{sag} = 240V- 167.14V = 72.86V

Assumed that pre-event voltage is exactly 1 p.u, thus E = 1. This result in the following expression for the sag magnitude:

Consider the single-phase DVR-compensated system shown in Figure 3.3 that the pre-event voltage is exactly 1 p.u and consider a DVR compensated single phase system as shown in Figure 3.4 Let us assume that source voltage is 1.0 p. u and want to regulate the load voltage to 1.0 p.u. Let us denote the phase angle between v_s and v_i as. Further assume that during DVR operation, real power is not required except some losses in the inverter and the non-ideal filter components. These losses for the time being are considered to be zero. This condition implies that the phase difference betweenv_{DVR} and I_s should be 90^o. Let us first consider a general case to understand the concept. The DVR equivalent circuit with fundamental voltages and current is shown in Figure 3.4. Applying Kirchhoff's voltage law in the circuit, V_s +V_{DVR} = $I_S(R_{S+}jx_s)$ + v_i = I_S Z_S +V_I

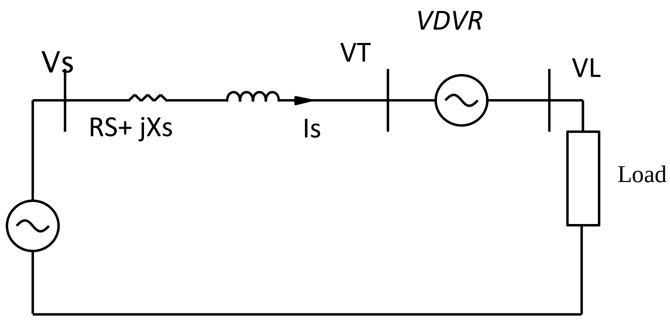

Figure 3.4 DVR based compensation diagram [10].

Note that in above circuit I_S=I_i = I. As shown below, the load voltage can be expressed in terms of load current and load impedance.

$$V_s + V_{DVR} = I\,(Z_S + Z_I) \quad (3.13)$$

Using (8), voltage source can be computed as follows

$$V_s = V_I + I_{\ RS} - (V_{DVR} - j_{IXS}) \quad (3.14)$$

Based on the above equation, the interaction of load voltage, voltages source and DVR voltages can be computed as follows.

$$V_I = \left(\frac{V_S + V_{DVR}}{Z_S + Z_I}\right) Z_I \quad (3.15)$$

From equation (9) Without DVR, the load terminal voltage V_I can be given as following.

$$I_l = \frac{v_s}{z_s + z_i} = \frac{1.0L0^0}{0.0242 + j0.003 + 0.0242 + j0.024_i} = 18.18L$$

$$V_I = I_L\ X\ \ Z_I = 18.18\text{ L} - 29.15^0\ X\ 0.0242 + j0.024 = 0.69\text{L } -15.5^0$$

The load voltage was lowered by 69%. The DVR is preferred to maintain load voltage and supply voltage in magnitude and phase angle. Thus, replacing $v_s = V_i$ in equation (8), we get,

$$v_s + v_{DVR} = I_s(Rs + jXs) + v_I$$

$$v_{DVR} = I_s(Rs + jXs)$$

$$v_{DVR} = v_{I\,(\frac{R_{S+jx_S}}{z_i})} = \frac{1.L0^0\ (\ 0.0242 + j0.003)}{0.0242 + j0.024} = 0.705L - 37.6^0\ p.u$$

Based on the above line current expressed as follows:

$$I_s = \frac{v_i}{z_i} = \frac{1L0^0}{0.0242+j0.024} = 33.33\text{L} - 44.76^0$$

It is to be noted that, although $v_s = v_I = 1$ L0º p.u, It doesn't mean that there is no power transfer from source to load. In actuality, the voltage at the entire effective source is as follows:

$$v'_s = v_s + v_{DVR} = 1\text{L } 0^o + 0.705\text{L} = 1.5\text{L } 15.42^0 \text{ p.u.}$$

Therefore, it indicates that the appropriate voltage source is leading the load voltage by an angle of 15.42º.

By assuming during high load condition, which means during swell condition neglect line resistance and load resistance v_{DVR} become:

$$V_{DVR} = \frac{1.L0^0 \ (\ j0.003)}{j0.024} = 0.125\text{p.u}$$

$$V_I = (1\text{L}0^0 + 0.125) \text{ p.u} = 1.125 \text{ p. u}$$

The real power of DVR in phase compensation method is calculated as follows: Since in phase compensation method $v_{DVR} = v_{sag}$

$$P_{DVR} = V_{DVR} X \ I_I \cos\theta_s = 167.14\text{V X } 33.33\text{L} - 44.76^0 \text{ X } \cos 0^0 = 3.954 \text{ KW}$$

$$P_L = \cos\theta \text{ X KVA} = 0.8 \text{ X } 75\text{KVA} = 60\text{KW}$$

$$Q_L = \sin\theta \text{ X KVA} = 0.6 \text{ X } 75\text{KVA} = 45\text{KV}$$

Because DVR has a limited amount of actual power and cannot adjust for greater levels of PQ issues. To avoid voltage sag, this strategy needs a big quantity of actual power, which necessitates a huge energy storage device.

At 25MVA, 132KV/15KV, 3-ϕ of transformer we can calculate the reactance and resistance of transformer in per unit as follows:

According to IEEE 141-1993 standard 25MVA, 132KV/15KV, 3-ϕ transformer has X/R = 7 and %Z = 10.

$\tan\theta = \frac{x}{z} = 7. \theta = \tan^{-1}(7) = 81.85^0$

$\sin\theta = \frac{x}{z} = \sin 81.85^0 = 0.989$

$\cos\theta = \frac{R}{z} \cos 81.85^0 = 0.1417$

X = 0.1 x 0.989 = 0.0989

R = 0.1 x 0.1417 = 0.01417

Therefore the reactance and resistance of the transformer in p.u is calculated as follows:

X_{trans}= (0.0989) ($\frac{25MVA}{25MVA}$) = 0.0989p.u

R_{trans}= (0.01417) ($\frac{25MVA}{25MVA}$) = 0.01417p.u

The back-boost transformer is characterized by decreasing and increasing voltage level which is rated according to “Dongan Company” in table Appendix F. Back-boost transformer character.

3.3.2 Voltage Source Inverter (VSI)

An electronic power system called a VSC is made up of switching and storage components. Any desired frequency, magnitude, and phase angle are produced as sinusoidal voltages. The purpose of an inverter system in a DVR is to temporarily replace the supply voltage or to create a deficient portion of the supply voltage by converting the DC voltage delivered by the energy storage device into an AC voltage. For the VSC, a variety of circuit topologies are possible. The two level or multilevel three-phase converters, which share a dc capacitor between all phases, are a commonly used technique. This capacitor's primary function is to reduce harmonic ripple; hence its energy storage needs are minimal, especially when it operates in balanced conditions. If necessary, this capacitor's size must be raised in order to maintain the voltage under imbalanced situations. Additionally, since the capacitor is shared by the three phases, sag or swell on only one phase might affect the waveforms of the injected current on the other phases. The H-bridge cascade inverter is another often utilized converter scheme. Because of their capacity to create waveforms with stronger harmonic spectra and reach greater voltages with a constrained maximum device rating, converters with this architecture are useful for high voltage or swell and power system applications.

3.3.3 Switching Devices

MOSFET, GTO, IGBT, and IGCT are the four primary types of switching devices (IGCT). Compared to the MOSFET and GTO, the IGBT is thought to be a more recent invention. In principle, it is a three terminal controlled switch that associations the GTO's high voltage capabilities with the MOSFET's quick switching speeds. This combination produces a medium speed-controlled switch that can handle the medium power range.

3.3.3.1 IGBT Sizing

Inverters or converters with high power often employ 'bridge' arrangements to create line-frequency alternating current to give two directional PWM driving to transformers, motors, or other loads. Bridge circuits include IGBTs, the emitters of which are switching nodes at high voltage and high frequency, necessitating that the gate drive PWM signal and corresponding drive power rails, which use the emitter as a reference, be 'floating' with regard to system ground, referred to as 'high side' drives. In addition, the drive circuit must be resistant to the switch node's high 'dV/dt' and have a low coupling capacitance. An IGBT's gate must be charged and drained during each switching cycle via *Rg* (internal and external gate resistance). The *IGBT* data sheet includes a gate charge curve, the interaction is as follows:

$$Pgd = Qg \ x \ F \ x \ Vs \qquad (3.16$$

Where: P -gate drive power,

Qg - data sheet charge for a chosen gate voltage swing, positive to negative, of value Vs. As per IEC 60747-9 data, extrapolate the parameters from the IGBT data below [20, 23]

I_C= 200A, Vce = 150V, Vge = ±15 V, Gate resistance is 2 for both the internal and external gates,

$Tc = 25^0 c \text{ and } Tj = 150^0 \ c$

Where:

I_C - is current collector

v_{ce}– is collector- emitter voltage

T_e– is gate emitter voltage

T_c– is temperature case

T_j – is temperature junction

The value of Qg at other gate voltage swings can be roughly determined by multiplying by the ratio of the actual versus data sheet voltage swings if the data sheet only provides a Qg value at particular gate voltages rather than a charge curve. Let see gate charge (Qg) value of 3.7 μC with ±15 V gate voltage swing 30 V. Gate charge approximates for a swing of +15 to -9 V total 24 V determined as:

Q_g = 3.7e-6 x 24/30 ≈ 3 μC

At 10 kHz this requires gate drive power is:

p_{gd} = 3μC x 10 kHz x 24V ≈ 0.72 W

In other case $P_{gd} = E \times F_{sw}$

By substituting $E = ½ \times Q_g \times (V_{gon} - V_{goff})$

$p_{gd} = ½ \times Q_g \times (v_{gon} - V_{goff}) \times F_{sw}$

Therefore $F_{sw} = \frac{2x\ Pgd}{Qg\ x(v_{gon} - v_{goff})} = \frac{2X0.72w}{3\mu C\ x(30v)}$ = 16 KHz, T_{sw}=62.5μs

Where

- p_{gd}– power gate driver
- Q_g– gate charge
- F_{sw} – frequency of switching
- T_{sw}– switching period

Pg/Vge = 30 mA, which is the discharge current and average charge given. The peak current Ipk, required to charge and discharge the gate is a function of Vge, gate resistance of the IGBT internal resistance Rg and external resistance Rg.

