Global Scientific JOURNALS

GSJ: Volume 8, Issue 12, December 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

Study of Electrical Power Supply to Borikiri Township Axis of Port Harcourt for Improved Distribution Using Dynamic Voltage Restorer (DVR) Method.

[1]Thompson Elsie Victor, [2]S. L. Braide and [3]D.C. Idoniboyeobu
[1,2,3]Department of Electrical Engineering, Power Option Rivers State University, Port Harcourt.
[1]telsie133@gmail.com,[2] sepiribo.braide@ust.edu.ng [3]*idoniboyeobu*.d@*ust.edu.ng.*

ABSTRACT

This research work critically examined how to improve on the electrical power distribution for Borikiri Township axis of Port Harcourt using the dynamic voltage restorer (DVR) method. Dynamic voltage restorer (DVR) acts as a device used injecting 3-phase voltage connected in series and is synchronize with the voltage sag which is compensated through the distribution feeder voltage. Dynamic voltage restorer is operated as a power electronic device which is used in protection of customer loads and sensitive loads from voltage disturbances coming from the grid such as voltage sags and swells, voltage variation, transients and harmonics in the electrical power distribution network. In this research work, the Electrical Transients Analyser Program (ETAP version 12.6) and Simulink Environment (MATLAB) were used for simulation. The case study for the variation of the existing and improved power factor, absorbed current before and after power factor, power of the capacitor bank, loss reduction with power factor, reduction of voltage drop and power factor using a capacitor, Pf using a capacitor concerning to Bus Location were investigated vigorously. From our simulations the results indicate that Navy Medical has the lowest existing power factor of 8.1% and an improved power factor of 91.5% instead of having the standard existing power factor of 85.0% and improved power factor of 91.0%. In the case study of absorbed current, Greenson 1 has the lowest absorbed current of 58A. The results also show that the average absorbed current of 58A. The results also show that the average absorbed current as 80A, therefore Greenson 1 should be upgraded to the average absorbed current of 80A. While in the case study of the power of the capacitor bank, Greenson 1 has the lowest power of the capacitor bank of 0.54kVAR and should be upgraded to the power of the capacitor bank of 1.90Kvar. In the case of loss reduction in power factor, Egbema has the lowest loss reduction in power factor with 12.8% while Navy Medical has the highest loss reduction in power factor with 22.6%. The results show that Navy Medical which has the highest loss reduction in power factor with 22.6% should be upgraded to meet the average reduction rate of 13.0%. In the case of a reduction of voltage drop, the results show that Egbema has highest the reduction of the voltage drop of 2.15V, and Oba Street has the lowest reduction of the voltage drop of 0.39V, therefore, Egbema should be upgraded to meet the reduction of voltage drop rate of 1.5V. The next case study is an implementation of power factor (pf) using a capacitor and the result shows that Wilson Bakery has the highest pf using capacitor of 328.8 kVAR followed by Hydro-Graphy with 252.0 kVAR while Oba street has the lowest pf using a capacitor of 47.5 kVAR, therefore Oba street should be upgraded to the average pf using a capacitor of 105.5 kVAR as an average rate.

Keywords: Electrical Power Supply, Borikiri Township Axis of Port Harcourt, Improved Distribution, Dynamic Voltage Restorer (DVR) Method

INTRODUCTION

1.1. Background of the Study

As the power quality problems are instigating from utility and customer side, the solutions should come from both sides and are known as utility-based solutions and customer-based solutions respectively. FACTS devices (Flexible AC Transmission Systems) and Custom power devices are the best examples of those two types of solutions. Utility-based solution controlled the FACTS device effectively, while customer-based solutions controlled, maintained, and operates the custom power devices and installed at the customer jurisdiction.

However, the FACTS devices and Custom power devices are controlled by power electronic components under the solid-state condition.

Dynamic Voltage Restorers (DVR), Active Power Filters (APF), and Uninterruptible Power Supplies (UPS) are typical examples used as custom power devices. The problem of harmonic occurred under the non-linear loading conditions, while DVR and UPS are used to demonstrate compensate for voltage swell, voltage unbalance conditions, and voltage sag. This research work significantly focused on the control of a dynamic voltage restorer (DVR) for supply voltage disturbances.

The development in load demand can be determined by investigating the power flow on the existing distribution system to determine the corrected performance of the network. Power load flow analysis is carried out to find the sensitivity of feeder status with conductor length, a variation of power loading, and a total capacity of distribution transformers. Distribution networks are the solution that links the customers and generated powers (Jignesh, 2013). Power flow analysis is a basic and very important tool used in analyzing electrical power system network performance. The operation of the installed network under steady-state conditions can be executed and determine effectively. According to Agbetuyi (2014), the operating voltage at each bus can be determined in all branches in the circuit through the power flow analysis. It can be resolved if the voltage is at a steady and under various contingency conditions and whether equipment such as conductors and transformers are overloaded.

1.1.1 Principle operation of DVR

The Dynamic voltage restorer (DVR) is a power electronic switching device that consists of a Gate Turn-Off Thyristor, (GTO) or Insulated Gate Commutated Thyristor (IGBT), a capacitor bank is used as injection transformers and energy storage device. The main purpose of the DVR is to infuse a controlled voltage created by a forced commuted converter in a series to the bus voltage utilizing an infusing transformer. The voltage is regulated by the sinusoidal Pulse-width modulation (PWM) technique when DC is converted to AC inverter.

The DVR is injected into a miniature voltage to compensate for the voltage drop of the injection transformer and device losses under normal operating conditions.

Nevertheless, the DVR control system manipulates and synchronizes the voltage which is required to preserve the output voltage to the load by infusing a controlled voltage with a certain phase angle and magnitude into the distribution system to the critical load when voltage sag occurs in the distribution system.

It is noted that the DVR is capable of absorbing reactive power and generating while the energy storage system or external energy source is controlled by the active power injection of the device.

The DVR has a response time which is very short and limited by voltage sag detection time and the power electronics devices. 25 milliseconds are calculated as the predictable response time compares to the traditional methods of voltage correction such as tap-changing transformers.

1.2 Statement of Problem

A major problem associated with the Borikiri axis of Township in the 11KV distribution network is the low voltage experienced in most areas covered by the study network. This has shown the way that the installation of transformers has no adequate development, resulting in loss of power along with the feeders under consideration and drop in the voltage profile due to the size and distance covered by the distribution lines feeding the areas. The cause for demanding high-quality power is mainly about the recent manufacturing and process equipment, which is controlled at high efficiencies and also requires high-quality defect liberated power supply for the thriving operation of their type of equipments. Automation devices, power electronic components, and adjustable speed drives are examples of such equipment.

Breakdown of the system due to the low quality of power output may completely shut down the industries which will cause a major financial loss to both the commercial and end-user at large. Therefore the industries constantly demand high-quality power from the supplier or the utility.

There are some abnormal electrical conditions which caused both the commercial and the end-users to function effectively which can disrupt the process such as:

1. Voltage interruptions
2. Voltage swells & sags.
3. Blown fuses on three-phase capacitor banks
4. Transients due to capacitor switching, lighting loads, nonlinear loads, etc.
5. Partial transposition of transmission lines.
6. The irregular distribution of single-phase loads that can continuously be changing transversely to a three-phase power system.
7. Asymmetry of line and transformer winding impedances.

The industries may undergo lost data on volatile memories, the erroneous notion of robotics, increased maintenance costs, burned-out motors, and burning core materials especially in plastic industries, semiconductor plants, and paper mills as a result of the above abnormalities.

1.3 The Aim of the Study

This research work aims to improve the electrical power distribution for Borikiri Township axis of Port Harcourt using the Dynamic Voltage Restorer Method.

1.4 Objectives of the Study

The objectives of this research work will:

i. Using the Dynamic Voltage Restorer Method to calculate for variation of the following parameters concerning bus location;
   a. Existing and improved power factor.
   b. Absorbed current before and after the power factor.
   c. Power of the capacitor bank, Loss reduction with power factor.
   d. Reduction of voltage drop and power factor using a capacitor.
   e. Power factor **(**Pf) using a capacitor with respect to bus location

ii. Use of Electrical Transient analyzer program (ETAP Version 12.6) to model and simulate the existing network.

iii. Use of Simulink Environment (MATLAB) to model and simulate the existing network.

1.5 Scope of Work

The scope of this research work shall be limited to a 33kV distribution network in Borikiri Township, Port Harcourt axis and to find a suitable technical solution to the factors that have adversely affected the reliability and quality of power supply to the distribution system. The scope of this research is limited to areas covered by the power supply system at Borikiri Township 11kV distribution network, Rivers State. The study focuses on the Bus input and line input data as well as the power supply capacity of the distribution transformer rating in the Network. The capacity condition on the distribution transformers is needed by the utility company in charge of electrical power distribution in the study zone.

1.6 Significance of the Study

The Significance of this research work is that it will determine the real and active power that flows at each bus, power losses, as well as tackling the problem of low voltages experienced, poor power factor at the load end, frequent outages, in the long run, provide adequate information for planning future expansion and upgrade the existing capacity of the system.

