MITIGATING EFFECTS OF VOLTAGE DEVIATION ON DELSUTH HEALTH CARE FACILITY UTILIZING DYNAMIC VOLTAGE RESTORER (DVR)

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Abstract: This paper examined power supply at DELSUTH with the aim of mitigating effects of voltage deviation. The 11KV feeder from 7.5MVA substation which supplies the Hospital was analyzed using Dynamic Voltage Restorer (DVR) device on ETAP 16.0 software environment. It was observed that load flow analysis is vital in understanding the operating nature of the network, by considering the reactive power, voltage deviation magnitude and power losses in the network. From the simulation there was low voltage profile in the transformers feeding the clinical area. The voltage profile was improved by upgrading the network to standard power factor.

Keywords: capacitive power, voltage deviation, DVR, voltage profile, power factor

1. INTRODUCTION

Reliability of electricity supply by utilities operators and their customers is crucial to organizations operating in a highly competitive business environment, because it affects profitability. In Nigeria as of today, [1] the power generated passes through complex network of transmission and distribution systems using different power transformers, overhead lines, and protection equipment. The deregulation of power networks to augment the imbalances between generation and distribution results in the integration of multiple power electronics devices which in turn causes a lot of disturbance and increase in energy consumption in the network. This is a major contributor to technical issues of power quality nature that affect the connected load especially sensitive equipment and the entire distribution network. Although over the years, power distribution systems have reached a very high level of reliability, voltage disturbances cannot be totally avoided. Any disturbances to voltage waveform can cause problems related with the operation of sensitive loads. Distribution line end users equipment needs reliable constant sine wave shape, frequency and symmetrical voltage with a steady root means square value to continue operation. Poor voltage quality in distribution networks can be due to variations in consumer's demand forces for reactive power which causes electrical equipment to draw more than their rated current, resulting in excessive heating capable of inflicting severe damage. Voltage deviation is considered the most severe since the sensitive loads are very susceptible to temporary [2, 3] deviation in system voltage. In some cases, these disturbances can lead to a complete shutdown of entire facilities, causing severe economic consequences to the affected institutions. In the electricity value chain, the distribution section is crucial because it's deliver power supply to consumers with different power quality requirements. One of such consumer is the Health care facilities, with essential requirements of comparatively high standard and security of power supply. Also, with critical applicability of

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microprocessor based medical diagnostic equipment used in Health care sector, it necessary that power fed to such facilities are of high quality because any deviation can result [4] to their malfunction or failure. This tread has contributed to the present day power distribution system paradigm shift toward the direction of quality.

However, [5, 6] electricity supplies in Health Care facilities are matters of life or death because patients care activities in Hospital are becoming rapidly more dependent on the quality of power supply. The major aim of present days Health care providers are to provide quick and accurate results for patient aimient management using modern tools at moderate energy consumption price in order to gain from Hospital technology investment. The World Health Organization (WHO) study on impact of power supply in hospitals revealed that one-third of medical device breakdowns are due to poor power quality issue. Hence, the global slogan "Health for all in the third millennium" requires a reliable and sustainable electricity supply in hospitals. Power supply reliability depends on the nature of voltage and current quality received by the end user. Voltage disturbance from the utility grid infect end consumers apparatus, while current disturbance instigated by the end users could attack the entire grid distribution network. An unstable and low power quality is highly tolerated because of it advance effects on modern clinical setting. Power quality issue can cause malfunction of medical equipment such as incorrect diagnostics results, display distortion, control fault, delay of processing of results and damage of other facilities.

Traditionally, load shedding, tap changing of step down transformers, voltage stabilizers/regulators and capacitors bank techniques are engaged in preventing issue of voltage deviation disturbance in distribution networks which are considered as inefficiency. The nonlinear characteristic nature of most industrial loads that draw lagging current, due to increase in the demand for reactive power, it is better to compensate imbalance, rather than altering the system impedance. The increasing interest in research work to improve efficiency and eliminate voltage deviation in distribution network feeding industries has resulted development of custom power device. The recent innovation in custom power devices like [7]. Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-STATCOM), and Unified Power Quality Conditioner (UPQC), has help to compensate imbalances experienced in distribution networks with low cost. Dynamic Voltage Restorer (DVR) device is used to performs electronic switching by injecting a control voltage to eliminate effects of fault on bus voltage with connected sensitive loads. The DVR is known for high performance characteristics of low harmonic disturbance, less power losses, small size, moderate cost and automatic voltage control which makes it better choice over other devices. DVR device is [8, 9] used to mitigate voltage deviation issue such as voltage drop, sag, dip, swell and interruptions in power distribution network. A diagram showing the layout of DVR device is presented in Figure 1.

