Enhancement of 11kV Distribution Network for Power Quality Improvement Using Artificial Neural Network Based DVR

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Abstract- Voltage sag and swell are major challenges facing Rumuomoi 11kV distribution network and no mitigationor control by means of custom power devices has been considered. This Research work is aimed at addressing these power quality challenges in Rumuomoi 11kV distribution network using artificial neural network (ANN) controller based dynamic voltage restorer. The artificial neutral network controller used to control the dynamic voltage restorer was trained with the input and target data obtained from simulation with PI controller. Matlab Simulink software is used for this research. The proposed dynamic voltage restorer system was tested with replicated model of Rumuomoi 11kV distribution network. The result obtained shows that Bus 7 with 0.938p.u, Bus 8 with 0.9244p.u, Bus 9 with 0.9148p.u, Bus 10 with 0.9035p.u, Bus 11 with 0.8912p.u and Bus 12 with 0.8811p.u violated the statutory limit condition of 0.95-1.01p.u. After optimization of the network using DVR, there was no bus voltage violation which shows that DVR was effective in improving voltage profile as well as mitigating voltage sag and swell from the distribution network.

Indexed Terms- Enhancement, Distribution, Power Quality, Artificial Neural Network, DVR.

I. INTRODUCTION

The importance of electricity cannot be overemphasized in modern times as it is the basis for socio-economic and technological development of any nation. According to Uwho et al. (2022) one of the most basic need of life is energy. The researcher further said that among the various types of energy, electrical energy has a significant impact on how a society operates. According to Gupta (2016) the availability of electricity in the right proportion is key for the enhancement of industrial, commercial and domestic activities. According to Braide et al. (2021) distribution system is the last stage of power supply system and also the most noticeable segment of the power system by end users. According to voltage levels, distribution system can be classified into primary, secondary and tertiary subsystems. Primary distribution network receives bulk power from transmission system at 33kV by means of stepped-down transformer while secondary distribution network receives power at 11kV from a primary distribution network by means of stepped-down transformer and finally, tertiary distribution receives power at 230V from a secondary distribution network by means of stepped-down transformer (Theraja, 2005). According to Braide et. al. (2019) distribution transformer is one of the major power equipment which connects the power supply to the consumer. In power distribution system, equipment such as inductors, transformers, switchgears etc serve the sole purpose of delivering power to consumer load. Industrial, commercial and domestic loads are prone to reliability and power quality challenge. According to Braide et al. (2020) the consistency quality of electricity delivered to consumers has become an important factor that affects the drive needed for technological growth and development of modern facilities in the society. The need to mitigate power quality problems and maintain power of good quality has brought power system engineers, equipment manufacturers, researchers and statutory bodies to a focal point of methodology development. Today, several methods are developed to improve the quality of power to sustain the ever-increasing applications of sensitive and non-linear loads in distribution network. Conventionally, synchronous condenser, capacitor banks, static VAR compensators (SVCs), selfcommutated VAR compensators etc are used to control reactive power and improve power factor though with drawbacks such as instability problems, generation of high transient during connection and disconnection (Irfan et al., 2013). According to Braide et al. (2018) electric power distribution is the major component in the delivery of electric power.

The objectives of the study are:

i. To use existing data for analysis
ii. To employ dynamic voltage restorer (DVR) and artificial neural network (ANN) technique to correct the effect of voltage sag and swell on the Rumuomoi 11kV distribution network.
iii. To improve the power quality of Rumuomoi 11kV distribution network.

II. LITERATURE REVIEW

2.1 Extent Of Past Work

The Distribution system is the final stage of power supply system and also the most noticeable segment of the power system by end-users. According to (Okereafor et al., 2017) optimal delivery of uninterrupted power to the end users is a huge task. Because the distribution system is regularly faced with a high demand for power thereby is prone to system instability such as over loading.

Electric power distribution system is the most noticeable section of the power system and last stage in the delivery of electricity to the end users. Depending on the voltage level, the distribution system consists of three subsystems such as primary, secondary and tertiary distribution with voltage 33kV, 11kV and 0.415kV respectively. (Amesi, 2016)

This primary voltage is commonly used in industries, factories and also feed small substation where secondary distribution takes place. Primary distribution of power is usually achieved by using a 3 phase, 3 wire system. Distribution/service transformer transforms the voltage for the final residential domestic consumers. Single phase supply is usually at 230V while phase to phase voltage is 415V.