The findings and recommendations of Ibis research will help in providing solutions to the problems facing power flow on a 33KV distribution substation in Borikiri Township, Port Harcourt, Nigeria.

CHAPTER 2

LITERATURE REVIEW

2.1 General Structure of Power Systems

The Power system is designed to accumulate electrical energy produced in a large generation centre and convey it to the final load points where customers demand it. Power systems are delivered and comprised of other subsystems, in a deregulated market each subsystem is owned by diverse companies and free competition is allowed to contest with each other. The primary subsystems in the power system are presented and delivered in the sub-section (Salam & Malik, 2011).

2.1.1 Large Generation Centres

Greater parts of electrical energy are designed with large generation units gathered in a remote location, distant from final consumption points. There are diverse technologies that are traditionally designed have been used to produce electrical energy on a large scale, such as coal, hydro, gas, natural, nuclear, etc. Several of these plants were manufactured in the past when the whole power system was owned by one company; lower costs and economies of scale permitted these companies to manufacture in large yet still profitable plants.

2.1.2 Transmission system

The transmission system made up of a set of equipment, lines, and substations constructed to connect large generation plants and consumption centres, power consumption is mostly carried out in cities and industrial areas. The Lines mainly belonged to the transmission system length over long distances and transport large quantities of energy; for that reason, the line operates at high-voltage levels between 220 and 400 kV respectively.

2.1.3 Sub-transmission System

The sub-transmission system is an intermediary link between the transmission and the distribution system. The lines that make up the sub-transmission system cover shorter distances than those in the transmission system; therefore they operate at lower voltage levels (e.g. 45, 55, and 132 kV). Initially, the voltage is reduced due to the difference in voltage level for the transmission system. Big companies and other consumption facilities is the highest consumers of large load and they are directly connected to the sub-transmission system.

2.1.4 Primary Distribution System

The distribution substation is considered as the original component of the primary distribution system, a new voltage reduction is achievable when the energy is delivering from the transmission and sub-transmission system. Considering the distribution substation where one or more medium-voltage distribution lines such as 11 and 25 kV get their energy a step closer to the final consumers. The sub-transmission systems have large loads that are connected to the primary distribution system (Gönen, 2008).

2.1.5 Secondary Distribution System

The secondary distribution system is made up of low-voltage lines such as 230 and 400 V and step-down (LV/MV) distribution transformers that convey the energy to low power customers such as residential and commercial loads.

2.2 Distribution System Structure

The distribution substation is the interconnection element between the distribution system and the upstream power delivery system. By the side of the substation, it is observed that the step-down (MV/HV) transformer trim down the sub-transmission voltage level to a suitable value for primary distribution lines. To ensure a successful operation system the switching, different protection, and measurement equipment are installed at the substation. The primary distribution lines are extended across the consumption area supplied by the substation, these primary distributions lines are also known as feeders. The lateral lines branches obtain from the distribution feeders are extended until they get to step-down (LV/MV) distribution transformers, which are accountable for performing the final voltage reduction and regulating to achieve a voltage level that is adequate for customers usage (e.g. 230 and 400 V).

The secondary distribution line operates at low-voltage levels which transport the energy to the end-users interconnection point, therefore the lines are usually operated in one-phase but also operate in three-phase circuits.

In some developing countries such as Nigeria, the overhead lines are mainly used in rural circuits, while in urban circuit's distribution lines are generally underground and also in suburban areas there has a combination of overhead and underground circuits. Large industrial districts are usually supplied by contributed circuits as they represent large loads that can affect the service of other loads (Short, 2004).

2.2.1 Primary distribution circuits system

Primary distribution circuits are usually designed in radial form, compare to the transmission systems where circuits are designed in the meshed form. Comparing both circuits, it is discovered that the meshed circuits and radial circuits have some advantages in power distribution such as:

(1) Lower fault currents

(2) Protection is mostly overcurrent

(3) System design is less expensive and

(4) Voltage regulation and power flow control are easier to implement

Generally, the radial circuit design can represent different variations such as the open-loop and single feeder configurations (Short, 2005)

2.2.1.1 Single Feeder Configuration

During the single feeder configuration, all power stipulated by laterals and secondary circuits is supplied by a single primary line; where there is a failure or any other loss event that forces the feeder to be out of function (e.g. maintenance) will cause the loads to experience a service interruption. The single feeder layout can be represented by a branched-configuration, where several branches stem from the original feeder to cover a larger area. These branches are not to be confused with laterals; laterals present a much lower current capacity, while the branches have the same (or similar) capacity as the main feeder.

2.2.1.2 Open-loop Configuration

Considering the open-loop configuration where two feeders parting from the same substation are connected at their end terminals through a normally-open tie-switch. In a normal condition, each feeder supplies a different number of lateral circuits but can supply the necessary power to all circuits connected to both feeders. Load transfer between feeders is feasible by closing the normally-open tie-switch (either automatically or manually). This configuration represents greater reliability intensity than the single feeder configuration but requires that some feeders can carry the load matching to both feeders; besides, extra equipment is considered necessary (e.g. the tie-switch).

2.2.2 Secondary distribution circuits system

The radial configuration is the most common design in secondary circuits and it is found in both rural and suburban areas, on the other hand in urban circuits diverse configurations can be used depending on the type of load to be supplied. The spot configuration is used for large loads concentrated in one point (e.g.large buildings and factories), while the network configuration is used to supply a great number of loads distributed over a large area (Short, 2005).

2.2.2.1 Radial Configuration

The primary circuits have equivalent configuration compare with that of radial design found in distribution secondary circuits. A secondary circuit component comes from the step-down

(MV/LV) distribution transformer and it extended over the area where the consumers are located; due to the size of the covered areas, a branched-configuration is normally presented by the secondary circuits/

2.2.2.2 Spot Configuration

The spot configuration is mainly used for loads that involve dedicated circuits due to their high power demand; normally there are three or five feeders which deliver the power demanded by the load, system design allows normal operation with the loss of one or two of the primary circuits. Every feeder arrives at step-down (MV/LV) distribution transformers that supply part of the total load; the entire transformers are operated with a protection device installed on its secondary side.

2.2.2.3 Network Configuration

The network configurations have several primary circuit lines which feed the secondary network from multiple step-down (MV/LV) distribution transformers. Thus a secondary circuit connected at the low-voltage side of the distribution transformers has a structure meshed network, where the load power is supply. Therefore, the configuration is mainly used to supply the commercial and residential loads (both one and three-phase).

2.2.3 Distribution System Substations

The configuration of a distribution system substation depends mainly on the type of system supply (urban, suburban, or rural); desired reliability and load level will have an effect on the substation's design and auxiliary equipment required (Abou El-Ela et al., 2010).

2.2.3.1 Rural Substation

The rural systems are designed from substation with a simple configuration which is made up of one medium-voltage bus and high-voltage. The low load levels have a single transformer which is enough to supply the entire power demand and transformer protection will depend on the transformer's rated power. Primary distribution lines are linked to the medium-voltage bus and are protected by overcurrent relays or reclosers.

2.2.3.2 Suburban Substation

Suburban systems present higher load levels than rural systems; therefore more than one transformer will be necessary to serve the total system load. Suburban substations have a single bus on the high-voltage side, whereas each substation transformer has its medium-voltage bus; medium-voltage buses are connected through a normally-open tie-switch. In the case of transformer failure, the tie-switch can be operated and the load corresponding to the failed transformer will be served by the remaining in-service transformers. This configuration known as split bus reduces fault levels, facilitates voltage control, and prevents the presence of circulating currents among transformers. Some utilities prefer to use a single medium-voltage bus for all substation transformers, which allows a more uniform load distribution among transformers (Sheaffer, 2011).

2.2.3.3 Urban Substation

The urban substations configuration is more complex compared to those used for rural and suburban systems; there are two most common substation designs which are the ring-bus and breaker-and-a-half configuration. Considering the ring-bus configuration, the medium-voltage buses form a closed loop with each section separated by a circuit breaker while the distribution feeders and the secondary side of the substation transformers can be connected to the mid-point of any section, between two circuit breakers (Nack, 2015).

The breaker-and-a-half configuration made up of one or more branches connected between two medium-voltage buses, where each branch is consists of three circuit breakers respectively. The primary distribution lines or secondary side of a substation transformer is connected between any two adjacent circuit breakers. Mutually the two configurations can be willingly adapted to carry out load transfer or perform maintenance on one of the circuit breakers (Georgilakis & Hatziargyriou, 2013).

2.2.4 Distribution System Elements

The power distribution system is operated safely and requires many dedicated type of equipments to focus on; the type of equipments are installed all over the distribution system and it consists of vital elements such as circuit breakers, lines, power transformers, and control and monitoring apparatuses. The majority of these elements are vital and brief definitions are presented below.

2.2.4.1 Lines

Lines are liable for transporting electrical energy between two distant points; overhead lines are usually consists of bare aluminum (being ACSR a commonly used type), while underground lines normally use cables with polymer-insulation, such as EPR and XLPE. Conductors and cables are used for distribution lines which are characterized by their rated voltage and current capacity (Gözel & Hocaoglu, 2009).

