

Investigating Dynamic Voltage Restorer (DVR) Performance in Mitigating Non-Linear Load Impacts on the Katampe-Wuse II 33kV Distribution System

Royal Philemon*

Department of Electrical and Electronics Engineering, Modibbo Adama University, Yola, Nigeria

Abstract

Voltage unbalance is simply a variation in the phase-to-phase voltage in three-phase electrical systems, which affects power quality. The effects of voltage quality are such as transient, voltage sags, voltage swells, interruption and harmonics. The improvement of power quality is carried out in this work using a dynamic voltage restorer (DVR) for minimising power quality problems as a result of non-linearity in the distribution system in which the 33 kV Katampe-Wuse II, Abuja power distribution line is considered as a case study. This study involves: Investigation of the impact of non-linear loads on the distribution system and investigation of DVR improvement to the power quality on the distribution system. The result of the study revealed that the 33 kV Katampe-Wuse II distribution system experienced a power reduction of 14.6%, having a non-linear load of 2 MW, and the DVR improved the power quality of 33 kV Katampe-Wuse II distribution system with an injected reference voltage of 0.5298 kV.

Keywords: Biodiesel, Techno-Economic Assessment, Non-Edible Seed Oils, High Free Fatty Acids, Levelized Cost of Fuel, Two-Stage Transesterification

1. Introduction

Power quality problems have become an important issue for electricity consumers at all levels of usage. The deregulation of electric power has boosted public awareness of power quality among the different categories of users. The power quality problems have a negative impact on customers - industrial, commercial and even residential such as reduced equipment lifespan and performance, low productivity and quality, increased energy consumption and cost, malfunction of sensitive equipment and higher safety risks. Power quality problems commonly encountered in electrical power systems include voltage sags, voltage swells, transients, harmonics, and voltage flicker (Raghayendra & Vijay, 2015). Among these disturbances, voltage sags and swells are important concerns in distribution systems because they cause deviations in supply voltage that may affect the performance, reliability, and proper functioning of sensitive electrical equipment (Bollen, 1999; Institute of Electrical and Electronics Engineers [IEEE], 2019).

Voltage swells are generally less frequent than voltage sags in electrical distribution systems. They may occur when large inductive loads are switched off or when large capacitor banks are energised (Bollen, 1999; IEEE, 2019). Voltage sags, on the other hand, are significant power-quality disturbances because sensitive electrical equipment may malfunction when the supply voltage temporarily decreases. A voltage sag is characterised by a reduction in the root-mean-square (RMS) voltage, with or without a phase-angle shift, followed by recovery to its normal value. Common causes include short-circuit faults and the starting of large induction motors, which draw high currents and produce voltage drops across the impedance of the distribution network (Bollen, 1999). Despite their short duration, voltage sags can interrupt industrial processes and affect the operation of sensitive electronic equipment and control systems (Bollen, 1999; IEEE, 2019).

The compensating custom power devices are used for active filtering, load balancing, power factor improvement, and voltage regulating (sag/ swell) (Kailash and Deepak, 2020). These devices are mainly

*Corresponding email address: royalphil4u@gmail.com

three types: static shunt compensator, series compensator, and hybrid compensator, also called Distribution Static Synchronous Compensator (DSTATCOM), dynamic voltage restorer (DVR) and Unified Power-Quality Conditioner (UPQC), respectively. Each of which has its own benefits and limitations (Eyad, 2014). The DVR is considered the better solution among all the compensating custom devices in mitigating the voltage sag and swell due to its high performance, capacity to manage the active power flow, high energy capacity, small size and lower cost compared to DSTATCOM and UPQC. In addition, DVR also has functions such as reactive power compensation and harmonic compensation (Muhammed et al., 2021). This work investigated the performance of DVR in improving the Impact of Non-Linear Loads on the Katampe-Wuse II 33 kV power distribution system. The single-line diagram of the Katampe-Wuse II 33KV power distribution system is shown in Figure 1 below.