2.1.1 Characteristic of Good Distribution System

i. Maximum reliability of power supply.
ii. Good power factor.
iii. Minimum duration of interruption.
iv. Voltage drop should at consumers end not less than $\pm$ 5% of nominal.
v. Efficiency is not less than 90%

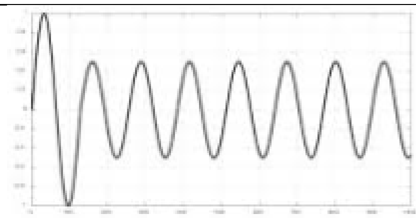
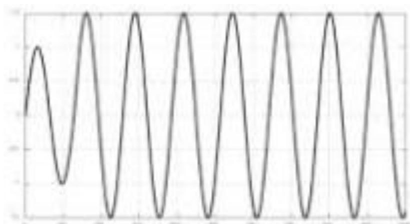
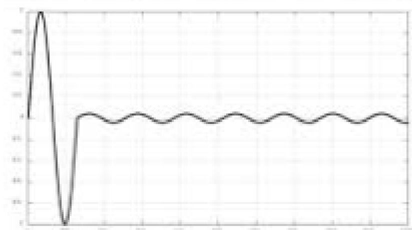
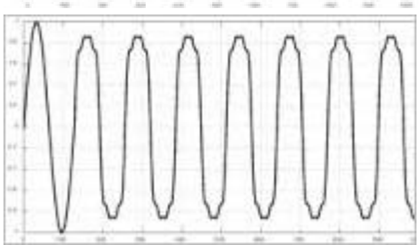
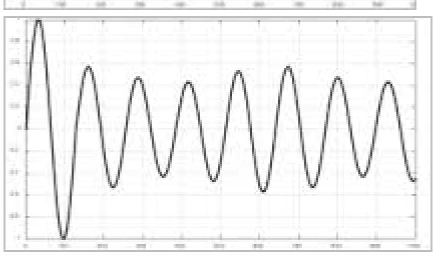
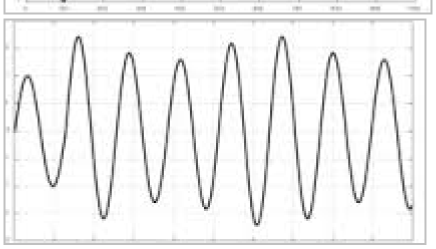
2.2 Overview of Power Quality Issues

Power quality is the measure to which power supply quantities such as voltage, frequency and other waveform maintain statutory specification or standard. According to Sankaran (2002), with the discovery of electricity years back, power quality problems has been but was not a major challenge as equipment in those days were not very susceptible to variations in power system parameters. In recent years, the rising concern is as a result of number of factors which include: rising use of equipment designed with no performance margin, increase in electricity demand in homes and industries, and inter-connection of electrical utility into complex grid. Other factors are customer awareness, increased emphasis on overall power system efficiency (Roger et al., 2004). Also increased use of embedded generation and renewable energy sources and modification of consumer demand pattern (Zahir, 2011).

2.3 Detection and Classification of Power Quality Disturbance

According to Vijayarajan (2010) one of the challenges in power quality is detection and classification of disturbance waveforms in a more efficient way as visual observations have proved inefficient. Several techniques employed to study the characteristics of signal and classify power quality disturbances are critically analyzed by Saxenaet al. (2010). They also identified the challenges of each method, and emphasized that intelligent approaches using, digital signal processing, expert systems, artificial intelligence and machine learning are better with some unique advantages. According to Joseph (2011) power quality disturbances are classified as transient, interruptions, swell/overvoltage, sag/under voltage, waveform distortion, voltage fluctuation, frequency fluctuation and voltage imbalance. The waveforms are shown in table below

Table 2.1: Classification of Power Quality Disturbance (Source: Joseph, 2011).