2.2.4.9.1 Factors Considered when Selecting a Sectionalizer

There are diverse kinds of sectionalizers based on their mode of operation, ratings, and capabilities. When selecting a sectionalizer for certain applications there are some important factors to consider as highlighted below.

1. **Phase:** single-phase or three-phase constructions depending on the supply:

The single-phase sectionalizer protects the single-phase circuits such as the taps or branches of a three-phase feeder. Typical three-phase sectionalizers open all the three phases concurrently. This can be as a result of a phase or ground fault.

2. **Operating mechanism:** the commonly used sectionalizers have either hydraulic or electronically operated mechanism. The hydraulic contacts are opened by pre-tensioned springs. Mainly some of these sectionalizers have the provisions for manual opening and closing using a hook stick. The electronically controlled mechanisms are easier and more flexible to set compared to the hydraulic mechanism. They have both manual and automatic motor controlled opening and closing features.

3. **The system voltage and current:** The sectionalizer current and voltage rating should be equal or greater than the maximum voltage and load current at the point where it is installed.

4. **Maximum short-circuit capacity:** this should be greater or equal to the fault current level at the point of installation.

CHAPTER 3

MATERIALS AND METHOD

3.1 Materials Used

1. The DVR consists of:

   a) An Injection transformer
   b) A Harmonic filter
   c) Storage Devices
   d) A Voltage Source Converter (VSC)
   e) DC charging circuit

2. Electrical Transient and Analysis Program (ETAP Version 12.6)

3. Simulink Environment (MATLAB)

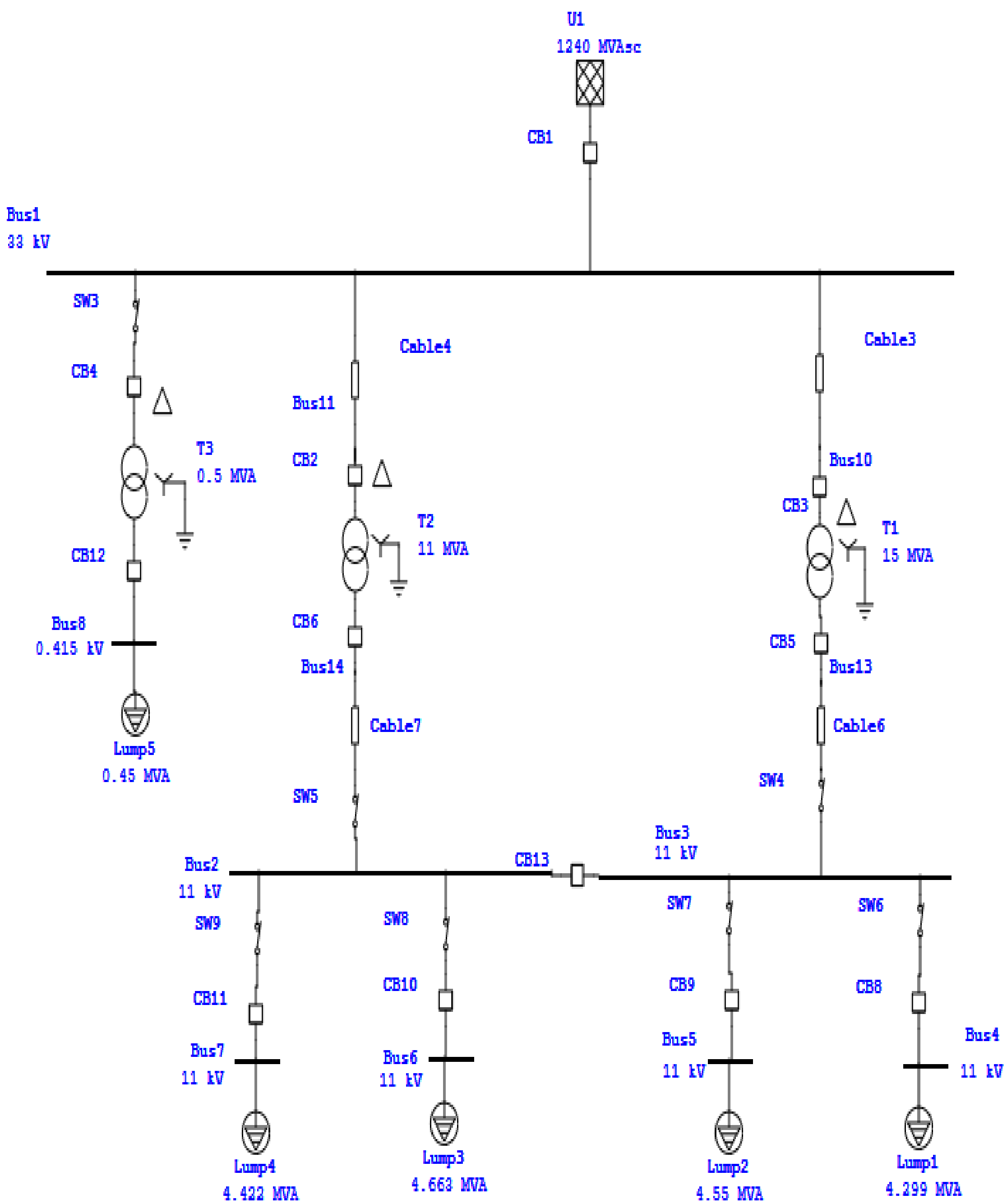


Figure 3.1 Single Line Diagram of Borikiri Network Port Harcourt

Table 3.1: Main Specification of the DVR

Parameter	Value
Nominal grid voltage	200V (L-L)
Nominal load voltage	120V (L-L)
Maximum series voltage Injection	100V (L-L)
Switching/sampling frequency	10 kHz
Max. Inverter dc-bus voltage	120 V
Capacitor of DC- bus	26μF
Filter inductance	2.7mF
Filter capacitance	50μF

3.2 Method Used

3.2.1 Principle operation of Dynamic Voltage Restorer

The Dynamic Voltage Restorer is a solid-state power electronic switching device that consists of a Gate Turn-Off Thyristor, (GTO) or Insulated Gate Commutated Thyristor (IGBT), a capacitor bank is referred to as an energy storage device, and injection transformers. The main idea of the DVR is to inject a controlled voltage generated by a forced commuted converter in a series to the bus voltage through an injecting transformer. A DC to AC inverter controls this voltage by the sinusoidal Pulse-width modulation (PWM) technique. Under the normal operating condition, the DVR injects only a small voltage to compensate for the voltage drop of the injection transformer and device losses. Nevertheless, when voltage sag occurs in the distribution system, the DVR control system analyzes and synthesizes the voltage required to preserve output voltage to the load by injecting a controlled voltage with a particular magnitude and phase angle into the distribution system to the critical load.

It is noted that the DVR is capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of DVR is very short and limited by the power electronics devices and the voltage sag detection time. The expected response time is about 25 milliseconds, and which is much less than some of the traditional methods of voltage correction such as tap-changing transformers.

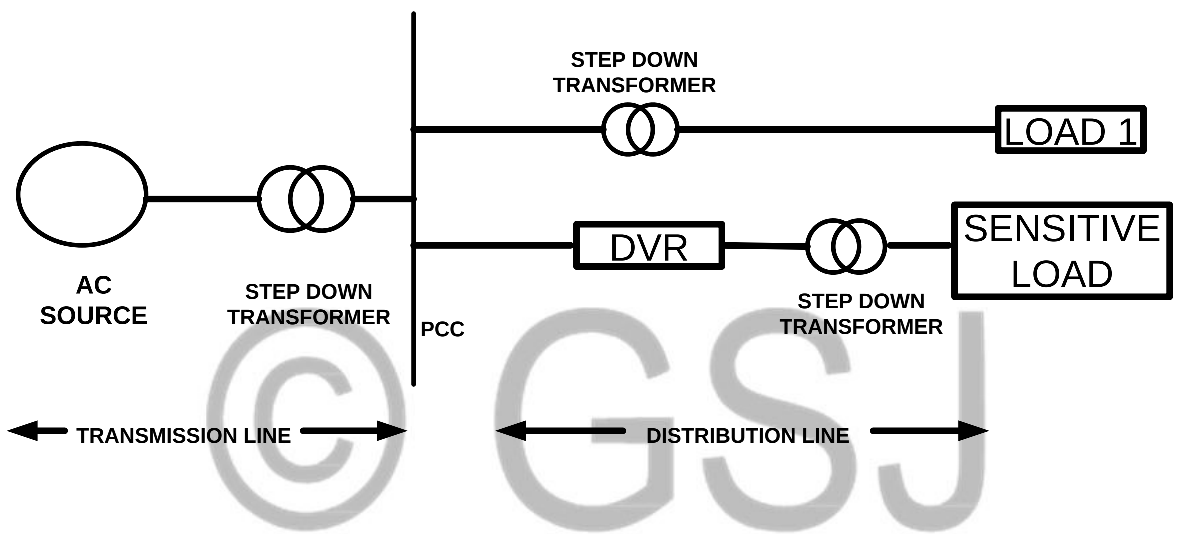


Figure 3.2: Location of DVR

3.3 Basic Configuration of DVR

Multi-loop control is used with an outer voltage loop to regulate the DVR voltage and an inner loop to control the load current. This technique has the strengths of feed-forward and feedback control approaches, at the expense of complexity and time delay. The basic configuration of Dynamic Voltage Restorer is illustrated in the figure below.