$I_{PK} = \frac{v_{sw}}{R_{gint} + R_{gext}} = \frac{24v}{2\Omega + 2\Omega}$ = 6A

Where

I_{PK}– The charge and discharge peak current required

V_{SW}–swing gate voltage

R_{gint} – Internal gate resistance

R_{gext}– External gate resistance

The all gate drive energy *E* per cycle is given by:

$E = Q_g$ x V_{ge}= 72 μ

The bulk capacitors on the +15 and -9 *V* rails supply this energy in proportion to their voltages so the +15 *V* rail supplies *45μ.* Calculate the minimal capacitance "*C"* by multiplying the energy delivered by the capacitor's energy difference between its start and finish voltages, shown as:

$$45\ \mu J = \frac{1}{2}\ \text{C}\ (v_{inital} - v_{final})^2 \qquad (3.17)$$

$$\text{C} = \frac{2\ x\ 45e^{-6}}{(15v - 14.5v)^{\ 2}}\ = 360\ \mu F$$

The switching "DC-link" voltage is driven over their barrier by either DC-DCs or high-side *IGBT*. Because of this large "*dV/dt,*" the DC-DC isolation barrier of value faces displacement current through its capacitance:

$$I = C.\ dV/dt \qquad (3.18)$$

The maximum allowable power dissipation (*Pdis*) in the *IGBT* for a specific case temperature using the datasheet parameters is given by [21]:

$$Pdis = \frac{\Delta T}{RTh} = \frac{Tj - Tc}{RTh} = \frac{(150-25)^2 c}{0.25K/W} = 1.5\text{kw}$$

The following formula is used to determine the size of the inverter needed for this system:

$$\text{Size of inverter} = \frac{Total\ load + 20\ \%AI}{E\%} = \frac{TI(1+20\%)}{E\%} = 66.5kw \qquad (3.19)$$

Where

Al – additional load 20% of entire load

E% - inverter efficiency (80%)

Total load – 44.3kw actual load

3.3.4 Passive Filters

Filters in *DVR* turn the inverted *PWM* waveform into a sinusoidal waveform by removing undesired harmonic components caused by the *VSI* operation. Passive filters use inductance, capacitance, and resistance components to regulate harmonics. They are widely used and very affordable when compared to other methods of removing harmonic distortion. They do, however, have the drawback of possibly interfering with the power system, and it is critical to test any possible system interactions when they are created. It used to shunt harmonic currents off the line or to prevent their flow between system components by adjusting the elements to generate a resonance at a specific frequency.

Shunt passive filters. The single-tuned "notch" filter is the most common form of passive filter. The notch filter is series-tuned to provide low impedance to a certain harmonic current and is shunt-connected to the power supply. Harmonic currents are therefore deflected from the line's usual flow route by the filter. In addition to 34 harmonic suppression, notch filters can provide power factor adjustment. Actually, power factor correction capacitors may be utilized to construct notch filters.

A shunt passive filter can be designed for this system and applied at a 415V source. The load where the filter was be installed is approximately 44.27kVA ($\sqrt{3}$ X 1XV *P.f)* with a power factor of 0.8 lagging.

A) Reactive power demand for a 65 percent power factor would be

- 44.27 x sin [cos^{-1} (0.65)] = 33.64kvar

B) Reactive power demand for an 80 percent power factor would be

- 44.27 x sin [cos^{-1} (0.8)] =26.56 kvar

C) Required compensation from the filter:

- 33.64kvar - 26.56 kvar = 7.07kvar

D) The corresponding filter reactance for a notional 4kvar15V system is calculated by:

$$X_{filt} = \frac{v^2}{Q} = \frac{415^2}{7.07kvar} = 24.3\Omega \qquad (3.20)$$

The capacitive reactance and inductive reactance at fundamental frequency differ by an amount called x_{filt}.

$$x_{filt} = x_{cap} - x_I \quad (3.21)$$

With respect to tuning at the 4.7th harmonic:

$$x_{cap} = h^2 x_I = 4.7^2 x_I \quad (3.22)$$

As a result, the desired capacitive reactance may be calculated by:

$$X_{cap} = \frac{x_{filt + h^2}}{h^2 - 1} = \frac{24.3 \ x \ 4.7^2}{4.7^2 - 1} = 25.5\Omega \quad (3.23)$$

To achieve this reactance at a 415V rating, the capacitor would have to be rated.

$$Q_C = \frac{v^2}{x \ cap} = \frac{415^2}{25.5\Omega} = 6.75\text{kvar} \quad (3.24)$$

The filter was designed by using a rated 6kvar capacitor and a 415V capacitor. It is a frequently used size close to the required value. Capacitor rating, x_{cap} = 25.5 Ω

Compute filter reactor size.

$$x_{L \ fund} = \frac{x_{cap}}{h^2} = \frac{25.5\Omega}{4.7^2} = 1.15\Omega \quad (3.25)$$

$$L = \frac{x_{L \ (fund)}}{2\pi \ x \ 50} = 3.67\text{mH}$$

And harmonic frequency is given by:

$$F_h = \frac{1}{2\pi\sqrt{Lc}} \text{ where is } 4.7 \text{ x } 50\text{Hz} = 235\text{Hz} \quad (3.26)$$

$$c_{eq} = \frac{1}{4\pi^2 (Fh)^2 \ L} \ 125\mu\text{F}$$

At the fundamental frequency, the combined capacitor and reactor's apparent reactance is determined as:

$$X_{fund} = |x_{L \ fund} - x_{cap}| = |1.15\Omega - 25.5 \ \Omega| = 24.35 \ \Omega$$

The fundamental frequency filter current is:

$$I_{fund} \frac{v_{actual}}{\sqrt{3}\,x\ X_{fund}} = \frac{415v}{\sqrt{3}\,x\ 24.35} = 9.8\text{A}$$

The fundamental frequency operating voltage across the capacitor bank is:

$$v_L = L_{cap} = \sqrt{3}\ \text{X}\ I_{fund}\ X\ x_{cap} = \sqrt{3}\ \text{X 9.8A X 25.5}\ \Omega = 432.8\text{V}$$

This is the capacitor's nominal fundamental voltage. It needs to be adjusted for any unanticipated conditions and be less than 110 percent of the capacitor's rated voltage (maximum system voltage). The actual reactive power produced exceeds the capacitor rating because the filter draws more fundamental current than the capacitor by itself:

$$Q_{var(fund)} = \sqrt{3}\ \text{X}\ I_{fund}\ X\ Vactual = 7\ .04\text{Kvar}$$

3.3.5 DC Charging Circuit

DC charging circuit provides two purposes: the first one is for charging the energy source following a sag compensation event, and the second purpose is to keep the dc link voltage at the nominal dc link voltage. The dc-link is charged using a variety of topologies, such as an external power supply or by attaching the DVR's dc side to a regulated or uncontrolled rectifier to maintain the dc voltage. An auxiliary feeder or a main power line can be attached to the rectifier's opposite side.

As a broad range of voltage fluctuates during discharging and charging, it serves as an interface circuit in an energy storage system for UCAP. Furthermore, if an inverter is attached, the UCAP is required to give a consistent DC voltage to the inverter circuit. As a result, the DC-DC converter is crucial in this system. Figure 3.4 depicts a two directional DC-DC converter type using UCAP as energy storage. The DC-DC converter should be able to resist the power generated during the discharge mode during a voltage sag or swell event. The quantity of active power assistance is determined by the depth and period of the sag. In contrast, during a swell condition the DC-DC converter may be able to absorb the system's increased power [18]. Thus, a bidirectional DC-DC converter operates in boost mode when draining and buck mode while charging.

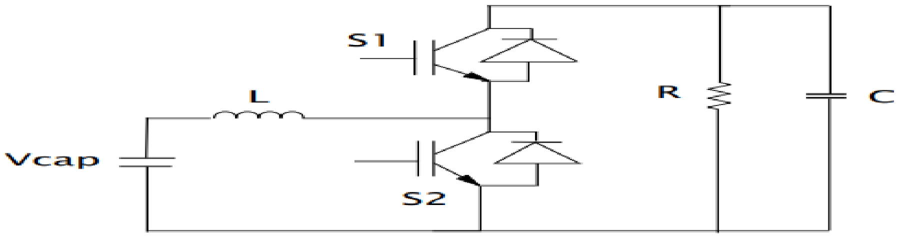

Figure 3. 5 Two directional DC-DC converter with UCAP model [19].

There are several DC-DC converter circuits that can change the amplitude of the DC voltage or invert its polarity. The switch in this proposal is achieved utilizing IGBT semiconductor switches. The average output voltage (V out) is a function of the IGBT switch's duty cycle (D). In the buck converter, the dc voltage is reduced and the conversion ratio M (D) = D [14]. A boost converter, which uses a similar design, generates an output voltage (V out) that is larger in magnitude than the input voltage (Vin). It has the conversion ratio M (D) = 1/ (1 – D). The switch in a buck-boost converter alternately links the inductor across the power input and output voltages.

This converter inverts the polarity of the voltage and can raise or reduce the magnitude of the voltage. M (D) = - D/ is the conversion factor (1 – D). As a result, the duty cycle (D) is determined by the output voltage requirement of the three-level bridge IGBT switch as well as the input voltage drop at the dc-link.

$$V_{out} = \frac{1}{1-D} V_{in} \tag{3.27}$$

3.3.6 Discrete Pulse Width Modulation (PWM)

The purpose of the discrete pulse modulation control scheme is to conserve a steady voltage amount at the critical load point even when the system is disrupted [12]. The control system, for example, just measures the RMS voltage at the load point; no reactive power measurement is necessary. The output pulses are in the form of a vector (with values of 0 or 1). The output vector contains: Two pulses for a one-arm bridge, depending on the "Generator Mode" choice. The bottom switch is controlled by pulse 2, while the upper switch is controlled by pulse 1. For a two-arm bridge, use four pulses. The upper switches of the first and second arms are controlled by pulses 1 and 3, respectively. Pulses 2 and 4 control the lower switches.

For a three-arm bridge, use six pulses. The upper switches of the first, second, and third arms are controlled by pulses 1, 3, and 5, respectively. Pulses 2, 4, and 6 operate lower switches. Twin 3-arm bridges require twelve pulses. The first 3-arm bridge must get the first six pulses (numbered 1 through 6), whereas the second 3-arm bridge must receive the last six pulses (numbered 7 through 12). By choosing "Internal generation," we can alter the output voltage's modulation index (m), frequency, and phase based on the internal parameters (m, Freq, and Phase). If not, external signals are employed to generate pulses. For single phase bridges (1-arm or 2-arm), the input vector's width must be 1, and for 3-phase bridges, it must be 3. (Single or double bridge).

3.3.7 Ultra-capacitors

Due to the electrodes utilized in these capacitors, ultra-capacitors differ from other types of capacitors. The technology of ultra-capacitors is based on carbon. The energy is stored by charge transfer at the border between the electrode and the electrolyte in an ultra-capacitor, which is a double-layer capacitor. Ultra-capacitors are coupled in series and parallel to get the higher voltage and suitable energy storage capacity. Due to the massive equivalent series resistance of the ultra-capacitor, which prevents the enormous amount of energy it stores from being distributed to the load, peak power is primarily constrained by joule losses in the ultra-ESR capacitor's [18].