Types of Disturbance	Wave Form	Condition	Causes
Voltage Sag			
Voltage Swell			
Interruption		is a complete loss of utility supply	
Harmonic Distortion			
Voltage Unbalance		occurs when the voltage magnitudes and/or phase angle between the different phases in a three-phase system are not equal	
Voltage Fluctuation		is the random change in voltage waveform usually of slight percentage of nominal amplitude with frequency of 0 to 30 Hz.	

2.4 Sources of Power Quality Problems

Sources of power quality problems can be categorized into load sources, power system sources and weather or environmental sources.

2.4.1 Load Sources

Shailesh et al.(2013) the operation of most loads connected to distribution system by most industrial and commercial users contribute substantially to power quality disturbances. Similarly, non-linear loads such as electronic power converters like uninterrupted power supply (UPS), inverters, fluorescent lighting also contributes to power quality disturbances . The switching of heavy loads such as electric motor in industries are load related sources. (Philippe, 2001).

2.4.2 Power System Sources

According Michael (2000) Power system sources include, faults, energizing of transformer, utility switching, power system impedance etc.

2.4.3 Environment Sources

Weather or environmental source are lightning, wind, rain etc. (PowerCet, 2010)

2.5 Power Quality Indices and Standards

According to WG Report (2004) identified power quality indices as harmonics, flicker, unbalance voltage, voltage dip and long interruption factors. This report also gave the limit values of these indices and standards of regulatory bodies such as IEC etc. In addition, power factor and total harmonic distortion are also considered as power qualify indices (Alexander, 2014).

Khalid (2011) International standard organizations such as IEEE. NEC, ANSI etc have developed standards to regulate power system parameters and power quality indices measured at point of common coupling (PCC). Standards for current and voltage harmonics and limits for total harmonic distortion (THD)) for different voltage levels and current rating arc given in(www.mtecorp.com,2015) report. Also, frequency, power factor limits, voltage limits for service and utilization voltages are given in www.narue.org/international (Thomas, 2006).

2.6 Application of Artificial Intelligence in Power System

Rathika and Devaraj (2010) artificial intelligence techniques are most effective techniques for developing optimal controllers for custom power devices. It was further reviewed that the commonly used artificial intelligence controllers are Fuzzy logic controllers and ANN controllers. Vinita et al.(2013) unlike the conventional PI and PID controllers, artificial intelligence base controllers can learn, remember, and make decisions, and have been proved to be more effective in terms of response and performance under parameter variations.

Another study with fuzzy logic and PI controller in stabilizing the dc-link voltage of UPQC using pq control strategy under condition like voltage sag, voltage swell, voltage unbalance, dc, shows fuzzy logic controller perform better than P1 controllers (Rama & Suhhransu 2011).

According to Joseph (2017) Artificial Neural Network (ANN) are becoming highly widespread due to its accuracy and efficiency. Neurons interconnection show the response depending on the stimulation of the input. The input neurons convert the stimulus to decision as network output. In order to make a decision, data samples are used in an iterative training section, and weights are changed until the expected results are obtained.

III. MATERIALS AND METHOD

3.1 Materials Used

The data used for this work were collected from the office of the Port-Harcourt Electricity Distribution Company (PHED) in Nigeria which includes:

i. Single line diagram of Rumuola-Rumuomoi 11kV distribution network
ii. Load data of Rumuola-Rumuomoi 11kV distribution network
iii. Line data of Rumuola-Rumuomoi 11kV distribution network.

3.2 Method

Artificial Neural Network (ANN) controller based dynamic voltage restorer (DVR) was adopted for this research work.

3.3 Software

Matlab 2018 application was used to model and simulate Rumuola Injection station.

3.4 Description Of Existing Network

Rumuola injection substation is located in Port Harcourt Nigeria at 4° 48’43” N latitude and 7°2’14” E longitude. Power supply to the injection substation is via 33kV line duly linked to Port Harcourt Mains

(Zone -2) sub-transmission substation. Figure 3.1 shows the single line diagram of Rumuola injection substation modelled in MATLAB software environment. The injection substation consists of 3x15 MVA 33/11kV power transformers and eight (8) outgoing feeders namely; Rumuomoi, Rumuola, New GRA, Water line, Omerelu, Bori Camp, Shell 1A, and Barracks. The Rumuomoi feeder indicated with blue is chosen as the feeder of interest because it plays host to many multi-nationals, co-operate businesses, and commercials therefore is considered one of the feeders with more power demand. Figure 3.2 shows the single line diagram of the radiating 11kV distribution network of Rumuomoi feeder consisting of twelve (12) transformers modelled in MATLAB software environment. Table 3.1 and 3.2 shows the load and line data of Rumuomoi 11kV distribution network respectively.