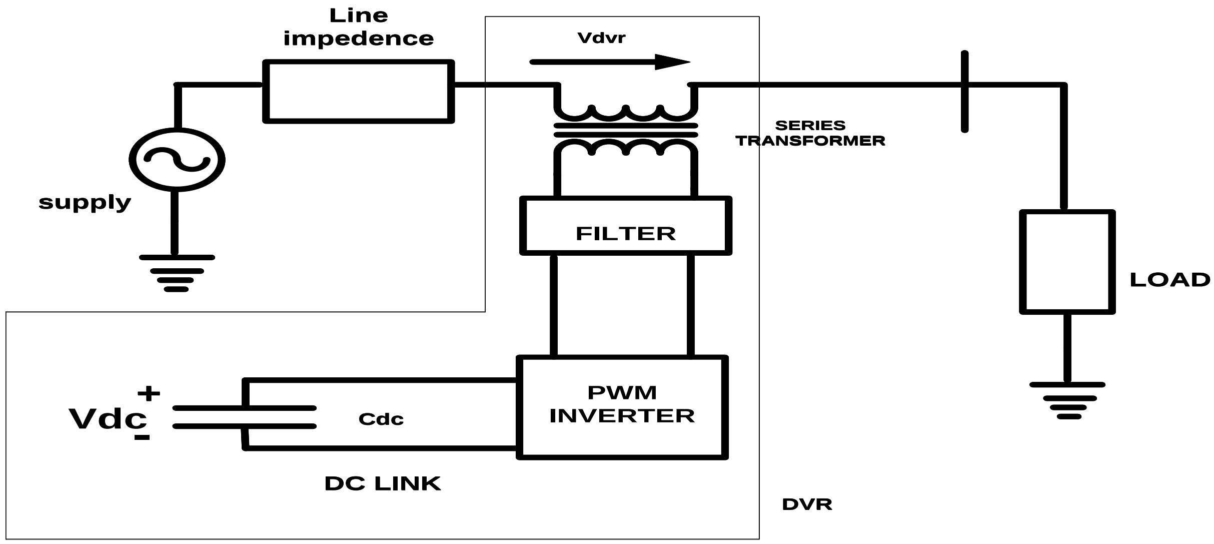


Figure 3.3: Basic Configuration of Dynamic Voltage Restorer

3.4 Equivalent circuit of Dynamic Voltage Restorer

The equivalent circuit of DVR is shown in figure 3.4.

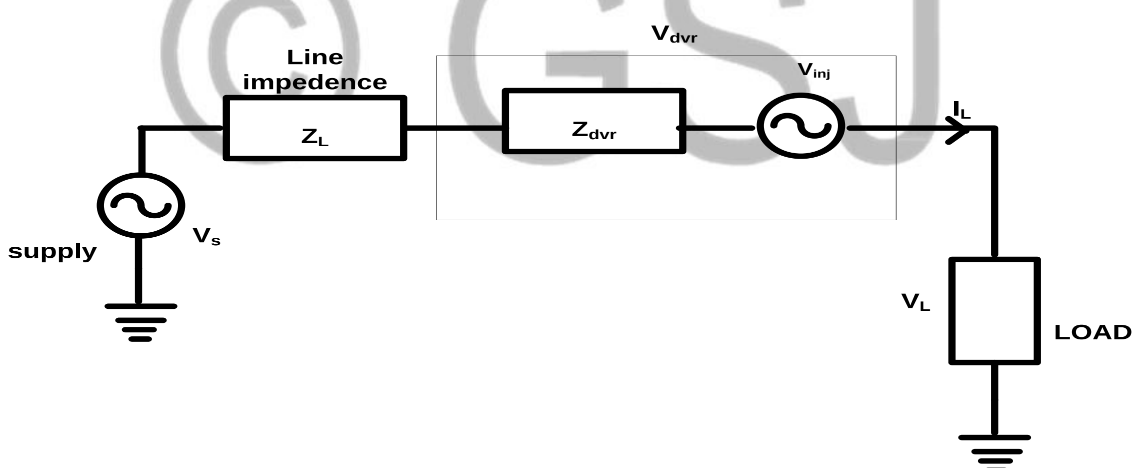


Figure 3.4: Equivalent circuit diagram of DVR

When the system voltage (Vs) sags/swells, the DVR injects a series voltage Vdvr during the injection transformer so that the required load voltage magnitude V_L can be retained. The series injected voltage of the DVR can be written as

$$V_{dyr} = V_L + V_L * Z_L - V_s \quad (3.1)$$

Where:

V_L= Desired Load voltage

Z_L= Line Impedance

V_S = source voltage under unbalance condition

3.5 Voltage injection methods of DVR

Voltage injection or Injection methods employing a DVR depend upon the limiting factors for instance; DVR power ratings, different types of voltage Sags/swells and various conditions of load. Several loads are responsive in the direction of phase angle jump and some are responsive in the direction of change in magnitude and some are responsive to both phase angle change and magnitude. However, the control strategies depend strongly on the type of load characteristics.

In this method, DVR supply both active and reactive power from the voltage source converter (VSC).

$$V_{dyr} = V_o - V_{s1} \quad (3.2)$$

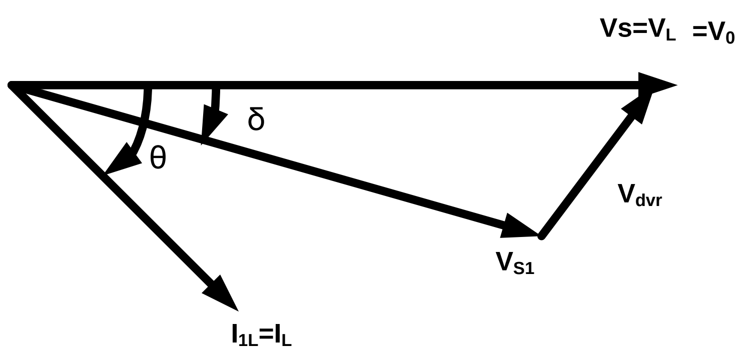


Figure 3.5: Pre-sag/swell Injection method

Where:

Vs = Source voltage

V_O = pre sag voltage

I_{L1} = I_L = Line current

V_{s1} = Source voltage under unbalance condition

V_{dvr} = Injected voltage

θ = load angle.

3.5.2 In-phase Injection method

This is the most straight forward method, where the injected voltage is in phase with the supply voltage regardless of the pre-sag/swell voltage and load current. The phase angles of the pre-sag/swell and load voltage are different but the most significant criteria for power quality that is the steady magnitude of load voltage are satisfied.

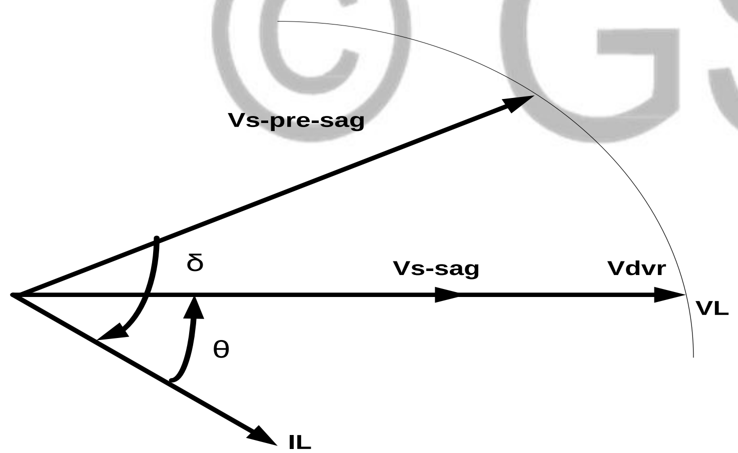


Figure 3.6: In-Phase Injection method

$$|V_L| = |V_s - pre - sag| \quad (3.3)$$

θ = load angle

One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies. The Practical application of this method is in non-sensitive loads to phase angle jump.

3.6 DVR Operating States

The DVR is designed to inject a dynamically controlled voltage i.e. V_{dyr}, which is generated by a forced commutated converter. The voltage is injected in series to the bus voltage with the help of an injection transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any harmful effects of a bus fault to the load voltage V_L. This signifies that any differential voltages caused by transient disturbances in the AC feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the injection transformer. The DVR has three approaches of operation which are: protection approach, standby approach and injection/boost approach.

In the protection approach, when the current on the load side exceeds a tolerable limit due to any fault or short-circuit on the load, DVR will isolate from the system. In the standby approach, the voltage winding of the injection transformer is short-circuited through the converter. While in the Injection/Boost approach, the DVR is injecting a compensating voltage through the injection transformer due to the detection of a disturbance in the supply voltage.