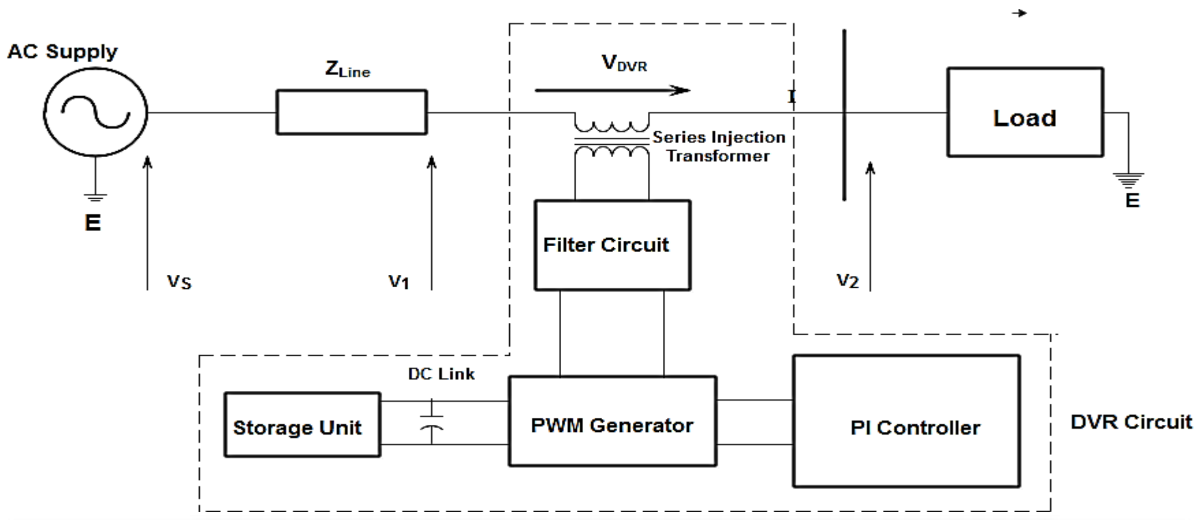

Fig. 1. Schematic diagram of DVR.

The DVR is made of a voltage source inverter, a series voltage injection transformer, AC filter, controlling unit, and a storage unit. The function of a DVR device [10]. is to provide sufficient and suitable voltage quality in series with the distribution network using boosting transformer each time there is voltage deviation in distribution network. Also, [11] DVR can be used for reactive power compensation, mitigation of harmonic mitigation and correction of power factor. Mathematically, an expression can be developed for DVR when connected to a bus in secondary distribution system at the point where the supply voltage V Supply decreases from standard acceptable value of the ±5 % rated nominal voltage. The DVR will provide an equivalent voltage through the boosting transformer in a way that the nominal acceptable customer load bus is maintained at all times. Figure 2 show DVR equivalent circuit diagram.