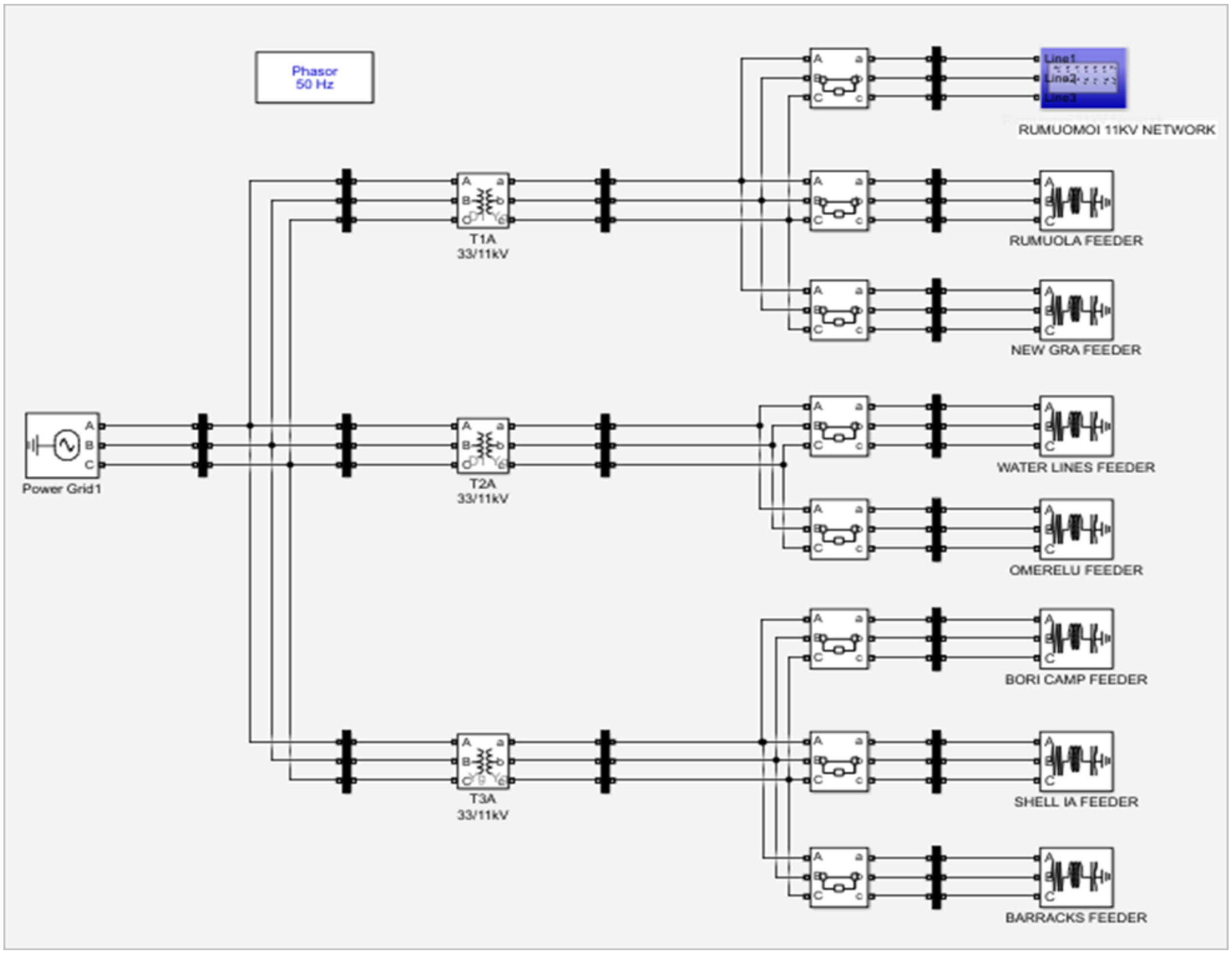


Figure 3.1: Matlab Simulink Block Representation of Rumuola Injection Substation

Table 3.1 Load Data (Source: Port Harcourt Electricity Distribution Company PHEDC)