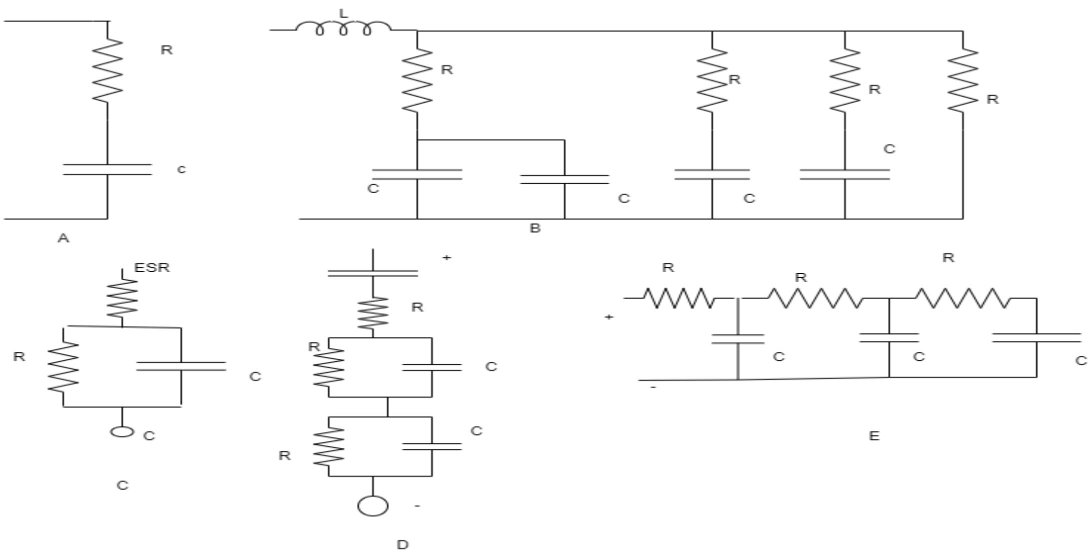

Figure 3. 6 (A) simple UC model (B) RC parallel branch model (C) UC model with ESR and RP (D) RC branch series-parallel model (E) transmission line model [21].

Different authors are proposed the modeling of U-CAP to study its electrical behavior under various operating condition. The model in Figure 3.6 (A), (C) and (D) are incomplete to describe the behavior of UC under various operating conditions. Therefore, more efficient ultra-capacitors models have been proposed recently by many authors are shown in Figure 3.6 (B) and (E). In this study transmission line model of Ultra capacitor is selected to rate the size of Ultra capacitor according to specified load.

3.3.8 Phase Sequence Analyzer

The three input signals are initially subjected to a Fourier analysis across a sliding window of one cycle of the given frequency to determine phasors Va, Vb, and Vc at fundamental or harmonic frequencies. The Vabc to 120 transformations are then used to generate the positive-sequence (V1), negative-sequence (V2), and zero-sequence (V0). This block can be used in a control system to monitor a positive sequence voltage or current. It is not affected by harmonics or unbalances. However, it causes some latency, as would any filtering system. Its reaction to a step change in V1, for example, is a one-cycle ramp.

3.4 Operating Principle of DVR

The DVR's primary role is to inject a dynamically regulated voltage,V_{DVR} created by a Forced commutated converter into series with the bus voltage through a booster transformer. The momentary amplitudes of the three injected phase voltages are managed such that any negative effects of a bus malfunction on the load voltage are eliminated (VL). This implies that any differential voltages induced by transitory disturbances in the alternating current feeder were compensated for by an equivalent voltage created by the converter and injected at the medium voltage level via the booster transformer.

The DVR operates regardless of the sort of fault or event that occurs in the system, as long as the entire system is plugged into the supply grid, i.e., the line breaker is not shut off. In the majority of practical cases, correcting for the positive and negative sequence compartment of the voltage disturbance observed at the DVR's input may result in a more economical solution. This solution is reasonable because the stepdown transformer's infinite impedance prevents a disturbance's zero sequence component from passing through it in a typical distribution bus configuration. Protection mode, standby mode, and injection/boost mode are the three operational modes for the DVR.

3.5 Methodology

Improving the power quality by Integration of ultra-capacitor and dynamic voltage restorer and RBFN is involves the step of procedure. First it starts the collection of voltage disturbance data from the EEP, according to IEEE standard and interruption frequency from Hawassa substation. At Hawassa substation there are fourteen feeders. Then for each of feeder the power supply, current and the rated three phase voltage are identified. Depend on the amount of the voltage the integration of UCAP and DVR was designed by sizing all the equipment and component which is utilizes in this system depend on the load. During the fault the result of voltage sag and voltage swell without integration of UCAP –DVR and with UCAP –DVR connection in series to the line is shown by matlab/simulink modeling.

3.5.1 Data Analysis

In order to solve voltage Sag and voltage Swell for distribution system the research methodology was used. This type of research methodology is used to rate the capacity of ultra-capacitor storage, DC-DC converter, series inverter (DVR) in terms of voltage, current and power based on the load profile at the location. The activities of this study was classified into two steps:

First step: Review, Data collection and Analysis:

- Data was collected from EEP, EEU, general literature, website, international journals, different books, You Tubes and online information.

Second step: Result and simulation was specified.

- Based on the load requirement and specified the ultra-capacitor, DC-DC convertor and DVR are rated. The simulation model for the proposing system is developed in MATLAB/simulink software.

3.5.2 Realization of Hawassa Distribution System

The distribution system is the electrical system between the sub-station fed by the transmission system and the consumer meter. The general parts of the distribution system are, distributors and service mains.

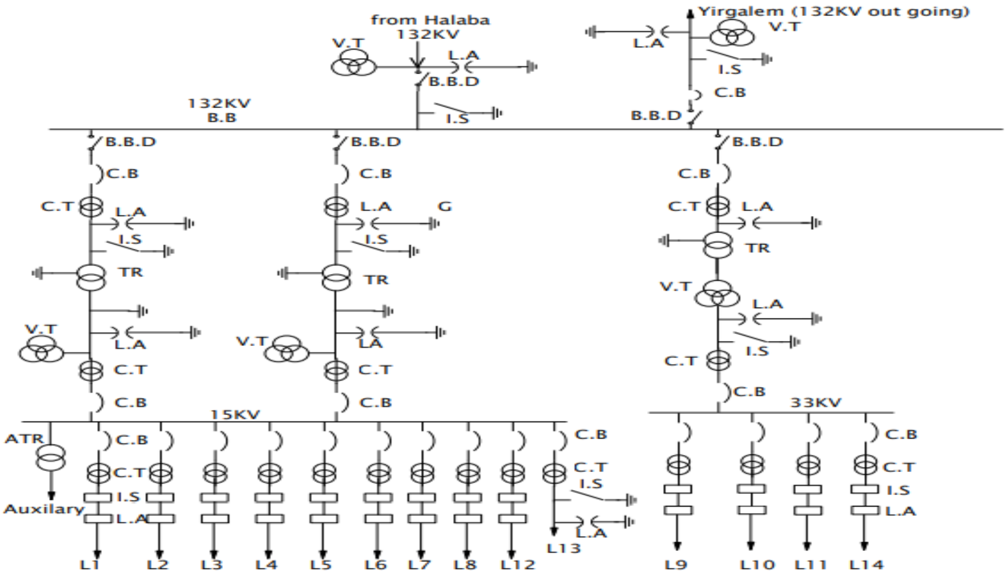

Figure 3. 7 Hawassa city substation, feeder and distribution system block diagram legend.

Source: Ethiopian Electric power

Where:

I .S – Isolated Switch

B.B .D – Bus Bar Disconnect

C.B – Circuit Transformer

C. T – Current Transformer

V, T –Voltage Transformer

L.A – Lightning Arrester

ATR- Auxiliary Transformer

TR- transformer and G- Ground. During load condition the maximum and minimum current of the feeder is describe based on EEP from figure 3 .7

Table 3. 1 Feeder maximum and minimum current value of each feeder

Line	Maximum Current (A)	Minimum current (A)	Voltage level (KV)
1	232	80	15KV
2	60	8	15KV
3	66	10	15KV
4	240	40	15KV
5	280	60	15KV
6	167	43	15KV
7	77	11	15KV
8	110	20	15KV
9	9	5	33KV
10	18	8	33KV
11	52	15	33KV
12	96	27	15KV
13	167	42	15KV
14	9	5	33KV

$$P = \sqrt{3}\ VI \cos\theta \qquad (3.\ 28)$$

The power quality is characterized in different categories depend on the duration of variation. From those according to IEEE 1159:1995 standard some of categories which related with this proposed are illustrated in table 3.2 below .and the permanent and temporary fault of frequency duration of Hawassa city distribution system was daily recorded at substation site as shown in table 3.3.

Table 3. 2 Power quality categories and its problem

Categories	Effect		Duration	Voltage magnitude pu
Short duration Variation	Instantaneous	Interruption	0.5 -30 cycles	< 0.1 pu
		Sag (dip)	0.5 -30 cycles	0.1 -0.9 pu
		Swell	0.5 – 30 cycles	1. 1 – 1.8 pu
	Momentary	Interruption	30 cycles -3s	< 0.1 pu
		Sag	30cycles -3s	0.1 -0.9 pu
		Swell	30 cycles -3s	1 .1 – 1.2 pu
	Temporary	Interruption	3s -1 min	< 0.1 pu
		Sag	3s -1 min	0.1 -0.9 pu
		Swell	3s -1 min	1.1 -1.4 pu
Long duration Variation	Under voltage		> 1 min	0.8 -0.9 pu
	Over voltage		>1 min	1.1 -1.2 pu

Table 3. 3 Interruption data of Hawassa distribution in June, 2022

Line (L)	Pef/month	Psc/month	Tef/month	Tsc/month	Sol/month	Oper/month
1	1 – times	4 – times	2 – times	12 – times	No	9 – times
2	No	No	No	No	No	2 – times
3	No	No	No	No	No	1 – times
4	4 – times	6 – times	2 – times	4 – times	No	12 –times
5	4 –times	4 – times	5 – times	12 – times	No	7 – times
6	6 – times	3- times	6 – times	9 – times	No	10 – times
7	No	3 – times	7 – times	14 – times	No	9 – times
8	No	2 – times	No	4 –times	No	1 – times
9	No	No	No	No	No	9 – times
10	13 – times	17 – times	4 – times	10 – times	No	11 – times
11	No	2 - times	No	No	No	3 – times
12	6 – times	7 – times	7 – times	10 – times	No	13 – times
13	5 – times	4 – times	2 –times	11 – times	No	7 – times
14	1 – times	1 – times	No	No	No	3 – times

Where:

Pef - is permanent earth fault

Psc - is permanent short circuit

Sol – is system over load

Tef –is temporary earth fault

Tsc – is temporary short circuit

Oper – is operational fault

The above table 3.3 data is taken from Hawassa substation which is shown the monthly occurred system faults. Through in days or within a period of time there is fault occurring on each of the feeder. Even though as gathered the data some of line are mostly occurring with the faults rather than others. This is due to the environmental problem, unbalanced load on a three-phase scheme, equipment not suitable for local supply and switching of heavy load. So as shown in table 3.3 above line number seven is familiar with this reason and it is selected as reference feeder in this paper to propose and to simulate by MATLAB.

The source of power supply means 132KV is supplied from Halaba town which is connected at point of common coupling (PCC) to 33/15/15 KV. But in this study, it is proposed that at custom power source which is supplied from single 15KV or 415V connected byΔ/Y. In the figure 3.8 below which shown the distribution system and the integration of UCAP- DVR connected in series to mitigate the power quality.