3.7 Voltage Unbalance

Voltages unbalance definitions:

There are three voltage unbalance Definitions that are stated and analyzed below:

1) NEMA (National Equipment Manufacturer's Association) Definition:

The NEMA definitions (3.1) of voltage unbalance, also known as the line voltage unbalance rate (LVUR), is given by

$$\% LVUR = \frac{Max\ Voltage\ \ Deviation\ \ from\ \ the\ Avg\ line\ Voltage}{Avg\ line\ Voltage} * 100 \tag{3.4}$$

The NEMA definition assumes that the average voltage is always equal to the rated value, which is 480 V for the US three-phase systems and since it works only with magnitudes, phase angles are not incorporated.

2) IEEE Definition: The IEEE definition of voltage unbalance is given in equation (3.5) and is also known as the phase voltage unbalance rate (PVUR), is given by

$$\% PVUR = \frac{Max\ Voltage\ \ Deviation\ \ from\ \ the\ phase\ line\ Voltage}{Avg\ phase\ Line\ \ Voltage} * 100 \tag{3.5}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Description of the Work

The chapter analyzes the performance of the Dynamic Voltage Restorer (DVR) through different supply voltage conditions (voltage sag, voltage swell, and voltage unbalance) to R-L load. The whole model of the DVR is constructed in the Simulink environment (MATLAB) and the use of ETAP version 12.6 is used to simulate the case study.

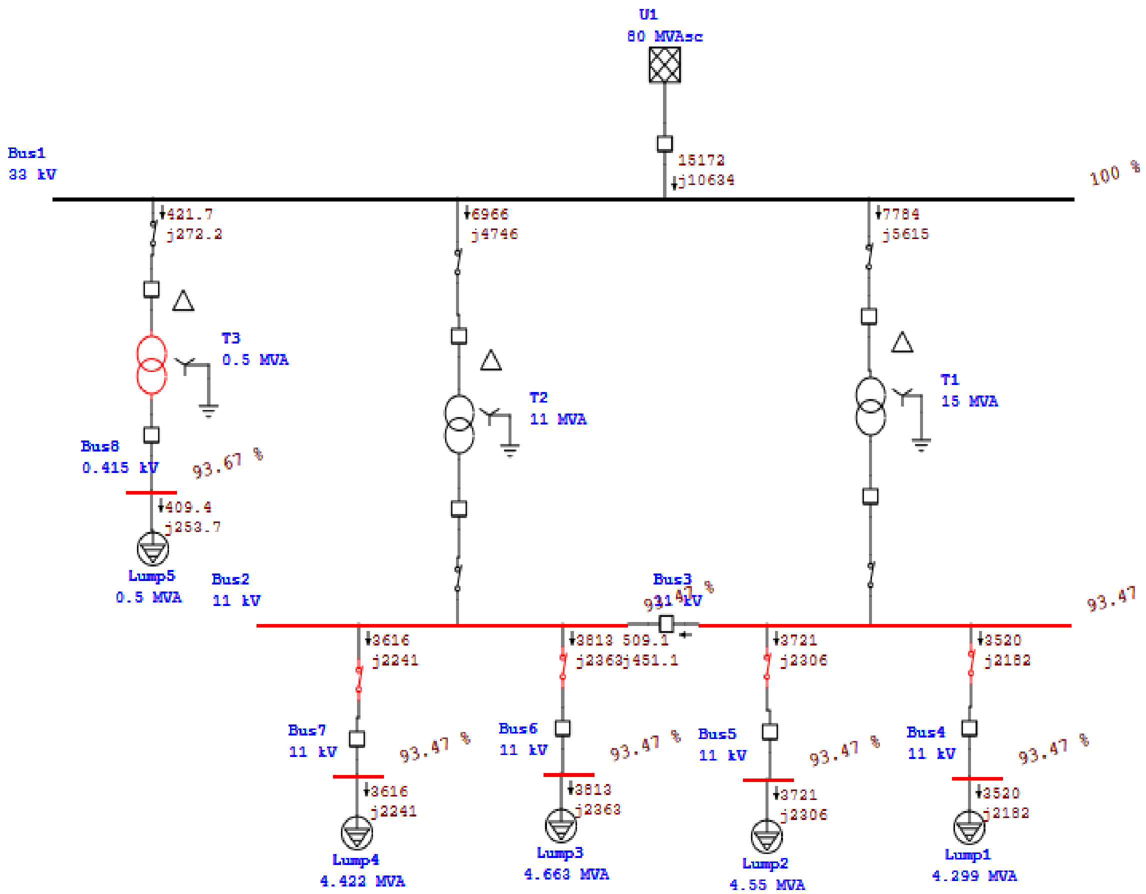


Figure 4.1 Simulated Single Line Diagram of Borikiri Network Port Harcourt

4.2 DVR Circuit Parameters used in the Analysis

Table 4.1 Simulation parameters used

Serial No.	**Quantity**	**Value**
1	Supply Voltage	415V, 50Hz (line-line)
2	Source Impedance	$R_s = 0.5\ \Omega$, $L_s = 0.1$ Mh
3	DC Capacitor	5000 uF
4	DC Link Voltage	680V
5	Ripple filter	$L_f = 2$ mH, $C_f = 50$ uF

9	Series Transformer	1:1
10	Switching Frequency	20 kHz
11	Load	Three Phase Balanced Linear Load $R - L\ load\ (R = 30\,\Omega, L = 0.302\,H)$

The injection transformer injects the AC voltage of the inverter to each phase of the line. While the control block generates the reference signals to the PWM inverter.

4.3 Supply Voltages

4.3.1 Case I: Balanced Supply Voltage

The voltage across the load is kept constant for different supply voltage disturbances. Once the rated balanced voltage is applied to the load, the injected voltage by the voltage source converter is zero ideally but supplies very a small voltage to compensate for the drop in the injection transformer.

The subsequent equations correspond to the balanced source voltage.