Distribution Substation				I_R	I_Y	I_B	I_N
Bus No	Bus Name	KVA	kV	(A)	(A)	(A)	(A)
1	Ohiamini Road	500	11/0.415	270	240	200	80
2	Location Road	500	11/0.415	200	190	210	90
3	Ideogu Estate	500	11/0.415	265	356	314	128
4	Omunakwa Road	300	11/0.415	419	380	400	102
5	Okabie Road	300	11/0.415	420	386	412	150

6	Amadi Road 1	300	11/0.415	460	420	440	60
7	Amadi Road 2	500	11/0.415	332	330	330	80
8	Bakery Road	500	11/0.415	300	380	375	85
9	Silicon Valley Ltd	500	11/0.415	295	385	365	75
10	PHWC	500	11/0.415	310	374	370	82
11	Super Geometrics	300	11/0.415	326	380	375	70
12	Ichiegbo Road	500	11/0.415	358	385	365	96

Table 3.2: Line Data (Source: Port Harcourt Electricity Distribution CompanyPHEDC**)**

Line ID	From Bus	To Bus	Impedance (Z)
1-2	Ohiamini Road	Location Road	0.015+j0.057
2-3	Location Road	Ideogu Estate	0.037+j0.049
3-4	Ideogu Estate	Omunakwa Road	0.026+j0.028
4-5	Omunakwa Road	Okabie Road	0.049+j0.041
5-6	Okabie Road	Amadi Road 1	0.083+j0.025
6-7	Amadi Road 1	Amadi Road 2	0.040+j0.011
7-8	Amadi Road 2	Bakery Road	0.058+j0.030
8-9	Bakery Road	Silicon Valley Ltd	0.027+j0.059
9-10	Silicon Valley Ltd	PHWC	0.042+j0.013
10-11	PHWC	Super Geometrics	0.055+j0.047
11-12	Super Geometrics	Ichiegbo Road	0.088+j0.060