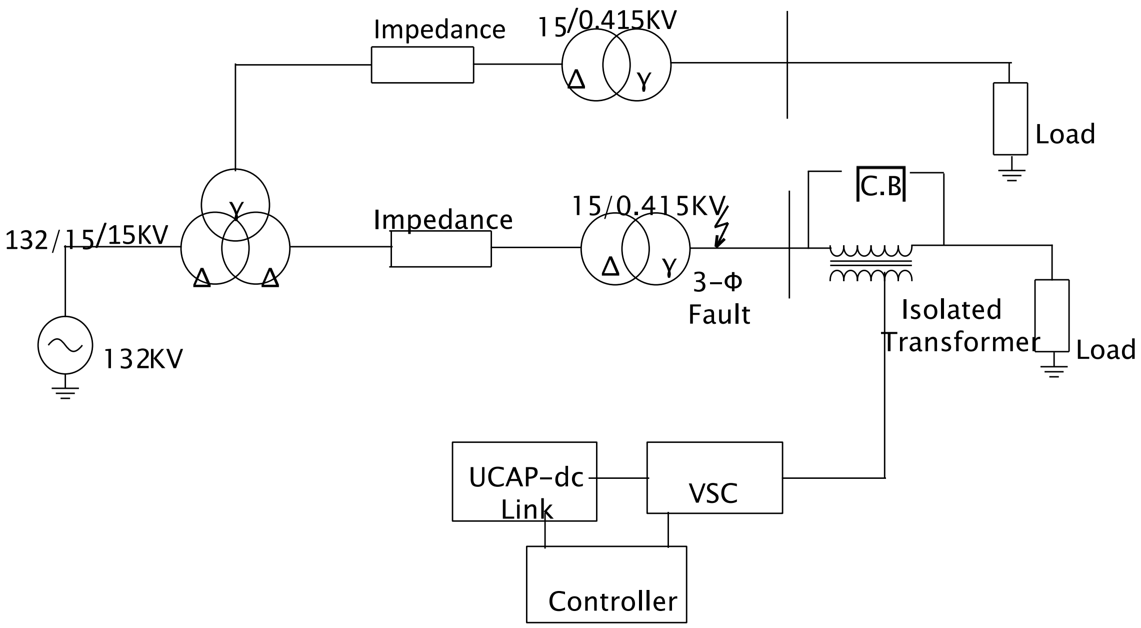

Figure 3. 8 Schematic diagram of UCAP-DVR test system

The UCAP –DVR simulation with their controller is verified for voltage compensation of the fault occurring at the point of 3 phase fault sign shown at figure 3.8 with the specified fault resistance and time duration (i.e., explained in simulation).

3.5 Conceptual Frame Work

Electric power is more essential for modern life and important to any for increasing the development in industrial applications and any other application so the power quality issues. To improve the power quality, we design mitigate voltage control performance by DVR as the country standard parameters using RBF network to do these, follow the flowchart show in Figure 3.9 summarizes the procedures that involves in this study to achieve its objective.

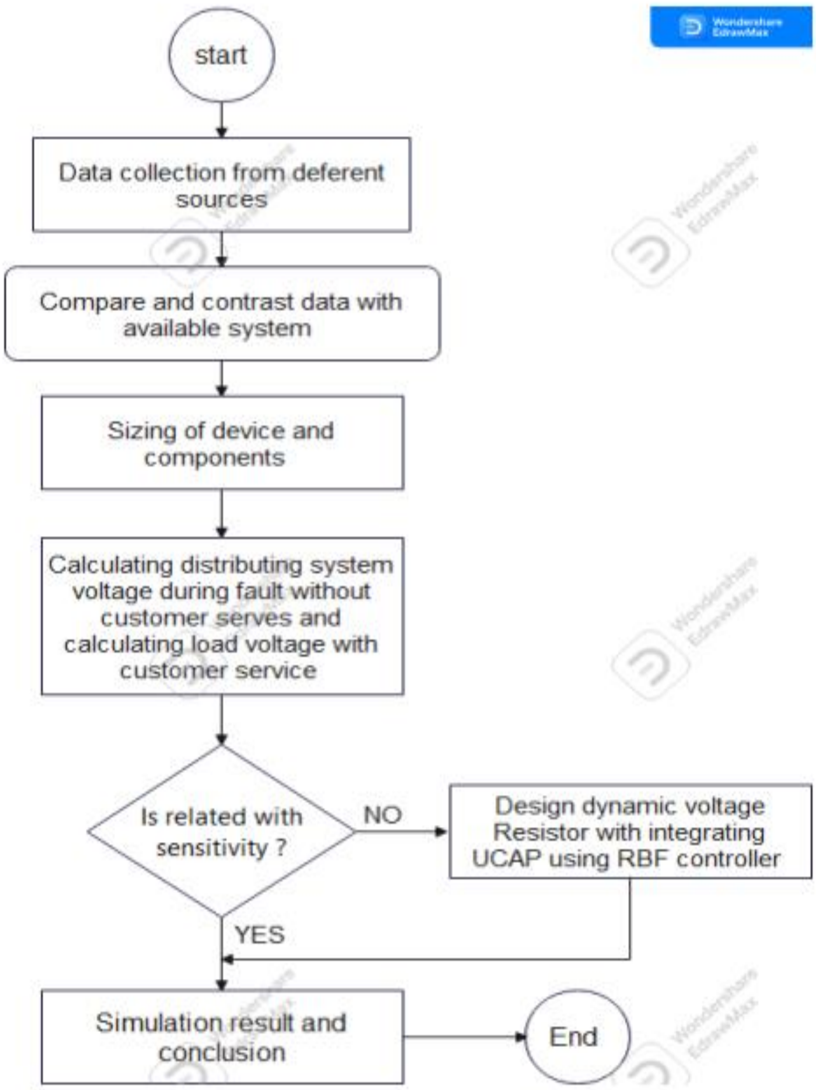

Figure 3. 9 Chart of overall thesis work methodology.

Figure 3.10 illustrates all interactions within the mitigate voltage control performance by DVR as the country standard parameters using RBF network. All of these interactions were considered in the development of the model.

In this thesis, Mitigation of voltage control performance by DVR as the country standard parameters using RBF network.

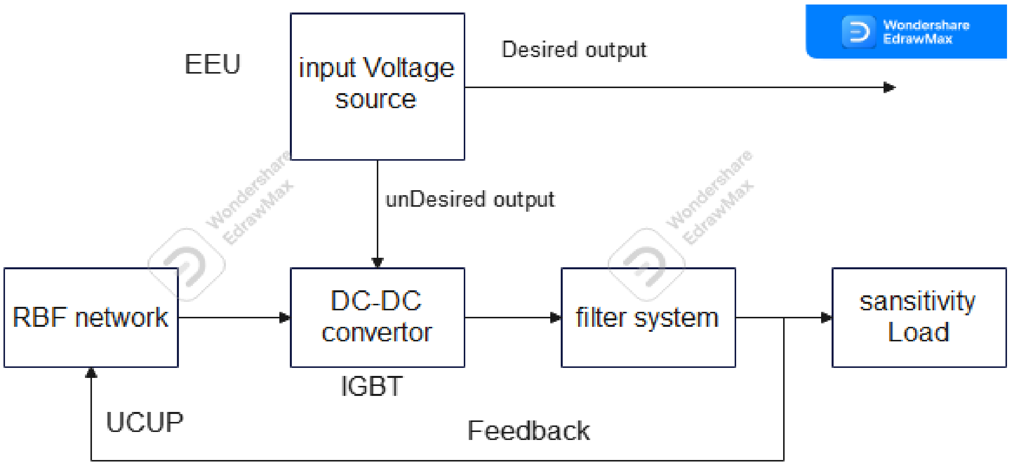

Figure 3. 10 Block diagram detail structure of conceptual framework of the study

All interactions inside the RBF networks mitigate voltage control performance utilizing DVR's typical country parameters in the process of developing the model, all of these interactions were taken into consideration.

In this, RBF network is used to reduce the voltage control performance utilizing DVR as the uniform standard parameters. The progress in improving the power quality of the system by integration of ultra-capacitor and dynamic voltage restorer is involves the step of procedure. First it starts the collection of voltage disturbance data from the EEP, EEU, according to IEEE standard and interruption frequency from EEP substation. Then for each of feeder the power supply, current and the rated three phase voltage are identifier.

Depend on the amount of the voltage the integration of UCAP and DVR is designer by size all the equipment and component which is utilizes in this system depend on the load.

During the fault the result of voltage sag and voltage swell without integration of UCAP - DVR and with UCAP -DVR connection in series to the line and RBF controller is show by MATLAB/Simulink model. Data Analysis In order to solve the voltage Sag and swell for distribution system the research methodology way use.

3.6 Overvoltage & under voltage

It is frequently caused by high distribution voltage caused by inappropriate transformer tap settings, shutting off a huge load, or excessive voltage drop correction on transmission and distribution systems, such as activating many capacitor banks. Overvoltage and under voltage are quality issues that can occur for a variety of causes. Overvoltage and can have serious consequences, including failure in the event of overvoltage and overheating and burning of motor coils in the case of under voltage.

Overvoltage: There is a common misperception that a voltage greater than the standard rated voltage amount equals increased output or efficiency. In actuality, this is not the case, and it causes more harm than benefit. Before we go into why overvoltage is harmful to equipment, let's define it. To be more specific, it occurs when a supplier voltage of 10 percent and above the rated motor voltage occurs, as seen from the listed standards.

When overvoltage happens for the first time, it generally affects the delicate system components - motherboards and circuit boards. All of these small electronic circuits are incapable of handling any more voltage and current peaks. Furthermore, it causes overheating because excess heat is converted instead of operational output like torque. All of this heat continued to build up, eventually causing the bearing and insulation systems to fail. Overvoltage and under voltage are both quality issues that can occur for a variety of causes. Overvoltage and under voltage can have serious consequences, including overheating insulation failure in the event of overvoltage.

Under voltage: occurs when the average voltage of the device falls below the rated voltage amount. Under voltage can degrade equipment performance and reliability if it occurs frequently. The winding suffers a significant amount of wear and tear, reducing the equipment's lifespan. Insufficient voltage indicates that the equipment must draw additional current to fulfill power needs. As a result of being unable to meet these requirements, the equipment is unable to function correctly.

The consequences are especially severe when the equipment's scale of application is used on industries and transmission distribution, The grid's interconnecting generators, transformers, compressors, loads, and static capacitors are all set to run as close to their maximum load and stipulated voltage as possible. The equipment will function sub parley and eventually break down when it is not operating at the rated voltage. The power quality is therefore transitory. Variation in both short and long durations. Sag, swell, and interruption are all examples of short.

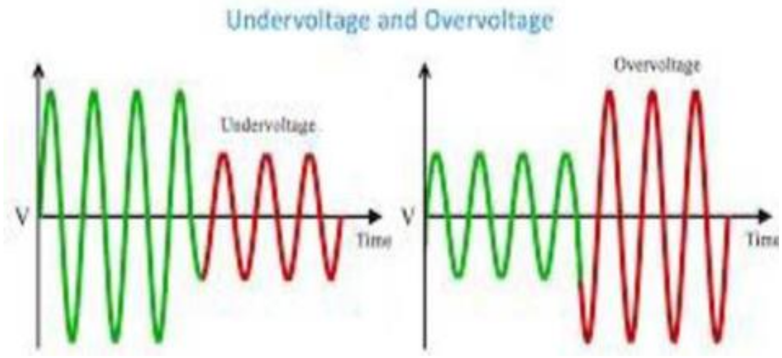

Figure 3. 11 Over voltage and under voltage.

Source of Dynamic Voltage Restorer (DVR) Control Using MATLAB/ Simulink [Part4] [28].

Three phase electric power (3 ∅) is a typical type of alternating current used in power generation, transmission, and distribution. A sort of polyphaser system that uses three or four wires with an optional neutral return line and is the most extensively utilized mode of power transfer by electrical networks globally. Three phase electricity is based on the voltage and currents on the three wires being 120 degrees out of phase. As an alternating current system, it enables voltages to be easily stepped up to high voltage for transmission and back down to low voltage for distribution, resulting in high efficiency.