$$v_{sa} = 338.846 \sin(wt) \tag{4.1}$$

$$v_{sb} = 338.846 \sin(wt) \tag{4.2}$$

$$v_{sc} = 338.846 \sin(wt) \tag{4.3}$$

GSJ: Volume 8, Issue 12, December 2020
ISSN 2320-9186

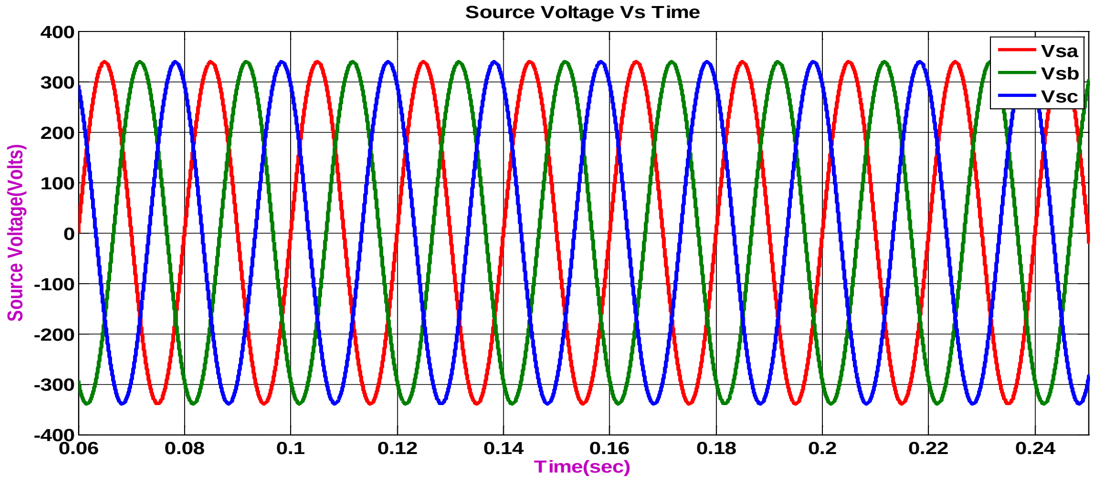


Figure 4.4: Source Voltage for Balanced Supply Voltage

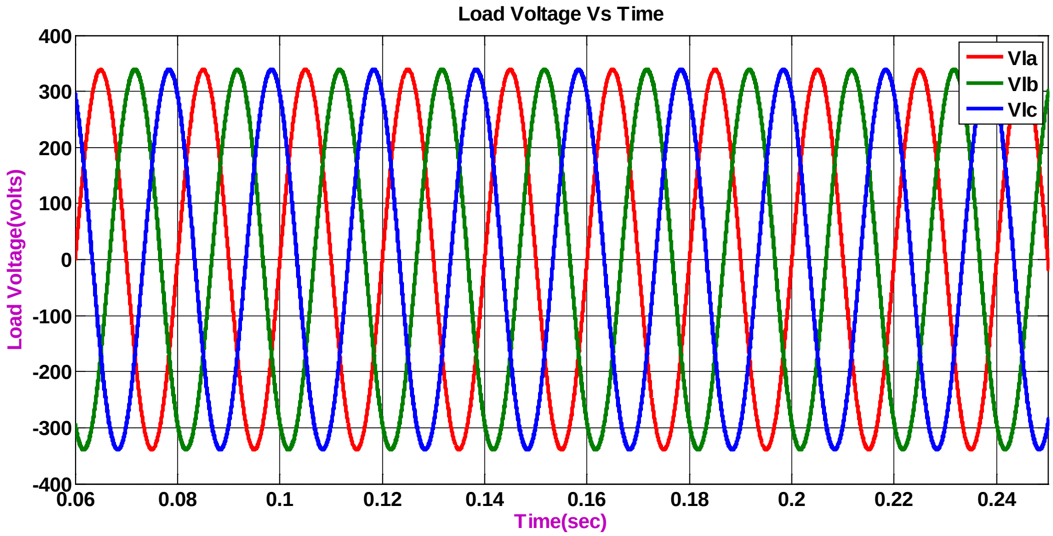
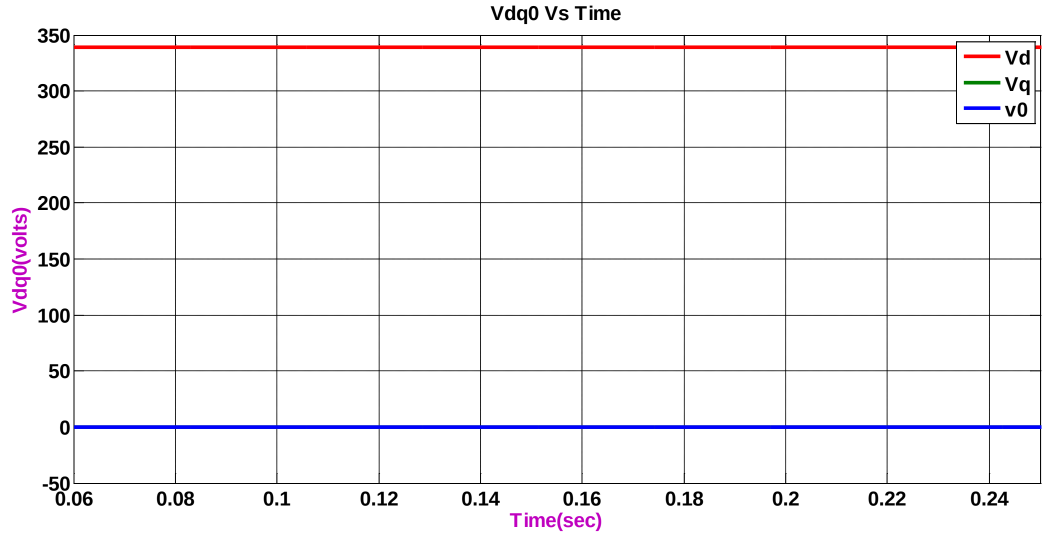


Figure 4.5: Load Voltage for Balanced Supply Voltage

(a)



(b)

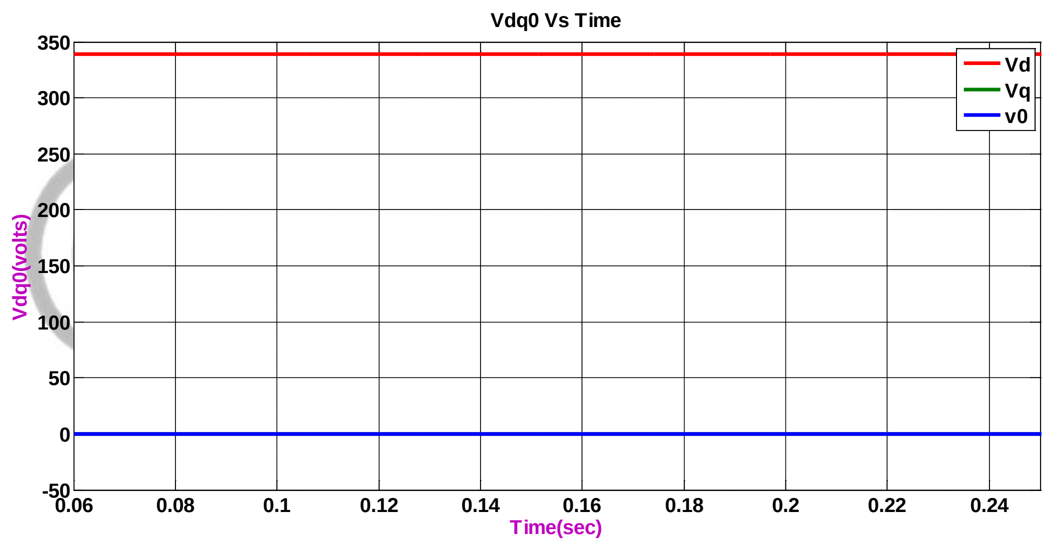


Figure 4.6: (a), (b) Direct, Quadrature, and Zero axis voltages

The above figure shows the waveform of Direct, Quadrature, and Zero axis voltages under balanced supply Voltage (simulation is done in Matlab Simulink. The Quadrature and zero axis voltages are of zero voltage after converting the source voltage to a synchronously rotating reference frame (abc to $dq0$).

Figure 4.7 shows the waveform of Balanced Sag Source Voltage (simulation is done in Matlab Simulink). The voltage sag is supplied from 0.08 to 0.2 seconds (6 cycles).

Figure 4.8 shows the waveform of Load Voltage (simulation is done in Matlab Simulink). The voltage is injected by DVR from 0.08 to 0.2 seconds. From the waveform, it can be observed that the voltage across the load is maintained to rated voltage.

4.3.2 Case II: Balanced Supply Voltage (Sag)

The subsequent equations represent the balanced sag voltage with 20% of sag. The peak value of phase voltage is 338.846V and line to line voltage of 415V.

$$v_{sa} = (338.846 \ * 0.8) \sin(wt) \tag{4.4}$$

$$v_{sb} = (338.846 \ * 0.8) \sin(wt - 120) \tag{4.5}$$

$$v_{sc} = (338.846 \ * 0.8) \sin(wt - 240) \tag{4.6}$$

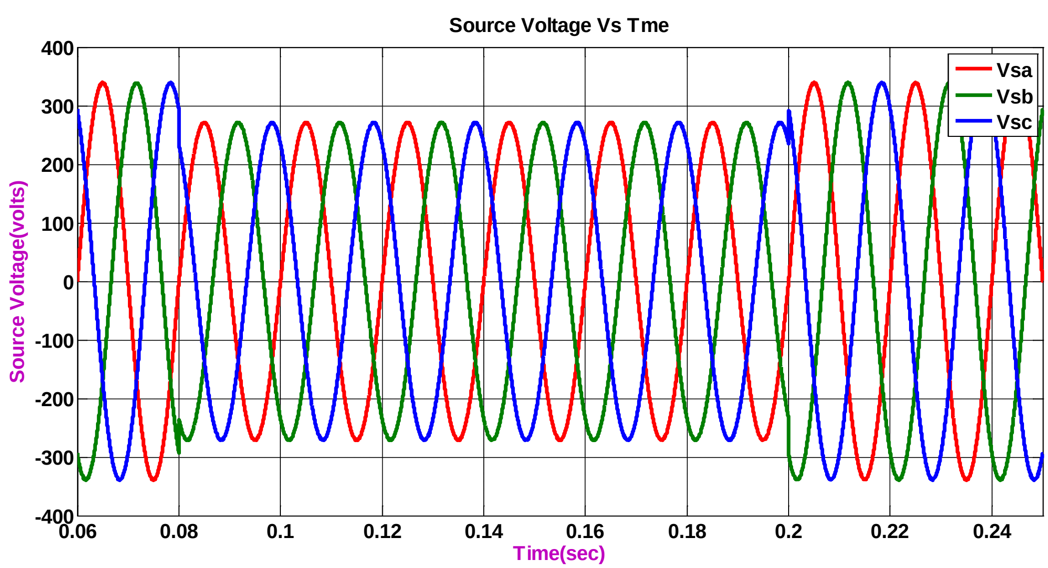
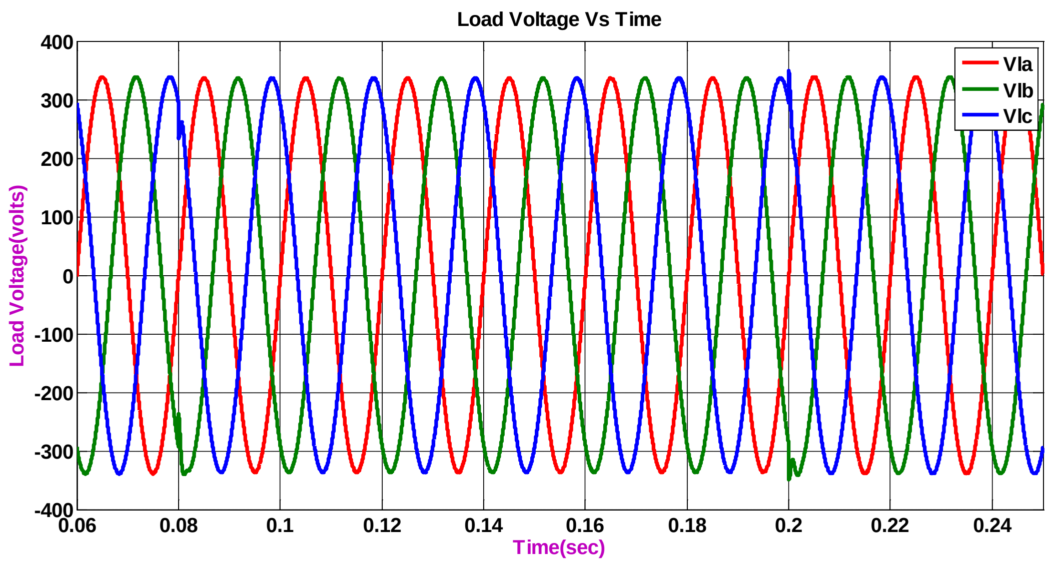