IV. RESULTS AND DISCUSSION

4.1 Result Obtained in simulation of Rumuomoi 11kv Distribution Network without ANN Based DVR Controller

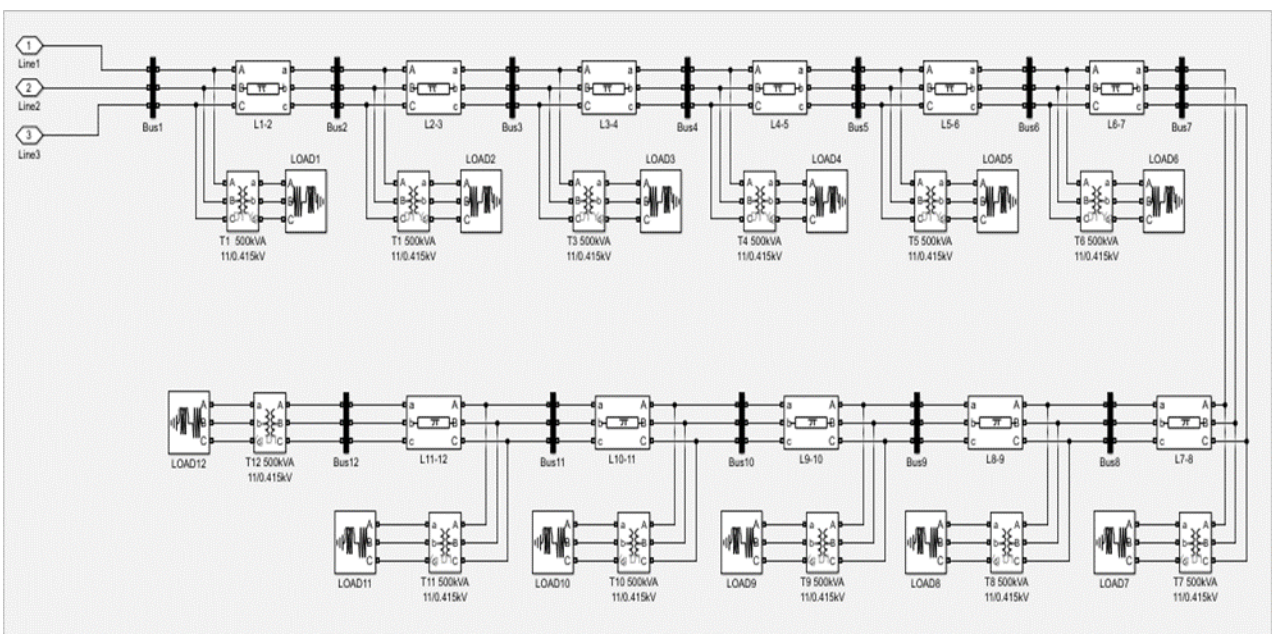


Figure 4.1: Matlab Simulink Simulation of Rumuomoi 11kV Network without ANN Based DVR Controller

Figure 4.1 shows the existing Rumuomoi 11kV distribution network in MATLAB Simulink software environment when DVR is not installed in the network. The single line diagram consists of twelve (12) 11/0.415KV distribution transformers with electric power supply from Rumuola Injection Substation

Table4.1: Bus Voltage without ANN Based DVR Controller

Bus No	Bus Name	Nominal (kV)	Operating (p.u)
1	Ohiamini Road	11	0.9746
2	Location Road	11	0.9692
3	Ideogu Estate	11	0.9666
4	Omunakwa Road	11	0.9642
5	Okabie Road	11	0.9585
6	Amadi Road 1	11	0.9549
7	Amadi Road 2	11	0.9381
8	Bakery Road	11	0.9244
9	Silicon Valley Ltd	11	0.9148
10	PHWC	11	0.9035
11	Super Geometrics	11	0.8912
12	Ichiegbo Road	11	0.8811

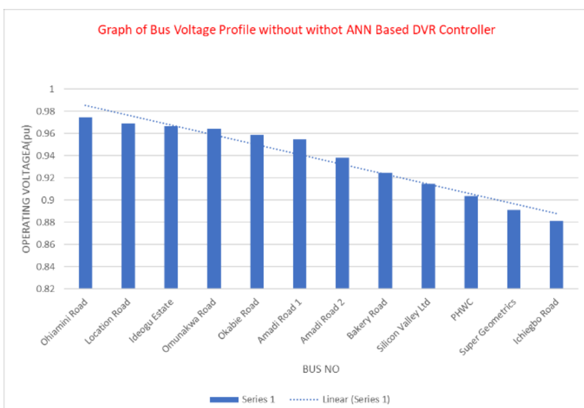


Figure 4.1 Plot of Operating Voltage Against Bus No.

The existing Rumuomoi 11kV distribution system was simulated in MATLAB software based on two (2) scenarios.

In the first scenarios, without ANN based DVR controller. The study was successfully carried out using data obtained from Port Harcourt Electricity Distribution Company (PHED). The electric power supply to the network is via feeder 1 from 3x15MVA 33/11kV injection substation at Rumuola also known as Golden lily**.**

Table 4.1 and Figure 4.1 show the calculated values and the graph of the bus voltage when DVR was not placed on the network. A cursory look at the voltage profile in Table 4.1 shows that [Bus 7, Bus8, Bus9, Bus10, Bus11, Bus12] violated in statutory limit condition of 0.95-1.01pu

4.2 Result Obtained in simulation of Rumuomoi 11kv Distribution Network with ANN Based DVR Controller

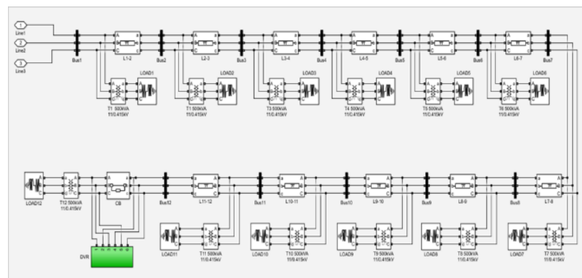


Figure 4.2: Matlab Simulink Simulation of Rumuomoi 11kV Network with ANN Based DVR