CHAPTER FOUR

CONTROLLER DESIGN

The method that works best for addressing non-linear problems with a lot of variables is an ANN. Self-organizing, quick parallel computation is one of ANN's key characteristics. Dealing with non-linearity makes the system dependable and has a quicker dynamic response.

Main Features of ANN: -

- A non-linear model which is easy to implement and understandable compared to other well-known statistical methods.
- Permits the modeling of physical parameters in large size systems without the requirement of unambiguous mathematical equations and experimental data.
- Adaptive to complex problems and can handle different level of complexity by changing the network topology.
- Quite easy and simple but it requires large amount of data related to input parameters to predict the output over a wide range of possibilities when training the same.

It is necessary to have output signals for each phase's current as well as for the ground current in order to categorize all forms of errors. Therefore, a total of four output variables is required.

- ✓ Set the output signal to "0" as the output signal for the normal system.
- ✓ Set the output signal to "1" for the fault condition.

4.1 Radial Base Function

Radial Base functions (RBF) network (in its natural form) has a single hidden layer of non-linear feed-forward networks and universal approximations, In RBF networks, the hidden nodes (basis functions) act quite differently from the output nodes and serve very distinct purposes. The distance between the input and the "weights" (RBF centers) is the argument of each hidden unit activation function in RBF networks. RBF networks are typically trained one layer at a time, with the initial layer unsupervised. RBF networks tend to use localized non-linearity's (Gaussians) at the hidden layer to construct local approximations. In back propagation neural network radial basis function is the most advantageous since it can approximate an arbitrary nonlinear function by training data with enough neurons. It is also more advantageous than the back propagation networks. It is able for online approximation of functions which are nonlinear.

From the different types of the membership function Gaussian radial basis function (GRBF) is the most commonly used which is expressed as:

$$f^{NN}(x) = \sum \alpha_{k} R_{k}(x) \quad . \; k = 1, 2. . . M, \tag{4.1}$$

$$R_K(x) = \exp[- v_k^2 \; |x - c_k|^2], \tag{4.2}$$

Where R_k (x) = is the Gaussian activation function for the

c_k = Center,

v_k = width, $\alpha\hat{e}$ -amplitude

RBF controller is capable of enhancing the transient stability by accomplishing the reduction of

1. Fault severity
2. Accelerating power

Feedback linearization with nonlinear excitation requires the machine angle and it is not capable to take care the network parameter variation. Due to these reasons the feedback linearized controller is not satisfactory. RBF is suggested to enhance the stability at the first swing. The system frequency can be monitored by NN while if there results in insufficient excitation and if the frequency value is corrupted RBF NN was provided power set which is able to communicate with other sets which are able for system frequency control.

The universal approximation and quicker learning pace of radial basis function networks set them apart from other neural networks. Three layers, the input layer, the hidden layer, and the output layer, make up an RBF network, a form of feed-forward neural network.

Numerous applications of radial basis function networks exist, such as function approximation, classification, time series prediction, and system control. Broom head and Lowe, two researchers of the Royal Signals and Radar Establishment, first proposed them in a 1988 study.

4.2 Structure of RBF NN

RBF NN consists of a single hidden layer with an output and input layer and to set of weights to connect the hidden layer with the output layer. It has simple structure than back propagation neural network.

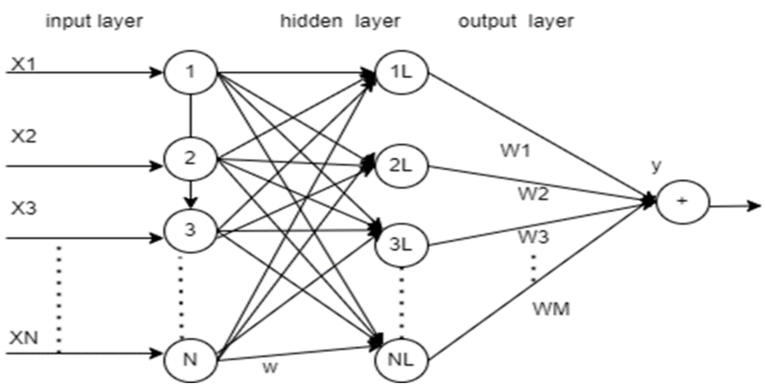

Figure 4. 1 Architecture of RBFNN

Where

X – Input layer

Y – Output layer

L –hidden layer

W – Weight

WM – nonlinear weight

Sake of simplicity only one output variable, y, in structure of considered figure 4.1 is the solution procedure in RBF therefore output y of the RBFNN becomes

$$y= \sum_{j=1}^{m} wj \,.\, \emptyset(\|x - cj\|) \quad (4.4)$$

Where: w_j is the weight between the hidden layer and the output layer.

$$e\,(p) = d\,(p) - y(p) \quad (4.5)$$

Then, the objective function for the error of (4.4) can be

$$E\,(p) = \frac{1}{2} e^2(p) = \frac{1}{2}\,(d\,(p) - y\,(p)) \quad (4.6)$$

4.3 Training of RBF NN

The training of RBF done in three sequential steps, the first stage is determination of clustering center and the next stage is determining the unit width. The reason why we choose Radial basis function neural network for the controls of Mitigation of voltage control performance by DVR is that Radial basis function neural network have useful of easy design, generalization ability, strong tolerance to noise and also fast online learning capability, RBF network make it is suitable to design and flexible control scheme.

The highest possibility of power quality disturbance the voltage sag and voltage swell in the power quality system dynamic voltage restorer is the main scheme to mitigate performance dynamic power quality disturbance, to obtain enhanced dynamic performance RBFNN control simple control effect and strong robustness control parameter of DVR and using RBF network the greater dynamic performance control and strong robustness.

To success RBF network-based mitigation of DVR's voltage control performance for the required parameters using the proposed controller has need a trainer to control the overall system so we take input and output training data as follow in the table 4.1 below.

Table 4. 1 Radial base function neural network input and output training data

line	fault current	Max. Coeff. Ø A	Max. Coeff. Ø B	Max. Coeff. Ø C	Max. Coeff. Ø G	o/p of A	o/p of B	o/p of C	o/p of G
1	ABC-G	86..8863	239.4336	0	42.7720	0	1	1	1
2	ABC	86.8863	186.6853	0	0	1	1	0	0
3	AB-G	86.8863	0	239.4336	0	1	0	1	0
4	AC-G	0	86.8863	239.4336	0	0	1	1	0
5	BC –G	1352300	103.9772	103.9772	160870 0	1	0	0	1
6	A-B	103.9784	3702400	134.3960	42.7725	0	1	0	1
7	A-C	130..9784	103.9772	103.9772	7.1737	0	0	1	1
8	B-C	1609700	4072500	16097000	157850	0	0	0	0
9	A-G	1609700	40725000	16097000	0.0081	1	1	1	1
10	B-G	7817800	20564000	103.9772	164700	1	1	1	0

Where: -

Coff. = Coefficient

Max. = Maximum

O/p = output signal

- ✓ Set the output signal to "0" as the output signal for the normal system.
- ✓ Set the output signal to "1" for the fault condition.

∅ = phase voltage

Radial basis function networks offer the advantages of being simple to construct, having high generalization, being resistant to input noise, and having the capacity to train online. As previously noted, the features of RBF networks make them ideal for designing flexible control systems. Various methods for creating and training RBF networks. A freshly discovered approach for building small RBF networks and conducting efficient training is presented. Finally, numerous tasks are used to assess the major aspects of RBF networks, such as their generalization ability, tolerance to input noise, and capacity to train online. Traditional neural networks are also compared to RBF networks.

Radial basis function Neural Networks for power system fault identification and classification first load the input and output training data in to MATLAB workspace, if saved the training data anywhere in the computer make to add the data to the MATLAB Workspace and also add all the input and output data with the testing data. Then to train the Radial basis function Neural Networks used the given input output data in a MATLAB code having its own syntax indicated in appendix.

For power system fault identification and classification, the indicated MATLAB code is similar to train Radial basis function Neural Networks for error goal identification and classification, In the MATLAB code the first two lines indicates the input and output training data, line three represents the error Goal which is set to zero such like these each line has its own necessary operations for a better working principle in the system.

When start screening by the play button to train Radial basis function Neural Networks of input output training data during this task when we observe Radial basis function Neural Networks is completed within a short period of time in all indicated possible cases, with hundreds of Neurons it has provided highest successful training with very small error we say Radial basis function Neural Networks is successful. After play the input output training data Radial basis function Neural Networks in a MATLAB workspace section it creates another file types, this file creates after successful training of Radial basis function Neural Networks training to test the performance and accuracy of Radial basis function Neural Networks for all possible indicated cases that is four cases.

This task gives presented in a MATLAB code as we train the Radial basis function Neural Networks using input output data, the first line represents the input tasting data and the second line used to simulate the trained RBFNN to test its performance for all four cases etc. then we obtain the result in the columns for all four cases. Finally, the compression operation according to its better performance and accuracy for all cases of RBF network-based mitigation of DVR's voltage control performance for the required parameters when accuracy is more than 90% it is acceptable selecting training system for controlling the voltage sag and voltage swell in the power quality system.

CHAPTER FIVE

RESULTS AND DISCUSSION

As discussed in the rate of injection transformer and distribution transformer are determined separately. In this study injection transformer is used as custom power device and the nominal voltage is dip with 168.2V or reduced by 70.08% of actual load voltage during fault condition. This result may be changed if the fault location is changed. Depend on the available load the apparent power of injection transformer was rated at 75KVA, which is equal with available distribution transformer.

During single phase to ground fault at available distribution transformer the missed voltage and voltage sag was calculated. So, in order to inject the missed voltage injection transformer is supplied from the storage device via inverter with 415V AC. That means UCAP is deliver 216.8V of DC-voltage, which is used as an input for DC-DC converter. Then at DC- link the output of DC-DC converter was rated at 300V of DC- voltage. This fixed DC- link voltage is inverted to injection transformer to mitigate the missed load voltage from distribution line. As a general the size of transformer and their parameter are specifically described in table 5.1 below.

Table 5.1 Transformers and their parameter size

Parameter	Injection transformer	Distribution transformer	Substation transformer
Rated voltage (V)	415	15,000/415	132,000/15,000
Power (KVA)	75	75	25,000
X (p.u)	0.021	0.024	0.0989
R (p.u)	0.0242	0.0242	0.01417
Z (p.u)	0.032	0.034	0.1
Zf (p.u)	0.073	0.078	_
Missing voltage (V)	168.2	167.14	_
Vsag (V)	71.8	72.86	_
Short circuit current(A)	3260.6	3061.37	_
phase	3-ϕ	3-ϕ	3-ϕ

According to IEC 60747.9 IGBT parameter standards data the switching frequency (Fsw) and switching period (Tsw) of the IGBT switching device was calculated. And also depend on the case temperature and junction temperature the maximum allowable power of IGBT was calculated, which is shown in table 5.2 below. The filter system is designed by connecting capacitance and inductance in parallel to convert the inverted PWM wave form into sinusoidal wave form. Their rated value is shown in table 5.2 below. The capacitance of Ultra capacitor which used as energy storage was designed for discharge duration of 5 seconds rated at 761F of capacitance and the equivalent capacitance is become 9.4F. But according to Maxwell technology the related UCAP available on the market is 800F, 2.7V per cell, equivalent series resistance of less than 1mΩ, leakage current of 1.5mA and current rate of 70A. The input DC voltage required for this study is designed to 216.8V and 81 UCAP cell is connected in series to supply such amount of DC voltage. Depend on the equivalent series resistance, current rate of UCAP and time duration of discharge the required maximum energy and maximum power for this proposed was calculated and shown in table 5.2 below. The missed voltage and voltage sag during single phase to ground fault without using custom power device is 0.696p.u and 0.304p.u respectively. The DVR voltage was designed at 0.705p.u to mitigate the missed voltage and also shown in terms of percentage and voltage measurements in table 5.2 below.