Figure 4.7: Source Voltage for Balanced Supply Voltage (Sag)

GSJ: Volume 8, Issue 12, December 2020
ISSN 2320-9186

(a)



(b)

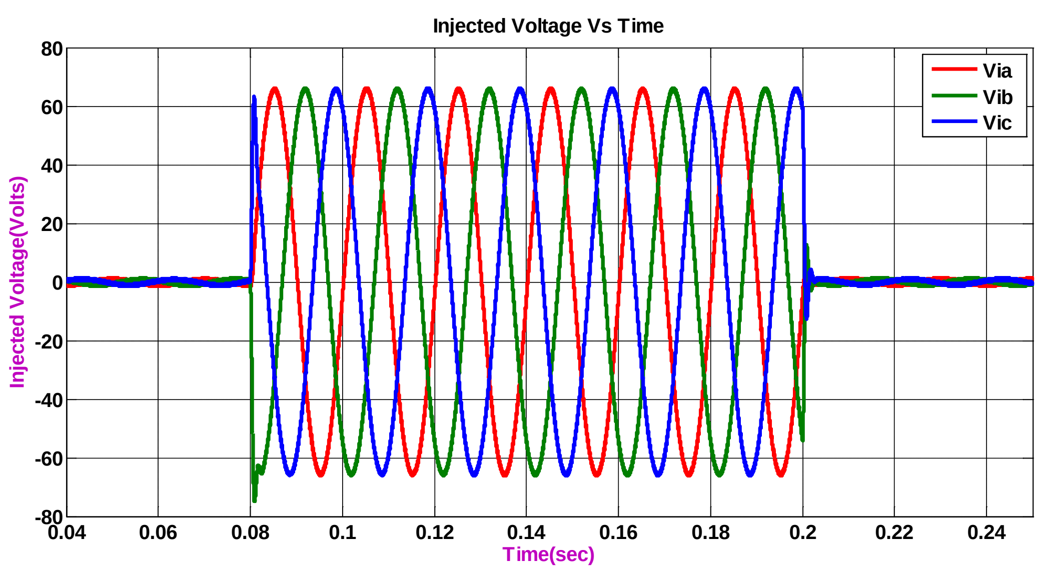


Figure 4.8: (a), (b) Load voltage for Balanced Supply Voltage (Sag)

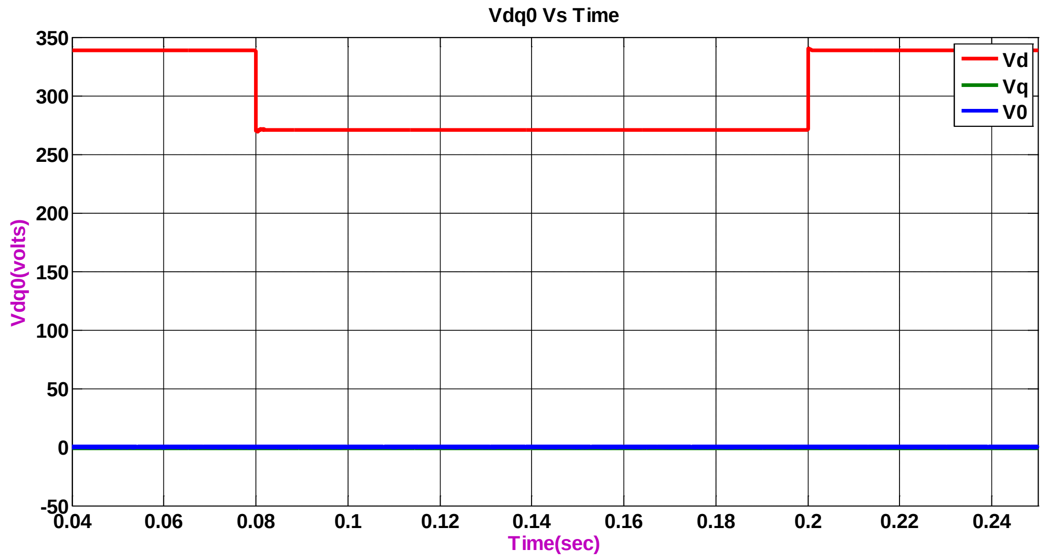
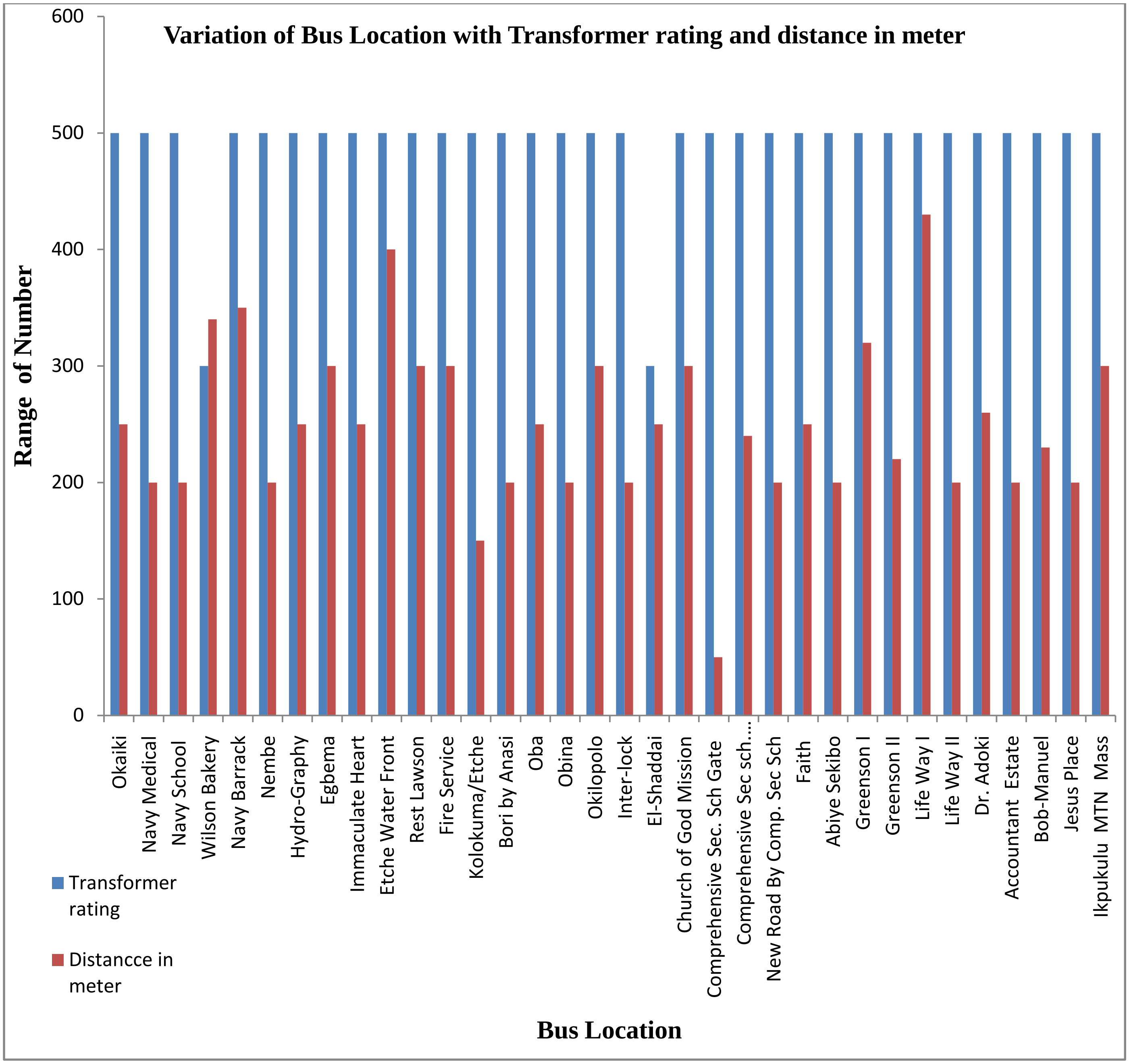


Figure 4.9: Direct, Quadrature, and Zero axis voltage


Variation of Bus Location with Transformer rating and distance in meter
Range of Number
600
500
400
300
200
100
0
Okaiki
Navy Medical
Navy School
Wilson Bakery
Navy Barrack
Nembe
Hydro-Graphy
Egbema
Immaculate Heart
Etche Water Front
Rest Lawson
Fire Service
Kolokuma/Etche
Bori by Anasi
Oba
Obina
Okilopolo
Inter-lock
El-Shaddai
Church of God Mission
Comprehensive Sec. Sch Gate
Comprehensive Sec sch....
New Road By Comp. Sec Sch
Faith
Abiye Sekibo
Greenson I
Greenson II
Life Way I
Life Way II
Dr. Adoki
Accountant Estate
Bob-Manuel
Jesus Place
Ikpukulu MTN Mass
Transformer rating
Distancce in meter
Bus Location

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This work critically examined how to improve the electrical power distribution for Borikiri Township axis of Port Harcourt using the Dynamic Voltage Restorer Method. An indication of power quality disturbances in low voltage distribution networks and DVR is a crucial effective and efficient power electronic custom power device. The main function of DVR is the protection of sensitive loads and other customers' loads from voltage disturbances coming from the grid such as; voltage sags and swells, voltage variation, voltage unbalance, harmonics and transients in the electrical power distribution network and case study for the variation of the existing and improved power factor, absorbed current before and after power factor, power of the capacitor bank, Loss reduction with power factor, reduction of voltage drop and power factor using a capacitor, power factor **(**Pf) using a capacitor with respect to bus location were investigated vigorously. The use of the Electrical Transient and Analysis Program (ETAP Version 12.6) and Simulink Environment (MATLAB) was used for simulation.