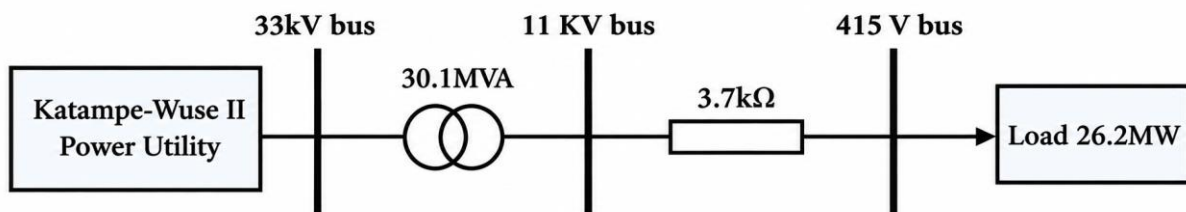


Figure 1: Single line diagram of Katampe-Wuse II 33KV power distribution system

2. Materials and Methods

The materials required to carry out this research work are a desktop or laptop Computer, MATLAB Software, the IEEE test standard and the parameters of the system, which include: source voltage, Source, line impedance, Grid frequency, linear load, non-linear load, power factor, operating target power factor, inductor and capacitor, DC-link source voltage and switching frequency.

Based on the theory of the DVR system, the DVR was developed and simulated using MATLAB software. The simulation was implemented on the Katampe-Wuse II 33 kV power distribution system without a DVR. Secondly, the simulation was implemented with the installation of a control DVR. The modelling and simulation of the Katampe-Wuse II 33KV Power Distribution System was carried out on MATLAB Graphical User Interface (GUI) and operated under both linear and non-linear loads. The parameters used for the simulation were obtained from the AEDC distribution network with respect to the Katampe 33kV feeder. This feeder links Wuse II, Abuja, to the AEDC distribution network. The output of each simulation was presented as the distribution system under load compensation, with a DVR connected to the distribution system.

3. Results

The parameters used for the simulation were obtained from the AEDC distribution network with respect to the Katampe 33kV feeder. This feeder links Wuse II, Abuja, on the AEDC distribution network. This feeder was taken to represent a real scenario of using a dynamic voltage restorer (DVR) in this study. The system parameters are shown in Plate I.

System Parameters

FEEDER and LOAD BUS PARAMETER

Time (s) fPFactor

Real LP (kW) Supply Voltage(kV)

iPFactor

Freq. (Hz)

Calculate feeder line

Plate I: Input parameters of Katampe-Wuse II Feeder

Table 1 contains the feeder input parameters of Katampe-Wuse II 33KV; Table 3 contains DVR stimulation parameters.

Table 1: Feeder Input Parameters

Parameters	Value
Effective load Power (P)	26.2 MW
V_{line} (V)	33 KV
Operating Frequency (F)	50 Hz
Time of operation (s)	3600s
Power Factor	0.85
Targeting Power Factor	0.92

The feeder simulation revealed that the feeder line had the following outcome in Table 2, as indicated in Plate II.

Table 2: The simulation outcome of load effect on Katampe-Wuse II Line

Parameters	Value
Load capacitance power (P_c)	32.02 KVAR
Design value of apparent power (P_{a1})	30.1 MVA
Operating value of apparent power (P_{a2})	20.9 MVA
Design value of current (I_1)	539.3 A
Operating value of current (I_2)	498.3 A
Reduction in power loss (R_p)	14.6%
Design value of power factor angle (θ_1)	31.8°
Operating value of power factor angle (θ_2)	23.1°
Design value of resistance (R_1)	61.2 Ω
Operating value of resistance (R_2)	66.2 Ω
Design value of total line impedance (Z)	3.7 K Ω
Operating value of total line impedance (Z)	5 K Ω
Design value of reactive power	50 kVAR
Operating value of reactive power	67 kVAR

The effective load power on the link between Katampe and Wuse II was 26.2 MW, and this feeder carried a non-linear sensitivity of 2MW according to the network engineer of the distribution system. The simulation revealed that there is a power reduction of 14.6 % on the Katampe-Wuse II Line, which was compensated using a dynamic voltage restorer (DVR) to improve power efficiency in the Katampe-Wuse II Line. The distance covered by the distribution line is 10km on a 33 kV distribution line. The line experienced initial current flow. (I_1) was 539.3 A based on a 0.85 power factor and was compensated to a 0.92 power factor

when the final current flow (I_2) was 498.2 A. The apparent load before compensation (P_{a1}) is 30.1MVA as obtained in Table 2. This procedure will help to determine the type of DVR injection transformer to be adopted based on the factor of safety (FOS).