Table 5.2 Size of components and their parameter

<table>
<tr><td rowspan="2">Switching Device (IGBT)</td><td colspan="2">Fsw</td><td colspan="2">Tsw</td><td>I c</td><td>VCE</td><td>Vge</td><td colspan="2">Qg</td><td>Pdis</td></tr>
<tr><td colspan="2">16 KHz</td><td colspan="2">62.5μs</td><td>200A</td><td>150V</td><td>±15 V</td><td colspan="2">3 μC</td><td>1.5KW</td></tr>
<tr><td rowspan="2">Filter</td><td colspan="2">X_{cap}</td><td colspan="2">Q_C</td><td>L</td><td>Ceq</td><td>F_h</td><td colspan="2">V_{L-Lcap}</td><td>I_{fund}</td></tr>
<tr><td colspan="2">25.5Ω</td><td colspan="2">6.75$Kvar$</td><td>3.67mH</td><td>125μF</td><td>235Hz</td><td colspan="2">432.8V</td><td>9.8A</td></tr>
<tr><td rowspan="2">UCAP</td><td>Ceq</td><td colspan="2">Rated capacitor</td><td>UCAP voltage e /cell</td><td>Duration of time</td><td>Req</td><td>%d_{min}</td><td>d_{max} %</td><td>E_{max}</td><td>P</td></tr>
<tr><td>18.8F</td><td colspan="2">761F</td><td>2.7V</td><td>5sec</td><td>40.5mΩ</td><td>19.5</td><td>≈ 100</td><td>441.8 KWs</td><td>88.36 KW</td></tr>
<tr><td>Vmissed with</td><td colspan="2">(V)</td><td colspan="2">p.u</td><td colspan="6">Percentage</td></tr>
</table>

Out DVR	167.14	0.696	69.6%
Vsag with Out DVR	72.86	0.304	30.4%
Vswell	(V)	p.u	Percentage
	270	1.125	112.5%
V_{DVR}	(V)	p.u	Percentage
	169.2	0.705	70.5
DC-DC convertor	duty cycle (D)	Input DC-source	dc-link voltage
	0.277	216.8V	300V
Inverter	Vdc input (V)	Vac output (V)	Size of inverter (KW)
	300	415	66.5

The above all parameter are included in the MATLAB/Simulink block diagram of UCAP-DVR integration in figure 5.1.

To overcome the power quality by using integration of UCAP-DVR it’s simple to operate, the excellent solution for temporary fault and it’s environmentally friendly. Since to implement the integration of UCAP-DVR for each of the feeder initially it may be high cost. Although now days in our country at most power distribution system there is no availability of custom device for protection of sensitive device and controller to mitigate the missing voltage during short period of fault occurring.

5.1 Simulation Result

The integration of UCAP-DVR MATLAB/Simulink diagram was showed in figure 5.1, the simulation was done without UCAP-DVR connection and with UCAP-DV through RBF controller to three phase distribution line.

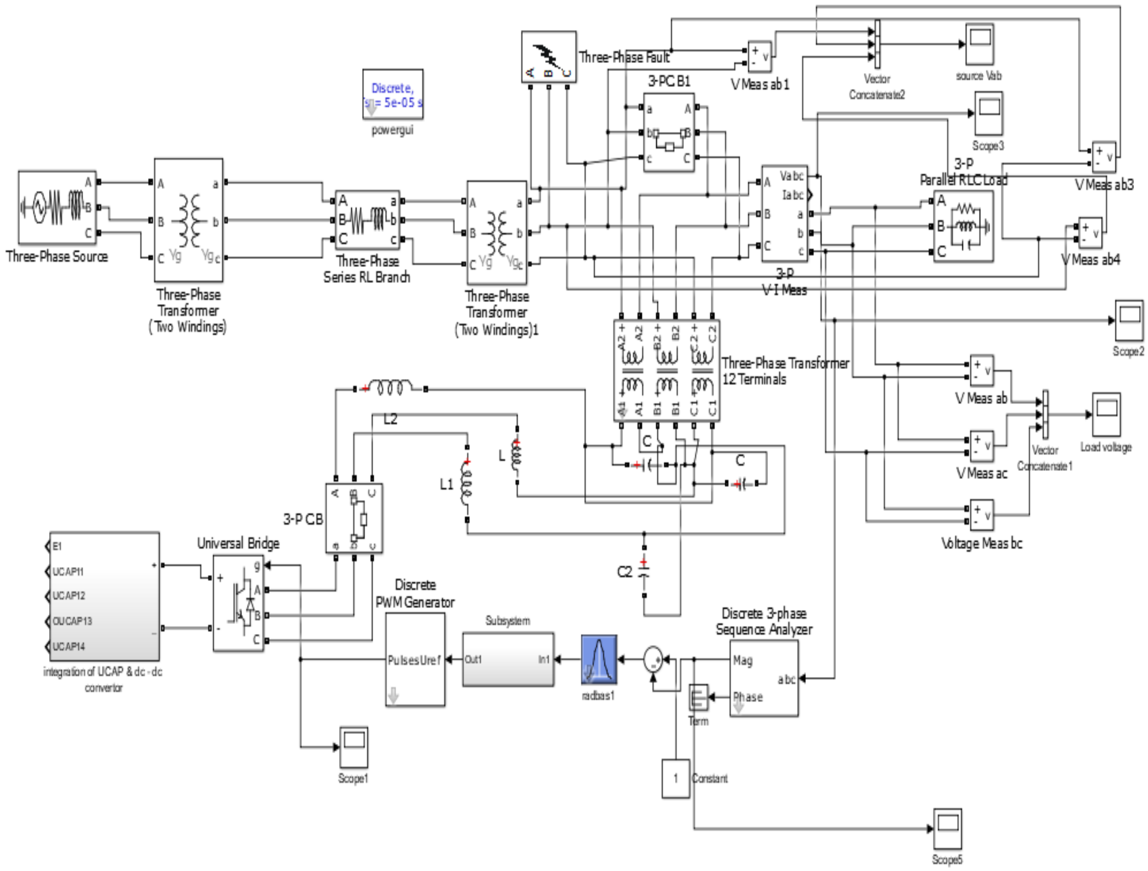

Figure 5. 1 MATLAB/Simulink block diagram of UCAP-DVR with *RBFN*.

In the above diagram the main 3∅ source is transmitted from Halaba substation at 132*KV* phase to phase voltage and at frequency of 50Hz. 132KV is reduced to 15KV via three phase transformer which is available at Hawassa substation. Then for the user 15KV is converted to low voltage at 415V by distributor transformer. In figure 5.1 above the fault sign block is connected to three phase line at low voltage side with fault resistance of 0.073 Ω. The UCAPDVR integration is connected in series between sensitive load and distribution transformer to mitigate the missed voltage during fault occurring. The block “integration of UCAP and DC-DC converter” illustrated in diagram 3.5 has the model of ultra-capacitor with bidirectional DC to DC converter circuit.

The firing angle pulse generated by PWM generator simulation was done. This is shown in Figure 5.2.

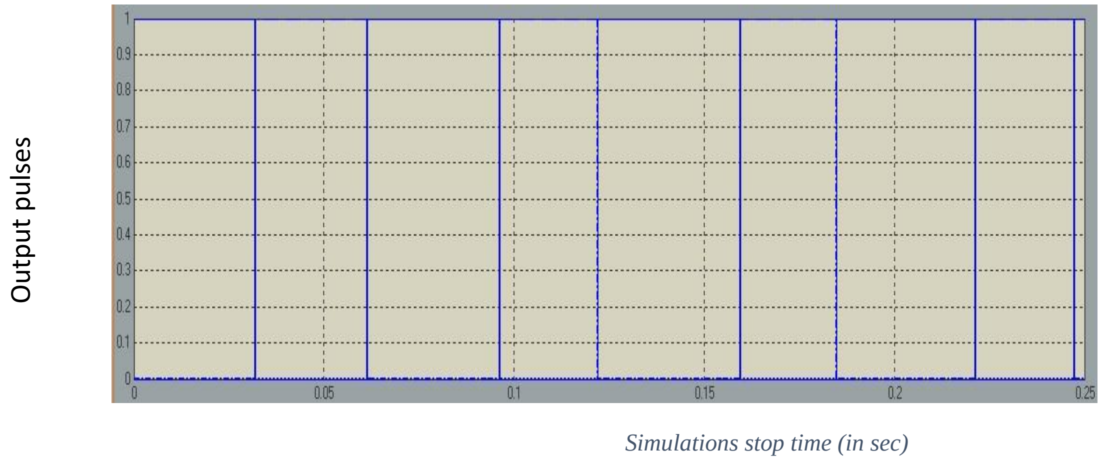

Figure 5. 2 The firing angle pulse generated by PWM generator signal.

In this research the obtained simulation outcomes are express the performance of integration of UCAP-DVR under single and 3∅ voltage sags status. These simulation results were conducted by using MATLAB / Simulink software as shown in figure 5.1 The configuration of the studied test system is as shown in Figure 3.8 The test were conducted by including a 3∅ voltage supplies of 15 /0.415 kV at 50 Hz that delivers feed a critical load. The pulse width modulation generator with a fall time (Tf) $1e^{-6}$ seconds (s) and tail time (Tt)$2e^{-6}$ in seconds (s) can control the inventers. The load considered in this study is with phase-to-phase nominal voltage of 415V, nominal frequency (FN) of 50Hz and reactive power of 45kVar.

The simulation result at a phase to ground resistive fault were demonstrated in the diagram of 5.3, with a resistance equivalent to 0.073 Ω. The low voltage side of the transmission transformer were producing the fault. It begins at 0.0667s and lasts at 0.15s. I perceived that the UCAP-DVR maintain the load voltage by instantly injects the necessary voltage component. The load voltage during fault with UCAP-DVR, without integration of UCAP-DVR and the injected voltage is shown figure 5.3, 5.4 and 5.5 respectively. In figure 5.3 below the load voltage sin wave is simulated with a three-phase fault of starting from 0.0667s to 0.15s and the phase to ground voltage is sag/dip up to 30.4 % (0.304p.u) of its nominal value.