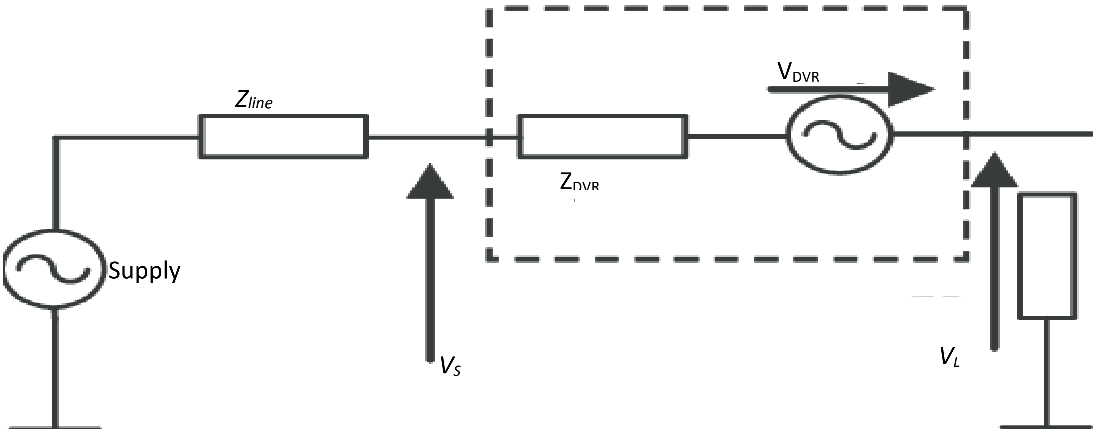

Fig. 2. DVR equivalent circuit diagram.

From the DVR equivalent circuit diagram, the DVR injected voltage can be written as equation (1).

$$V_{DVR} = V_L + I_L Z_{Line} - V_S \tag{1}$$

where, V_{DVR} is the injected voltage, V_L is the nominal load voltage, Z_{line} is line resistance and reactance, I_L is the load current, V_S is the supply voltage at disturbance. Thus, on detection of abnormal reduction in the supply voltage Vs from the desired nominal value, the DVR device injects a voltage into the system $V_{DVR,}$ which is in series with the transformer such that the desire load voltage V_L can be maintain at the terminal end. The active power and reactive power of DVR during compensation is show in equation (2) and (3) respectively:

$$P_{DVR} = I_L V_L \text{Cos}\,\emptyset \tag{2}$$

$$Q_{DVR} = I_L V_L \text{Sin}\,\emptyset \tag{3}$$

The DVR real and reactive power that is utilized is associated with the compensating voltage during occurrence of disturbance in the network. Therefore, the displacement angle between compensating voltage and load current is the maximum power of DVR require to provide satisfactory voltage to overcome deviation being experience by the connected load. The DVR power factor can be determine using expression as written equation (4).

$$\text{DVR Power factor } \emptyset = \tan^{-1}\frac{Q_{DVR}}{P_{DVR}} \tag{4}$$

Also, the load power factor have impact on the compensation performance the DVR device. A higher load power factor will leads to availability of useful energy to maintain constant voltage at the equipment end. Thus, load power factor can be determine using expression as written equation (5).

$$\text{Power factor } \theta_1 = \tan^{-1}\frac{Q}{P} \tag{5}$$

where, Q_{DVR} is the reactive power of DVR, P_{DVR} is the active power of DVR, Q is the reactive power of the connected load, P is the active power of the connected load and θ_1 is the present load power factor.

2. EXPERIMENTAL SETUP

This section has been divided into two. The first part presents the materials used in the research work while the research procedure is presented in the second part.

2.1. Materials used

33/11Kv and 11/0.415Kv Distribution Transformers rating, Network single line diagram, feeder data, cross sectional area of conductor =300mmsq, Cross link Polythene cable (XLPE), Electrical Transient Analyzer Program (ETAP) simulation software, and DVR.

2.1.1. Network description

The DELSUTH 7.5MVA, 33/11KV Injection Substation is located inside the Hospital premises, along Otefe road, Oghara in Ethiope west local Government Area of Delta State, Nigeria. DELSUTH 7.5MVA, 33/11kv Injection Substation receives power from Transmission Company of Nigeria (TCN), 2x30 MVA, 132/ 33kv Transmission Substation located at Pamo village near Sapele, Delta State, 10 km away, with Over Head line of 150mmsq Aluminum Conductor Steel Reinforced (ACSR) cross sectional area. The 7.5MVA, 33/11 kV injection substation stepped down the 33kv to 11kv passing through underground cabling system of 3x300mmsq cross link polyethylene (XLPE) Cable and further step down to 415 volts using distribution panels which supply power directly to the Medical facilities and Residential loads. Figure 3 presents a Photo view of DELSUTH 7.5MVA, 33/11 injection Substation transformer.