Plate II: Simulation Output

Analysis of DVR Performance

The DVR was installed on the Katampe-Wuse II feeder operating at 33kV with the following input

DVR Simulation

FEEDER LINE CONDITION

ent (rms) (A)	fcurrent (rms) (A)	% rPower	iPF angle	fPF angle	iResistar
877	498.2550	14.6385	31.7883	23.0739	61.1918
< >					

INJECTION LINE CONDITION

	DC-V(a,b,c) per phase (kV)	PQ-clarke-V(0,alpha, Beta) kV	PQ-clarke-I(0, alp
9	0.4326	1.7764e-15	3.9011e+03
0	-23.5447	0.5298	5.5142e+03
0	23.1121	-32.9905	-177.1395
< >			

simulation parameters shown in Table 3.

Table 3: DVR Simulation Parameters

Parameters	Value
Injection Transformer power, $P_{inj(FOS)}$	5.5 MVA
V_{DC}	19.05 kV
Factor of Safety (FOS)	1.25
Filter inductance	1 μ H
Filter capacitance	0.5 F
Filter Resistance	1 m Ω
Switch frequency	5 kHz
Sensitive or non-linear load	25 kW

The present study selected a factor of safety (FOS) of 25%, while power reduction in the distribution system was 14.6%. Therefore, only a transformer with 14.6% of 30.1 MVA was selected as the DVR injection transformer with 25% FOS, and it is calculated as:

$$\text{Power of injection transformer } (P_{inj}) = R_p * P_{a2} = 0.146 * 30.1 = 4.4 \text{ MVA}$$

$$\text{Power of injection transformer on FOS } P_{inj(FOS)} = FOS * P_{inj} = 4.4 * 1.25 = 5.5 \text{ MVA}$$

The simulation showed that the effective voltage supply obtained from the DVR using the PQ-Clarke transform is 1.7 pV, 0.5298 kV, and 32.99 kV in V(o, α , β) phases, respectively, as shown in Table 4.

Table 4: DVR Simulation Output

Parameters	Value
DC power source, P_{DC}	5.06 MJ
DC link capacitance	0.0279 F
DC- $V(a,b,c)$	0.043326; 23.5447; 23.5447 kV respectively
PQ- Clarke $V(o, \alpha, \beta)$	1.7 pV, 0.5298 kV; -32.99 kV, respectively
PQ- Clarke $I(o, \alpha, \beta)$	3.9 kA, 5.5 kA; -117.19 A, respectively

4. Discussion of Results

The effective load power on the link between Katampe and Wuse II was 26.2 MW, and this feeder carried a non-linear sensitivity of 2MW. The distance covered by the distribution line is 10km on a 33 kV distribution line. The line experienced initial current flow (I_1) was 539.3 A based on a 0.85 power factor and was compensated to a 0.92 power factor when the final current flow (I_2) was 498.2A. The apparent load before compensation (P_{a1}) is 30.1 MVA, while the apparent power after compensation (P_{a2}) is 20.9 MVA. The reactive power before load compensation is 50 kVAR, while the reactive power after compensation is 67kVAR. The simulation revealed that there is a power reduction of 14.6 % on the Katampe-Wuse II Line, which was compensated using a dynamic voltage restorer (DVR) to improve power efficiency in the Katampe-Wuse II Line.