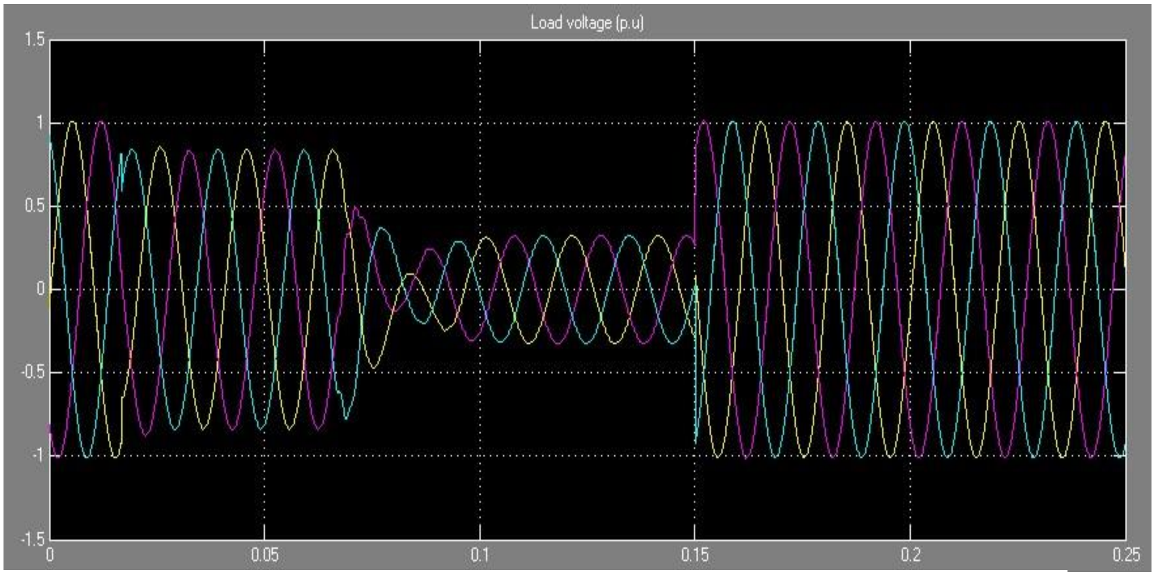

Figure 5. 3 Simulation waveforms for voltage sag.

During system fault without using any custom device to mitigate the power disturbance the output load voltage of the proposed distribution system is reduced by 0.696p.u or at 69.6% of the nominal voltage. The simulation result of output load voltage during fault without integration of UCAP-DVR is shown in figure 5.4 below.

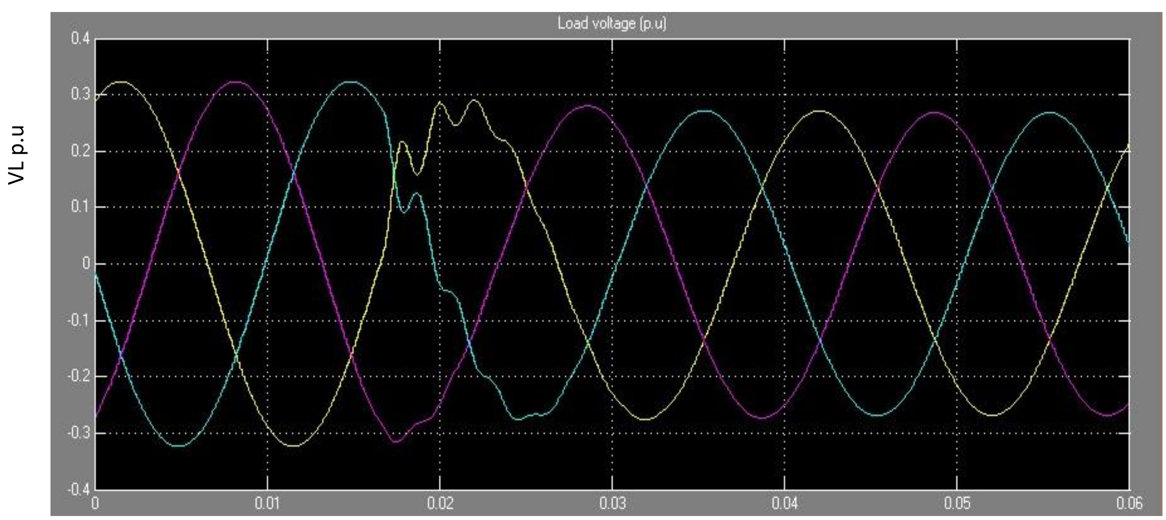

Figure 5. 4 Load voltages during sag, without UCAP-DVR.

Without released energy from storage device the injection transformer injects the voltage of [VinjA, VinjB and VinjC] for the voltage sag up to 1p.u for a period of 0.0667s to 0.15s is shown in Figure 5.5 below.

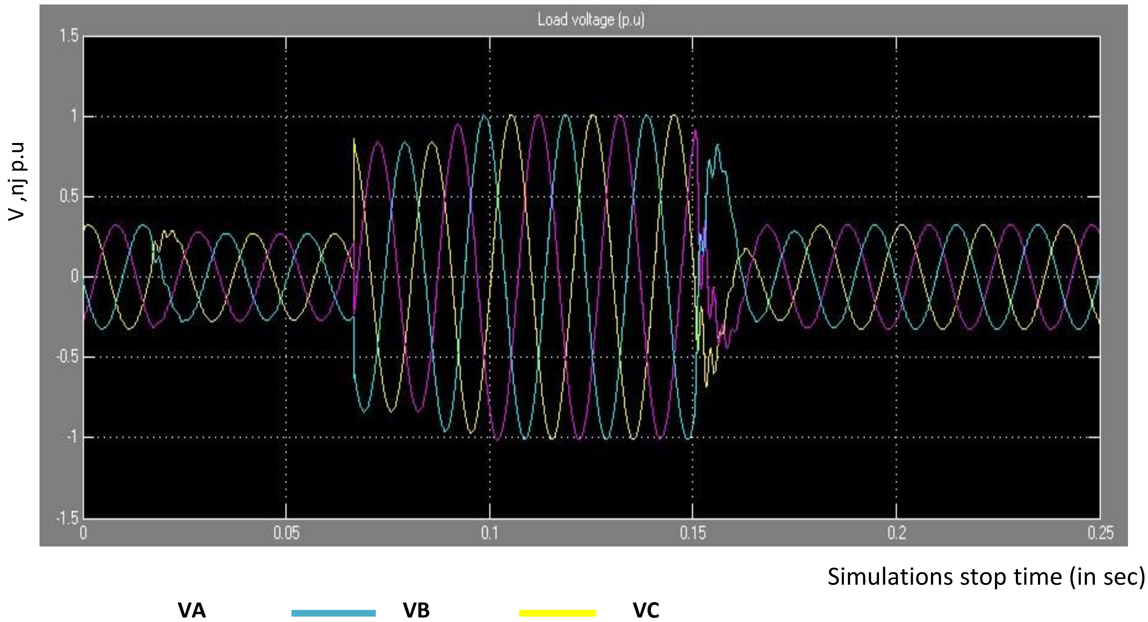

Figure 5. 5 Injected voltages [VinjA, VinjB and VinjC] during voltage sag.

From MATLAB/Simulink block diagram in figure 5.1 above, the critical load device was done from a resistance associated in parallel with capacitance and inductance. To verify the simulation result, by neglecting line resistance and load resistance from these sensitive load devices the load voltage is increased from 1p.u to 1.125p.u for period between 0.0667s to 0.15s. So, it represents the voltage swell is increased to 112.5% of the nominal voltage. The next Figure 5.6, were present the simulation result of swell.

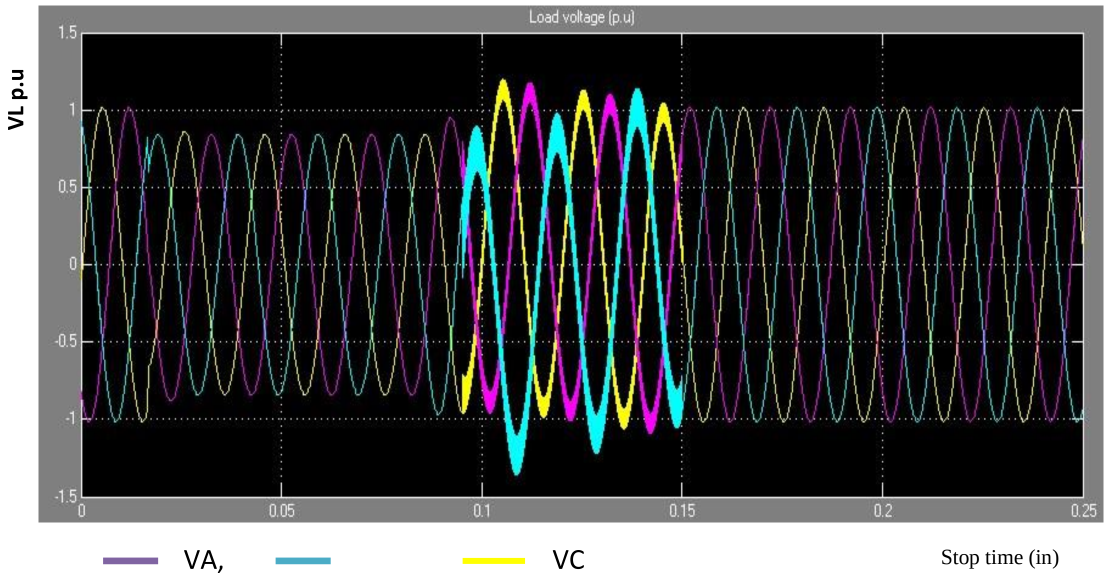

Figure 5. 6 Injected voltages [VinjA, VinjB and VinjC] during swell.

During system fault the voltage source is supplied from UCAP energy storage device to compensate output load voltage at 1p.u. The RBF control and integrating UCAP with DVR device compensated output load voltage simulation output is described in figure 5.7

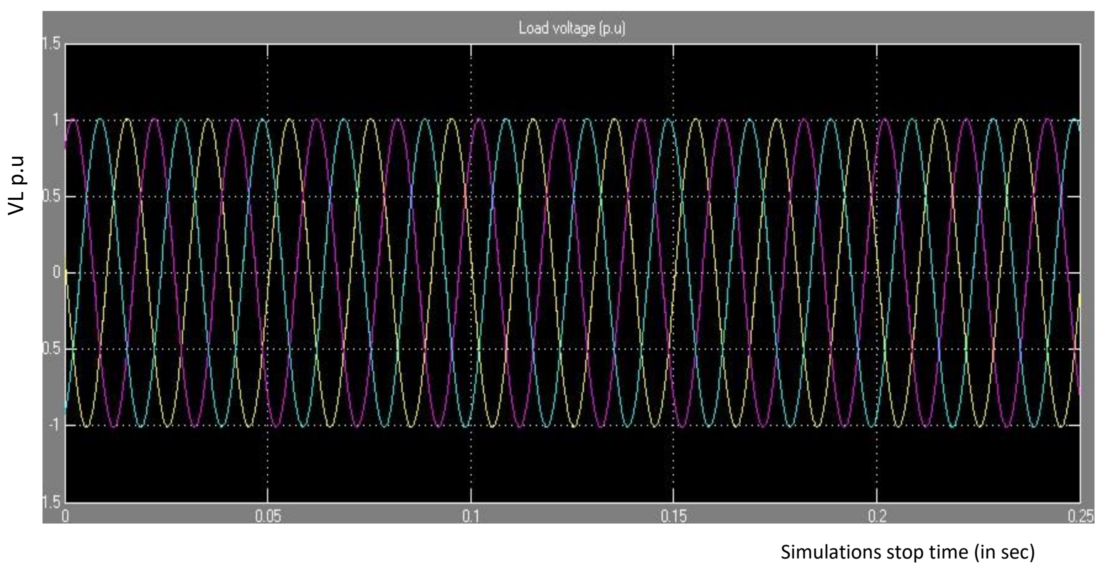

Figure 5. 7 Injected voltages [VinjA, VinjB and VinjC] during swell.