Fig. 3. Photo view of DELSUTH 7.5MVA, 33/11 Transformer Substation.

DELSUTH network comprises of 1x7.5MVA injection substation transformer with two out going feeders, and thirteen 11/0.415 KV distribution transformers feeding single and three phase loads. Feeder (i) comprises of Nine 11/0.415 KV distribution Transformer Substations of different rating and feeder(ii) has four11/0.415 KV distribution Transformer Substations. Feeder (i) feeds the main clinical building that housed the Sensitive loads such as medical diagnostics equipment- Magnetic Resonance Imaging, Computer Tomography, X-ray machine, life support machine in intensive care unit, incubator intensive care unit, theater equipment and other supporting facilities including; Autoclave, Bed lift and Dialysis machine [10]. It also feeds other areas such as Administrative buildings, Zenith bank, Hostels and Residential quarters Feeder (ii) feeds the water treatment plant, Power house, Sewage control system, Oxygen gas plant, Engineering workshop, laundry services unit, library, orthopedic ward and School of Nursing areas. The network has fourteen 11KV Ring Mains Unit (RMU) for protection and isolation purposes.

2.2. Method

In this section, the procedure and method used for mitigating the effects of voltage deviation on the DELSUTH distribution network are discussed. The method of simulation and result coordination is a load flow-based method using adaptive Newton-Raphson load flow techniques for the simulation in ETAP 16.0 environment with the integration of Dynamic voltage restorer (DVR) for mitigating effects of voltage deviation in the network using voltage deviation index factor method.

2.2.1. Collection of data

The single line diagram of 11kv DELSUTH network, various transformer ratings and distance from the 7.5MVA injection substation collected from Benin Electricity Distribution Company [BEDC] as shown in Table 1.

Table 1. Input load data for the substation.

S/N	Substations Name	Transformer Rating (kVA)	Distance from DELSUTH 11KV Feeder (km)
1	Clinical	1000	0.85
2	Clinical 11	500	0.90
3	MRI	500	0.80
4	Admin	1000	3.03
5	Hostel	300	0.86
6	Staff 1	500	3.81
7	Staff 11	500	4.22
8	Consult	1000	3.67
9	CMD	300	5.15
10	Power	500	0.54
11	Nursing	500	2.73
12	Water	500	1.06
13	Library	300	3.26

2.2.2. Sizing of DVR unit required to improve the distribution network

The size of DVR unit is computed using the system power factor improvement procedure. System Power factor can show how reactive power deviated from the standard value in the electrical system. The load flow report shows that the total load demanded of the network is 5.152MW at power factor of 0.8 lagging which is below the standard value of 0.95. The reactive power of DVR can be determined by considering the facility total power demanded. Therefore, using the facility total power demand P = 5.152 MW at 415V at an existing power factor of 0.80 is to be compensated from $\text{Cos}\emptyset_1 = 0.80$ to $\text{Cos}\ \emptyset_2 = 0.95$. Thus, the Reactive power Q_{DVR} of DVR device is calculated by applying equation (6).

$$Q_{DVR} = P(\tan\theta_1 - \tan\theta_2) = 5.152MW(\tan 31 - \tan 18.19) = 5.152MW(0.619 - 0.328) = 1.52MVAR \quad (6)$$

where, P is the real power before compensation, $\cos\emptyset_1$ is existing system load power factor before compensation, $\cos\emptyset_2$ is the desired power factor of the load after compensation, Q_{DVR} is reactive power of the DVR.

2.2.3. Modeling and Simulation of DELSUTH Network

The data collected as shown in Table 1 is used to model the DELSUTH distribution network in ETAP 16.0 software environment using Newton Raphson load flow technique. Secondly, simulation of the existing modelled network with DVR unit integration at point of common coupling [PCC] of the load bus 1 is carried out in ETAP 16.0 environment. This gives a measure of level of voltage deviation magnitude improvement in the system due to integration of DVR unit into the network. And the load flow results of the modelled network without and with DVR is shown in Table 2.