The simulation showed that the effective voltage supply obtained from the DVR using the PQ-Clarke transform is 1.7 fV, 0.5298 kV; 32.99 kV in $V(o, \alpha, \beta)$ phases, respectively and 3.9 kA, 5.5 kA; 117.19A in $I(o, \alpha, \beta)$ respectively. A current or voltage unbalance between phases in magnitude gives rise to negative- and zero-sequence components, causing negative- and zero-sequence current to flow. According to IEEE, voltage unbalance can be measured as the ratio of the negative-sequence to the positive-sequence component. Hence, the designed DVR inject a voltage imbalance into the distribution system. The voltage delivered by the PQ Clarke, V_α , was 0.5298 kV by the DVR into the distribution system, and this is referred to as the reference voltage by the DVR itself.

5. Conclusions

This work critically examined the performance of a DVR using a self-tuning filter on the Katampe-Wuse II distribution system. The study revealed the following conclusions: The impact of non-linear sensitive loads of 2 MW reduces the power on the Katampe-Wuse II distribution system by 14.6%, which the DVR is used to compensate for.

The voltage delivered by the PQ Clarke, V_α , was 0.5298 kV by the DVR injected into the Katampe-Wuse II distribution system, and this is referred to as the reference voltage by the DVR itself.

6. Recommendations

Based on the findings, the following recommendations were drawn:

- Mitigation of voltage disturbances in the distribution system requires the use of a dynamic voltage restorer. There is a need for proper sizing of the DVR components such as injection transformer, filter parameters like capacitor, inductor and resistor.
- The control system must be designed to detect voltage disturbances until desired harmonic responses are achieved.

References

Anita P., Manoj G., (2012). Dynamic voltage restorer for compensation of voltage sag and swell: a literature review, International Journal of Advances in Engineering & Technology, Vol. 4, Issue 1, pp. 347-355.