In figure 5.8 below shows that the wave of positive sequence during phase to ground fault. The sequence wave was simulated with a 3 Ø fault of starting at 0.0667s to 0.15s and the phase sag is up to (0.304p.u) of its nominal value.

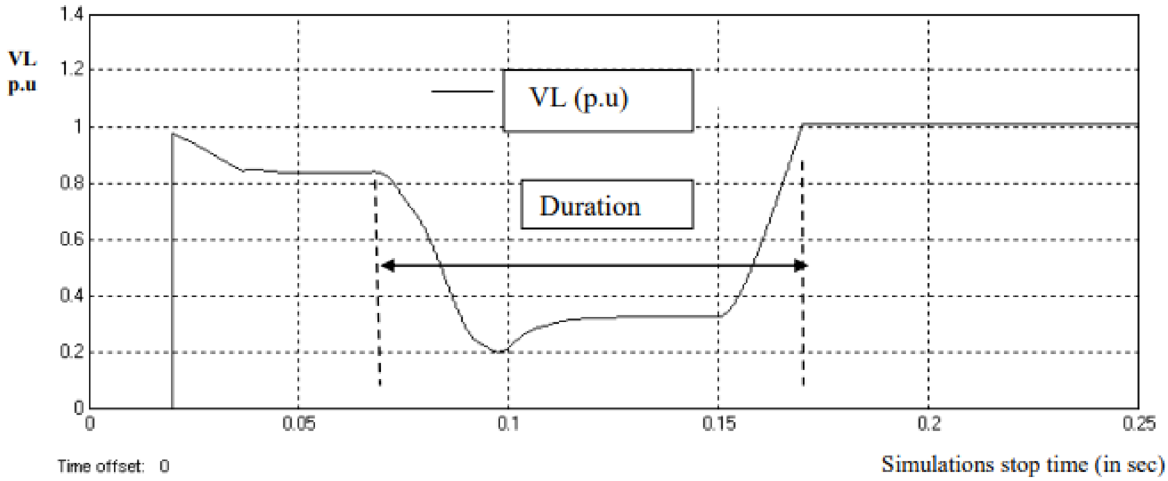

Figure 5. 8 Load voltages during a fault (from 0.0667s and to 0.15s) in p.u.

When stored power is delivered from UCAP via DC-DC convertor and DVR device, the compensated output load voltage after mitigation is described in the diagram of 5.9.

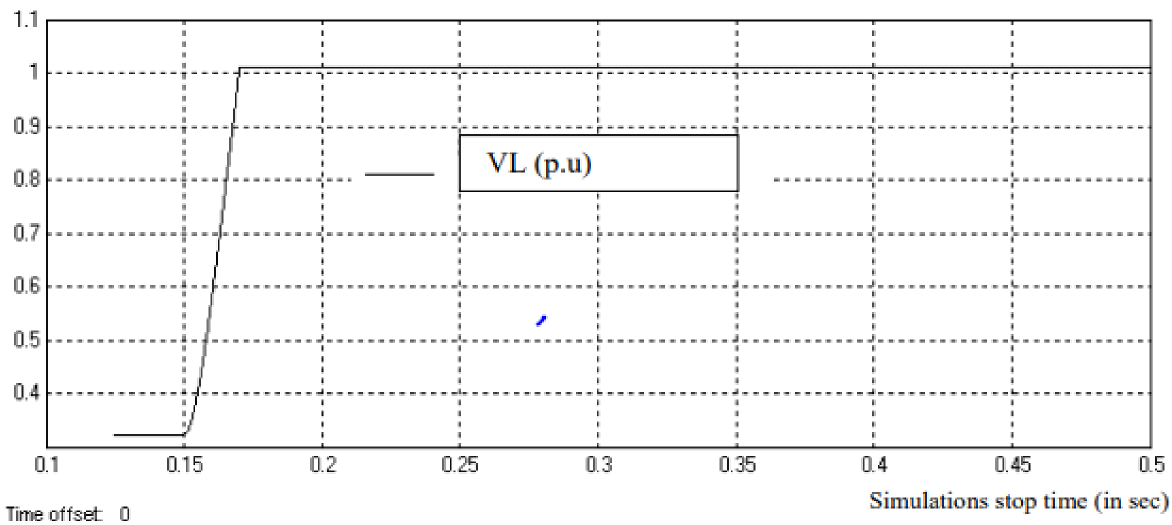

Figure 5. 9 Compensated voltage.

5.2 UCAP – DC to DC Converter Simulation Model

UCAP with DC-to-DC converter Simulink model were described in the next Figure 5.10 There are 81 UCAPs cell connected in series to give 216.8V, it is connected to the dc-link of the DVR and serves as input to the output to protect the operation under no-load conditions. To simplify Simulink model the UCAP cell connected in series are grouped into four places. Each of the groups of UCAP cell has 54.2V. As illustrated in section 3 it's necessary to understand the requirement parameter to size and model the ultra-capacitor. Here the considered parameters are energy (J), load power (KW), initial working voltage, discharge time from initial voltage to minimum voltage, total capacitance and discharge current. Actually, the voltage of ultra-capacitor per cell is small (less than 3V), since it's linked in series to increase the voltage value for high voltage load and it's linked in parallel to increase the requirement current. The discharge and charge time of UCAP is between 0.3second to 30second.

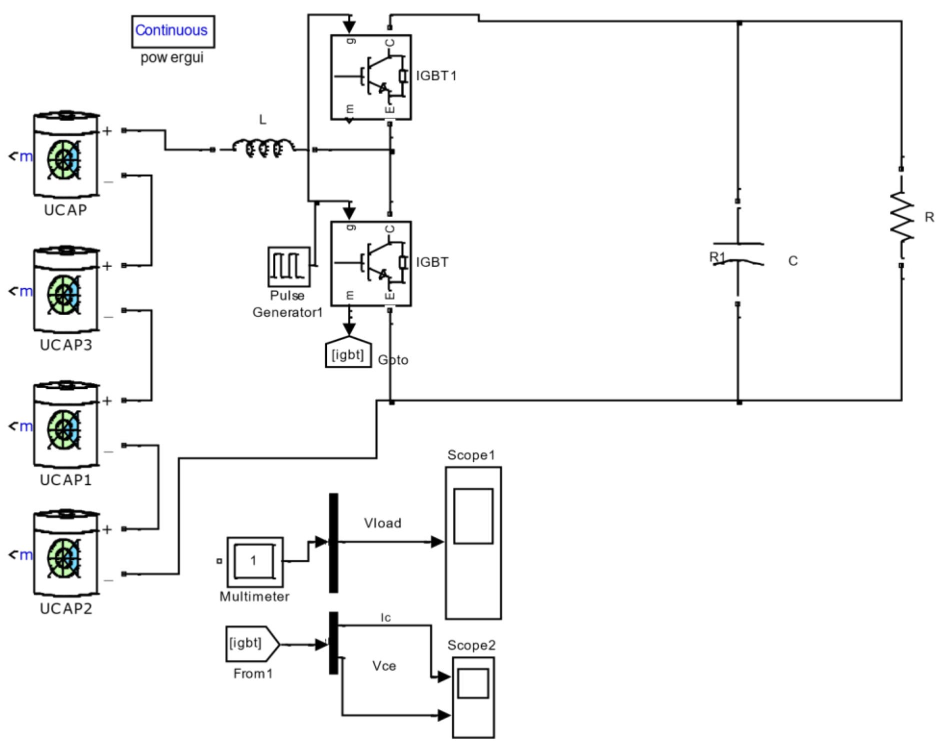

Figure 5. 10 The simulink model of UCAP with DC-DC converter

CHAPTER SIX

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

Based on the applied methodology and result, the following conclusions are drawn:

- The UCAP plays a big part because they have a lot of power to find out the stability and viability of the storage device system to reduce the power quality in a short amount of time.
- The unbalanced and balanced situations were maintained by the DVR without any problem and injects the appropriate voltage component to correct rapidly any irregularity in the supply voltage to keep the load voltage balanced and constant at the nominal value.
- Sag and swell voltage are presented at 30.4% and 112.5% respectively without integration of UCAP-DVR with three phase fault resistance equivalents to 0.073 Ω and load voltage is mitigated with integration of UCAP-DVR at DVR voltage of 70.5 %.
- The load voltage sin wave is simulated during three phase injection voltage starting from 0.0667s to 0.15s. The simulation of UCAP - DVR showed efficient compensation and deep manner.

6.2 Future Scope

Electric power quality mitigating techniques against power disturbance are a necessary measure to maximize the quality and reliability of power distribution for services. It is known that in Ethiopia somewhat there is the reliability of power distribution due to equipment tripping, failure of equipment's, limited financial capacity, knowledge and skills of technicians.

- The future scope of the simulated and calculated results can be done experimentally and practically.
- Mitigate the voltage permanently through the integration of DVR with high energy storage like SMESS.
- Since the mitigation techniques in Ethiopia is not common and widely practiced concept; it needs more training and exercise to aware people about the implementation of mitigation to deliver and utilize efficiently electric power.

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[32] Ethiopian Electric power substation data of Hawassa distribution in June, 2022

APPENDIX

Appendix-I The input and output of for RBFN

```
Clc
Clear all
Open ('mahiy.slx');
Sim ('mahiy.slx');
CurrentA = current1;
CurrentB = current2;
CurrentC = current3;
CurrentG = current4;
[cA, LA] = wavedec (currentA, 1, 'db4');
[CB, LB] = wavedec (currentB, 1, 'db4');
[cC, LC] = wavedec (currentC, 1, 'db4');
[CG, LG] = wavedec (currentG, 1, 'db4');
CoefA = detcoef (cA, LA, 1);
CoefB = detcoef (cB, LB, 1);
CoefC = detcoef (cC, LC, 1);
CoefG = detcoef (cG, LG, 1);
m = max (coefA);
n = max (coefB);
p= max (coefC);
q = max (coefG);
```

Appendix-II the RBF of Training by input and output

```
I = inputdata';

T =outputdate';

Goal = 0.0;

Spread = 1;

Net = newrb (I, T, goal, spread);
```

Appendix-III RBF testing 30% proving of RBFN accuracy

```
P = tesingdate'

Y = sim (net, P)

O = Y'
```

Appendix-IV Testing accuracy is more than 90% it is acceptable selecting training system for controlling the voltage sag and voltage swell in the power quality system.

1.1569	1.1569	1.1569
0.8528	0.8528	0.8528
0.6471	0.6471	0

Appendix-V Back-boost transformer character

	Boost- increase voltage										**Buck-decrease voltage**					
Load (V)	208	208	208	230	240	240	416	416	416	416	208	208	240	240	416	416
Line (V)	166	173	187	208	216	228	374	377	395	397	230	249	252	264	437	457
Load amps (A)	67	83	144	165	74	158	75	83	158	166	183	99	175	92	173	92
KVA	24	30	52	65.8	31	66	54	60	114	120	66	36	72.8	38.1	124.8	66
Line fuse	110	150	225	250	110	250	110	125	250	250	225	110	225	110	225	110