3. RESULTS AND DISCUSSION

In this section, the results of existing modelled network based on without DVR (Base-case) and Network with DVR installed are presented in Table 2. The results of the base –case voltage profile of 7.5 MVA network without DVR placement shows that the actual voltage magnitude recorded at each bus is below acceptable limits, when compared with IEEE standard requirement. It is observed that three buses are operating in critical under voltage state. Also, it can be seen from Table 2 that voltage profile improved with integration of DVR in the network. The various results obtained from the load flow studies such as voltage deviation index magnitude, voltage profile of load buses, Real and Reactive power loss with and without DVR installation in DELSUTH 13- bus network are presented in bar chart representation for better understanding as shown in Figure 4, 5 and 6 respectively. Figure 4 shows comparative plot of Voltage Deviation Index factor against corresponding bus numbers, for both without and with DVR in the modeled network. It can be seen that bus number 4-13 are within the range of standard voltage magnitude and bus number 1-3 fall out of approved IEEE voltage deviation limit of Vmin = 0.95 p.u and Vmax= 1.05 p.u. Also, Figure 5 shows comparative plot of the system voltage profile performance for both scenarios with and without DVR. It can be observed from the analysis that the lower tolerable voltage limits of 0.95 p.u (390V) which is the ±5 % limit that was recommended were violated. The minimum voltage occurred at bus 1 with 0.84p.u, with optimal allocation of DVR, the voltage magnitude increased to 0.99 p.u and also increases progressively all the network load bus voltage profile. Finally, Figure 6. shows the comparison of the system total real and reactive power losses with and without DVR integration into the network. As you can see from the figure that real power loss decreases from 956.7 KW to 707.7 KW while reactive power loss decline from 697.3 Kvar to 413.7 Kvar.

Table 2. Load flow results for voltage profile, VDI and power loss at each Bus with and without DVR placement.

SN	ID	VD (%)		VDI		REAL POWER LOSS		REACTIVE POWER LOSS	
		WODVR	WDVR	WODVR	WDVR	WOVDR	WDVR	WOVDR	WVDR
1	Clinical 1	84.19	99.8	0.8956	1.0617	30.5	6.7	46.9	23.3
2	Clinical 2	87.91	98.5	0.9275	1.0478	30.0	8.7	40.7	13.1
3	MRI	86.25	98.7	0.9175	1.05	32.2	7.7	48.3	11.5
4	Admin	95.56	97.6	1.016	1.0382	18.7	4.2	23.4	14.8
5	Hostel	95.62	98.9	1.0172	1.0521	15.6	3.5	18.3	5.2
6	Consult	96.14	99.6	1.0227	1.0595	19.7	6.6	34.7	10
7	Staff Q1	95.70	98.8	1.0180	1.0510	13.8	5.6	15.6	8.5
8	Staff Q11	95.52	98.8	1.0161	1.0510	10.6	6.2	15.9	21.6
9	CMD	95.50	99.4	1.0159	1.0574	19.0	2.4	13.4	3.6
10	Power H	96.84	99.1	1.030	1.0542	19.1	5.8	13.6	20.1
11	Water	96.40	99.3	1.0255	1.0563	10.9	7.3	16.5	10
12	Nursing	96.60	98. 8	1.0276	1.0510	17.7	5,2	11.6	7.5
13	Library	96.10	98.4	1.0220	1.0468	15.5	3.5	18.3	5.2

WODG – without Dynamic Voltage Restorer; **WDG** – without Dynamic Voltage Restorer

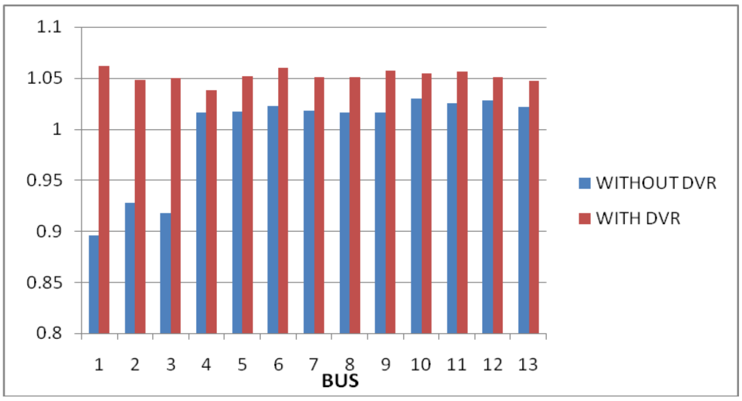

Fig. 4. Comparative plot of Voltage deviation index magnitude without DVR.