- Awais F., Muhammad M. O., Mohammed A. M. R., Ismail M., Siti Z. M. N., Izham Z. A. (2022). Dynamic voltage restorer (DVR) enhancement in power quality mitigation with an adverse impact of unsymmetrical faults, *Energy Reports, International Conference on Power and Energy Systems Engineering (CPESE), Fukuoka-Japan, Volume 8, Supplement 1*, pp. 871-882.
- Bollen, M. H. J. (1999). *Understanding power quality problems: Voltage sags and interruptions*. IEEE Press.
- Bollen, M. H. J. (1999). IEEE tutorial on voltage sag analysis. IEEE Power & Energy Society. <https://doi.org/10.17023/nfn1-y568>
- Dastagiri, R., Asif, M. (2014). Power Quality Improvement Using A DVR (Dynamic Voltage Restorer). *International Journal of Recent Development in Engineering and Technology*, vol. 2 no. 5, pp. 61-66.
- De-Gruyter T., (2015). Power Quality Issues and Solutions – Review, *International Journal of Emerging Electric Power Systems*, vol. 16, no. 4, pp. 357-384
- Eyad A. F. (2014). Power Quality Enhancement using Custom Power Devices, *International Journal of Emerging Electric Power Systems*, vol. 2, no. 1, pp. 13-28
- Ghosh, H., Shah, P. K., & Panda, G. K. (2012). “Design and Simulation of a Novel Self- Supported Dynamic Voltage Restorer (DVR) for Power Quality Improvement”, *International Journal of Scientific & Engineering Research*, vol. 3, issue 6, pp. 1-6.
- Gonen, T. (2008). *Electrical Power System Engineering*. CRC Press, Taylor and Francis Group. Florida USA.
- Grigsby, L. L. (2012). *Electrical Power Generation, Transmission and Distribution*, 3rd Edition. A series of Electrical Power Engineering Handbook: Chemical Rubber Company (CRC) & Francis Group, Florida, USA
- Hannah N. A., Dalila M. S., Nasarudin A. (2018). Improved Analysis of DVR Performance for Voltage Sag Mitigation, *ELEKTRIKA- Journal of Electrical Engineering*, vol. 17, no. 3, pp. 36-40.
- Ibrahim R., Haidar A.M.A., Zahim M. (2010) “The effect of DVR location for enhancing voltage sags, *Intelligent and Advanced Systems (ICIAS)*, International Conference on Intelligent and Advanced Systems, vol. 2010, pp. 1-4.
- IEEE 1547-2018: Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.
- Institute of Electrical and Electronics Engineers. (2019). IEEE recommended practice for monitoring electric power quality (IEEE Std 1159-2019). <https://standards.ieee.org/ieee/1159/6124/>
- Kailash N. V., Deepak J., 2020. A Review of Custom Power Devices for Power Quality Improvement, *International Journal of Innovative Science, Engineering & Technology, JISET*, Vol. 7 Issue 1, ISSN (Online) pp. 2348 – 7968
- Muhammad M. S., Aliyu A. And Aisha A. M., 2021, A Review of Dynamic Voltage Restorer (DVR) for Power Quality Enhancement, *International Journal of Engineering and Technology Research*, published by Cambridge Research and Publications, IJETR ISSN-2329-7309, Vol. 21 No.5, pp. 257-270.
- Paisan B., Nadarajah M. (2006). Rajamangala University of Technology Thanyaburi, Thailand, (2006). *Detailed Analysis of Load Voltage Compensation for Dynamic Voltage Restorers* TENCON, IEEE Region 10 conference, pp. 1-4.
- Prasad A. R. (2015). An overview and design of Dynamic Voltage Restorer to improve Power quality in microgrid. *International Journal of Electrical and Power Engineering*, Vol. no. 2, pp. 851 – 912.
- Praveena A., Jayashree M. (2014). Mitigation of Voltage SAG using Dynamic Voltage Restorer, *International Journal of Engineering and Advanced Technology (IJEAT)*, Volume 3, Issue 4, pp. 451- 479.
- Ranjan K. J., Babita N. (2019). Electrical Power Quality, *International Journal of Electrical Engineering (IJEET)*. Volume 10, Issue 3, pp. 56-63.
- Rosli O., Rahim N.A., & Marizan S., (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.
- Sangepu, R., & Muni, V. T. (2015). Effect of power quality issues in power systems and their mitigation by power electronics devices. *Discovery*, 28(105), 72–79.
- Shazly A. M., Garcia-Cerrada A., Abdel-Moamen M. A., Hasanin B. (2013). Conventional dynamic voltage restorer for mitigation of voltage sag in power distribution Systems, *International Journal of Electrical Engineering (IJEET)*. Volume 8, Issue 2, pp. 546-613.

- Shruti A., Lumesh K. S. (2017). Dynamic Voltage Restorer and Its Various Control Schemes. International Research Journal of Engineering and Technology (IRJET). Volume 04, Issue: pp. 2992-2996.
- Suneel K., Gurpreet S., Vishavdeep J. (2015). Voltage Correction Methods in Distribution System Using DVR, International Journal of Research Studies in Science, Engineering and Technology, Volume 2, Issue 6, PP 52-63.
- Tejinder S. S., Singh L. (2015). "Comparative analysis of custom power devices for Power quality improvement in non-linear loads," *2nd International Conference on Recent Advances in Engineering & Computational Sciences (RAECS)*, Chandigarh, India, pp. 1-5.
- Thompson E. V., Braide S. L., and Idoniboyeobu D. C. (2020). Improved Distribution Using Dynamic Voltage Restorer (DVR) Method. Global Scientific Journal GSJ, Volume 8, Issue 12, pp. 2320-2186.
- Tien D. V., Gono R., Leonowicz Z., (2018). Multifunctional Dynamic Voltage Restorer for Power Quality Improvement. Journal of Energies, Volume 11, No. 1, pp. 1351-1352
- Tiwari H.P., Sunil K. G., Ramesh P. (2010). *Study of Major Issues and Their Impact on DVR System Performance*. International Journal of Computer and Electrical Engineering, Vol. 2, No.1. pp. 1432-1497.
- Tiwari H.P., Sunil K. G. (2010). *Dynamic Voltage Restorer against Voltage Sag*. International Journal of Innovation, Management and Technology, vol. 1, no. 3, pp. 232- 237.