Figure 4.2 shows the Rumuomoi 11kV distribution system was simulated in MATLAB with ANN based DVR controller respectively. The simulation was successfully carried out using data obtained from Port Harcourt Electricity Distribution Company (PHED) and the electric power supply to the network is via feeder 1 from 2x15MVA 33/11kV injection substation at Rumuola also known as Golden lily**.**

Table 4.2: Bus Voltage with ANN Based DVR Controller

Bus No	Bus Name	Nominal (kV)	Operating (p.u)
1	Ohiamini Road	11	0.9828
2	Location Road	11	0.9826
3	Ideogu Estate	11	0.9824
4	Omunakwa Road	11	0.9821
5	Okabie Road	11	0.9819
6	Amadi Road 1	11	0.9817
7	Amadi Road 2	11	0.9815

8	Bakery Road	11	0.9901
9	Silicon Valley Ltd	11	0.9813
10	PHWC	11	0.9811
11	Super Geometrics	11	0.9809
12	Ichiegbo Road	11	0.9807

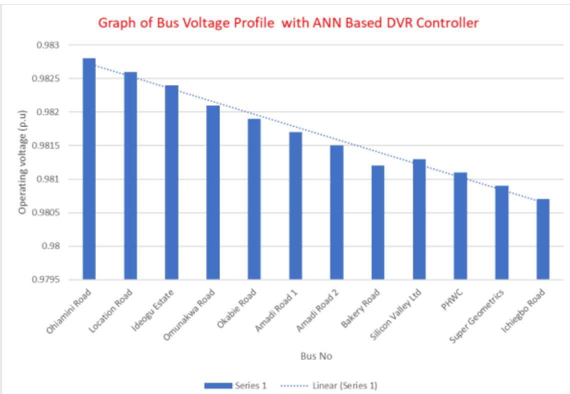


Figure 4.2: Plot of Operating Voltage against Bus No.

The existing Rumuomoi 11kV distribution system was simulated in MATLAB software based on two (2) scenarios

In the second scenarios, with ANN based DVR controller the study was successfully carried out using data obtained from Port Harcourt Electricity Distribution Company (PHED). The electric power supply to the network is via feeder 1 from 3x15MVA 33/11kV injection substation at Rumuola also known as Golden lily**.** Table 4.2 and figure 4.2 show the calculated values of the bus voltage when ANN based DVR controller was placed at the bus with the least voltage value. A quick look at table 4.2 and figure 4.2 shows no violation in bus voltage statutory limit condition of 0.95-1.01pu which means that the DVR device impacted positively on the network by improving the voltage profile, mitigate voltage sag and swell in the network.

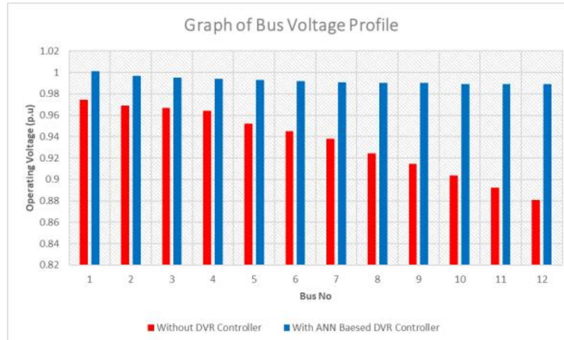


Figure 4.3: Plot of Voltage Profile of Comparison for Rumuomoi 11kV Distribution Network

Figure 4.3 shows voltage profile comparison plot for Rumuomoi 11kV distribution network without DVR and with ANN based DVR respectively. A quick look at the figure 4.3 shows that the voltage profile of the network improved significantly when ANN based DVR was connected to the system.

CONCLUSION

The study examined the existing Rumuomoi 11kV distribution network consisting of twelve (12) 11/0.415kV distribution transformers and the use of ANN and DVR controller for mitigating voltage sag and swell as a result of fault or nonlinear loads in the distribution network. The network was modeled in Matlab 2018 application software. It was found from the research that the use of DVR in the 11kV distribution network to reduce power quality problems was a success and hence, the voltage profile of the existing Rumuomoi 11kV distribution network is now within acceptable limit for reliable power supply to the consumers. More work should be carried out to design a renewable power source that can enhance recharging of the DC storage device.

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