The dynamic voltage restorer (DVR) consists of the gate turn-off thyristor (GTO) and insulated gate commutated thyristor (IGBT) which is solid-state power electronics switching device having a capacitor bank which is used as an energy storage device and injection transformers. The main idea of the DVR is to insert a controlled voltage generated by a forced commuted converter in a series to the bus voltage employing an injecting transformer. The dynamic voltage restorer method was used to calculate for variation of the following parameters with respect to bus location; Source Voltage for Balanced Supply Voltage, Load Voltage for Balanced Supply Voltage, Source Voltage for Balanced Supply Voltage (Sag), Direct, Quadrature, and Zero axis voltage, Waveform of Balanced Swell Voltage, existing and improved power factor, absorbed current before and after power factor, power of the capacitor bank, loss reduction with power factor, reduction of voltage drop and power factor using a capacitor, power factor (pf) using a capacitor with respect to bus location.

5.2 Contribution to Knowledge

This research work has contributed to knowledge as follows:

i. This work examined the existing state of the system and to restore the load voltage, active and/or reactive power should be injected into the distribution feeder.

ii. This work also examined how to provide the solution to various power quality problems such as variation of the existing and improved power factor, absorbed current before and after power factor, power of the capacitor bank, Loss reduction with power factor, reduction of voltage drop, and power factor using a capacitor, power factor **(**Pf) using capacitor with respect to bus location to the system.

5.3 Recommendations

Based on the experimental results and analysis the following recommendations were drawn:

1. The general idea of DVR will assist end-users, engineers, researchers, and suppliers of electrical power to gain insight for further research and studies on the subject.
2. The power quality disturbances in low voltage distribution networks should be examined in detail by checking the existing and improved power factor, reduction of voltage drop, and power factor using a capacitor with respect to bus location.

3. To improve the performance of DVR efforts need to be made on energy savings, reduced parts and losses, reduced rating, minimum power injection and selective harmonics mitigation.

REFERENCES

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

Benachaiba, C., & Ferdi, B. (2009). “Power Quality Improvement Using DVR”, American Journal of Applied Sciences, 6(3): 396-400.

Bollen, M.J. (2003)."What is power quality?" Electric Power Systems Research, 66(1): 5-14.

Chan, K., Leung, K., Chung, H., & Hui, S. (2006). Boundary controller for dynamic voltage restorers to achieve fast dynamic response, Applied Power Electronics Conference and Exposition.

Daniel, D., & Ambra, S. (2003). “A Summary of the Draft IEEE P1409 Custom Power Application Guide” Transmission and Distribution Conference and Exposition, IEEE PES, 3(7): 931-936.

Dugan, R. C., McGranaghan, M. F., Santoso, S., & Wayne, H. (2002). ‘‘Electrical Power Systems Quality second edition, McGraw-Hill, New York.

El-Mofty, A., & Youssef, K. (2001). "Industrial power quality problems," Electricity Distribution, Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEE Conf. Publ No. 482), 2(5).

Fawzi, J. (2009). “Modeling and Simulation of Different System Topologies for Dynamic Voltage Restorer” Electric Power and Energy Conversion Systems, EPECS '09. International Conference, IEEE. 9(12): 1-6.

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

Hingorani, N. & Gyugyi., L. (2000). Understanding FACTS – Concepts and Technology of Flexible AC Transmission Systems, IEEE Press, New York.

IEEE Standard 100-1992, IEEE Standard Dictionary of Electrical and Electronic Terms.

John, G., & Frede, B. (2001). “Control Strategies for Dynamic Voltage Restorer Compensating Voltage Sags with Phase Jump”, Applied Power Electronics Conference and Exposition, IEEE, 2(6): 1267-1273.

Jowder, F.A. (2009). Design and analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation, Generation, Transmission & Distribution. 3(7):547-560.

Keulenaer, H. (2003). The hidden cost of poor power quality, European copper institute.

Lee, S.J., Kim, H., & Sul, S.K. (2004). A novel control algorithm for static series compensators by use of PQR instantaneous power theory, IEEE Trans on Power Electronics. 19(3):814-827.

Li, Y.W., Vilathgamuwa, M., Chiang Loh, D.P., & Blaabjerg, F. (2007). A dual-functional medium voltage level DVR to limit downstream fault currents”, Power Electronics, IEEE Transactions. 22(12):1330-1340.

Mahesh, S., Mishra, M., Kumar, B., & Jayashankar, V. (2008). Rating and design issues of DVR injection transformer”, Applied Power Electronics Conference and Exposition. 449-455.

Masoud, A. (2002). “Power Quality in Electric Networks: Monitoring and Standards” the second world engineering conference, 8(3): 137-14.

Michael D., Stump, G., & Keane, J. (1998). “The role, of custom power products in enhancing power quality at industrial facilities”, Energy Management and Power Delivery, (2)6: 507-517, International Conference.

Newman, M.J., Holmes, D.G., Nielsen, J.G., & Blaabjerg, F. (2003). A dynamic voltage restorer (DVR) with selective harmonic compensation at medium voltage level, Industry Applications, IEEE Transactions. 41(6): 1744-1753.

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

Omar, R., & Rahim, N.A. (2008) "Modeling and simulation for voltage sags/swells mitigation using dynamic voltage restorer (DVR), "Power Engineering Conference, 2008. AUPEC '08. Australasian Universities, 1(5):14-17.

Omar, R., Rahim, N., & Sulaiman, M. (2011). “Dynamic Voltage Restorer Application for Power Quality Improvement in Electrical Distribution System: An Overview” Australian Journal of Basic and Applied Sciences, 5(12):379-396.

Paisan, B., Nadarajah, M., & Rajamangala, K. (2006). University of Technology Thanyaburi Thailand, “Detailed Analysis of Load Voltage Injection for Dynamic Voltage Restorers” TENCON, IEEE region 10 conference, 12(6):1-4.

Padiyar, K. (2007). “Facts controllers in power transmission and distribution” new age international (P) Ltd publishers.

Pakharia, A., & Gupta, M. (2012). “Dynamic Voltage Restorer for Compensation of Voltage Sag and Swell: A Literature Review”, International Journal of Advance in Engineering & Technology, 4(1):347-355.

Pillay, P., & Manyage, M. (2001). “Definitions of Voltage Unbalance” IEEE Power Engineering Review.

Posada, J., Ramirez, J., & Correa, R. (2011). "Voltage compensation for common disturbances at the distribution level," Innovative Smart Grid Technologies (ISGT Latin America), IEEE PES Conference on, 4(16).19-21.

Stones, J., & Collinson, A.(2001). "Power quality," Power Eng. Journal, 15(.2): 58-64.

Roncero-Sanchez, & P., Acha, E. (2009). Dynamic voltage restorer based on flying capacitor multilevel converters operated by repetitive control, Power Delivery, IEEE Transactions on. 24(2): 951- 960.

Tiwari, H., & Sunil G.(2010). “Dynamic Voltage Restorer against Voltage Sag” International Journal of Innovation, Management and Technology. 1(3): 232-237.

Vilathgamuwa, M., & Wijekoon, H. (2007). "Mitigating Zero Sequence Effects in Dynamic Voltage Restorers," Power Electronics Specialists Conference, PESC 2007. IEEE, 17(21):3079- 3085.

Woodley, N., Morgan, L., & Sundaram, A. (2015). "Experience with an inverter-based dynamic voltage restorer," Power Delivery, IEEE Transactions on, vol.14, no.3, (1999) 1181-1186. Electrical & Computer Engineering: An International Journal (ECIJ). 4(2):95.

Yash, P., Swarup, A., & Bhim, S., (2008). “A Review of Compensating Type Custom Power Devices for Power Quality Improvement” IEEE Power India Conference, 5(9): 1-8.

Zhan, C., Ramachandaramurthy, V., Arulampalam, A., Fitzer, C., Kromlidis, S., Barnes, M., & Jenkins, N. (2001). "Dynamic voltage restorer based on voltage space vector PWM control," Applied Power Electronics Conference and Exposition, 2001. APEC 2001. Sixteenth Annual IEEE, 2(8): 1301-1307.