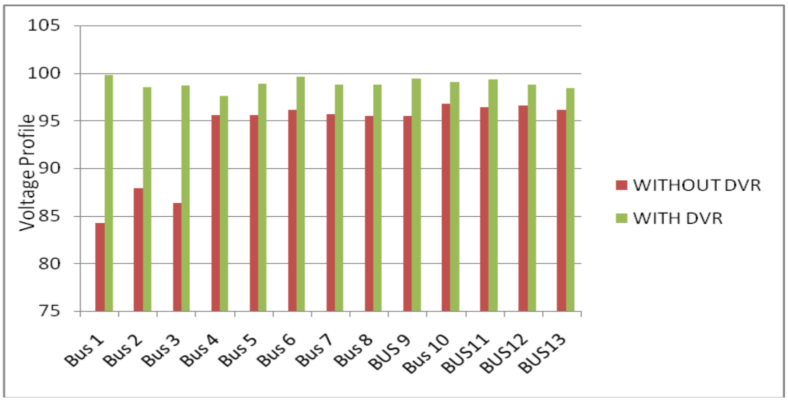

Fig. 5. Comparative plot of network voltage profile magnitude without and with DVR.

The results obtained so far for DELSUTH radial distribution networks (13-bus), clearly indicate the effectiveness and applicability of combination of Newton Raphson technique, voltage deviation index and system power factor improvement approach used to mitigate the effect of voltage deviation in radial distribution networks.

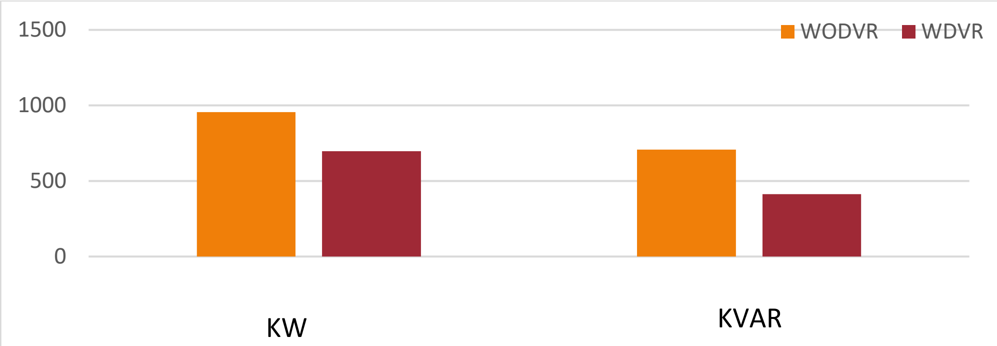

Fig. 6. Comparative plot of real Power and reactive power loss in DELSUTH Network.

4. CONCLUSIONS

Modern Hospitals facilities have microprocessor embedded such as elevators, Magnetic Resonance Imaging machine, Computer Tomography scan, incinerators, gas compressors and others equipment are easily affected by voltage deviation. And most of this equipment operation involves a magnetic field which consume more reactive power contribute to increase in voltage deviation at consumers terminal buses and high energy consumption. The deviation of voltage at the consumer's terminals are undesirable in the distribution network because it causes malfunction of sensitive loads resulting economic loss. Hence the urgent need to kept system voltage profile within prescribed limits of the ±5 % declared voltage by regulation authority. Against this back ground, a DVR device carefully sized and placed based on voltage sensitivity index method was employed in this work dynamically compensate the reactive power demand, reduced real power loss and improved the voltage deviation magnitude of the network buses to the desired minimum value of 94%. Furthermore, this work have make recommendations for improvement of services quality delivery for DELSUTH Health care facility.

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