ENHANCED POWER QUALITY IMPROVEMENT USING ENERGY STORAGE INTEGRATED DYNAMIC VOLTAGE RESTORER

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ABSTRACT
Power quality disturbances such as voltage sag, swell, and interruptions significantly affect sensitive loads in power distribution systems. This paper proposes a Dynamic Voltage Restorer (DVR) capable of mitigating these disturbances without employing conventional controllers such as P, PI, PID, fuzzy logic, or neural networks. The proposed DVR consists of a battery energy storage system, Voltage Source Inverter (VSI), LC filter, series injection transformer, and control circuitry for pulse generation. The three-phase supply voltages are transformed into the Direct–Quadrature–Zero (DQ0) reference frame and compared with reference values to generate error signals. Under normal operating conditions, no compensating voltage is injected. During disturbances, the detected error signals are processed through inverse DQ0 transformation to generate switching pulses for the VSI, enabling appropriate voltage injection to restore the load voltage to its rated value. Simulation results obtained in MATLAB/Simulink demonstrate the effectiveness of the proposed DVR in mitigating balanced and unbalanced sags, swells, and single- and three-phase outages.

Keywords:
Dynamic voltage restorer (DVR), sag, swells, short interruption, power quality, VSI.

I INTRODUCTION

Power quality disturbances in modern power systems arise from faults and switching events in both transmission and distribution networks. At the transmission level, FACTS devices are employed to enhance stability and improve voltage regulation, whereas at the distribution level, custom power devices are used to mitigate disturbances such as voltage sag, swell, and interruptions. The severity of these disturbances varies depending on the type of utility and the nature of connected loads, making it difficult to rank them based on impact. Among these issues, voltage sag and swell are the most frequent and are typically caused by faults, motor starting, transformer energization, capacitor switching, or sudden load changes.

According to IEEE standards, voltage sag is defined as a short-duration reduction in RMS voltage, while voltage swell refers to a temporary increase above the nominal value. Although many faults are self-clearing within a few milliseconds, their impact on sensitive loads can still be significant. Since power quality issues originate from both the utility and consumer sides, effective mitigation measures must be implemented at both levels. While utilities manage transmission-side solutions, consumers rely on custom power devices to maintain acceptable power quality standards at their premises.

In modern industrial environments, automation systems extensively use embedded devices such as microcontrollers, processors, and digital control systems, which are highly sensitive to voltage variations. Even minor deviations in supply voltage can lead to system malfunction, production interruptions, and economic losses. For example, in manufacturing industries, voltage fluctuations can disturb motor operation and affect product quality. Therefore, maintaining stable and high-quality power supply is essential to ensure reliable operation, prevent downtime, and avoid financial losses in precision-based industries.

II LITERATURE SURVEY

Power quality enhancement has gained significant attention in recent years due to the increasing use of sensitive electronic equipment in industrial and commercial applications. Various custom power devices have been developed to mitigate disturbances such as voltage sag, swell, harmonics, and interruptions. Among them, the Dynamic Voltage Restorer (DVR) has emerged as an effective and economical solution for protecting critical loads at the distribution level.

Early research on DVR mainly focused on compensation techniques using conventional control strategies such as Proportional (P), Proportional–Integral (PI), and Proportional–Integral– Derivative (PID) controllers. These controllers were widely adopted due to their simple structure and ease of implementation. However, their performance is often limited under rapidly changing disturbance conditions and unbalanced voltage scenarios. To overcome these limitations, researchers introduced intelligent control techniques such as fuzzy logic controllers and artificial neural networks to improve dynamic response and accuracy of compensation.

Several advanced optimization-based approaches, including Cuckoo Search Algorithm, Harris Hawks Optimization, predictive control strategies, and adaptive neuro-fuzzy systems, have also been proposed to enhance DVR performance. These techniques aim to improve transient response, reduce harmonic distortion, and ensure accurate voltage restoration. Although such methods provide improved performance, they increase system complexity, computational burden, and implementation cost.

DVR topologies can broadly be classified into two categories: direct converter-based DVRs and energy storage-based DVRs. In direct converter-based DVR systems, the compensating voltage is derived directly from the AC supply. While these systems can mitigate voltage sag and swell to some extent, they are unable to compensate during complete outages due to the absence of supply voltage. On the other hand, energy storage-based DVR systems utilize battery banks or capacitor banks to supply the required compensating energy. These systems are capable of mitigating deep voltage sags, swells, and even complete interruptions.

Despite the availability of numerous control strategies and topologies, most reported DVR systems rely heavily on complex controllers, optimization algorithms, or artificial intelligence techniques for compensation. In contrast, the proposed work simplifies the control mechanism by utilizing DQ0 transformation theory without employing any conventional or intelligent controller. This approach reduces computational complexity while maintaining effective compensation capability.

III EXISTED SYSTEM

In the existing power distribution systems, voltage sag, swell, and interruptions are mitigated using a Dynamic Voltage Restorer (DVR) with conventional control techniques. Most of the existing DVR systems use controllers such as PI, PID, fuzzy logic or neural network–based controllers as shown in fig(1), to generate switching pulses for the Voltage Source Inverter

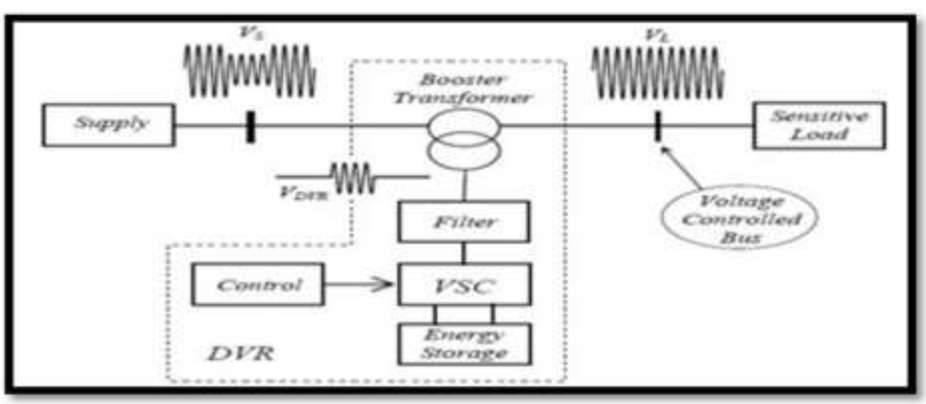

Figure 1: Voltage Sag,Swell and interruption with controller

In this system, the three-phase supply voltage is continuously sensed and compared with a reference voltage. The difference between the actual voltage and reference voltage produces an error signal. This error signal is given to a controller (PI/PID/Fuzzy/ANN), which processes the signal and generates appropriate PWM pulses. These pulses control the VSI. The VSI converts DC power from the energy storage device (battery or capacitor) into AC compensating voltage.

The compensating voltage is injected into the line through a series injection transformer. During voltage sag, the DVR injects boosting voltage; during voltage swell, it injects opposing voltage to reduce the magnitude. Thus, the load voltage is maintained at the rated value. However, the performance of the system depends highly on controller tuning and algorithm complexity, which increases implementation cost and control complexity.

IV PROPOSED SYSTEM

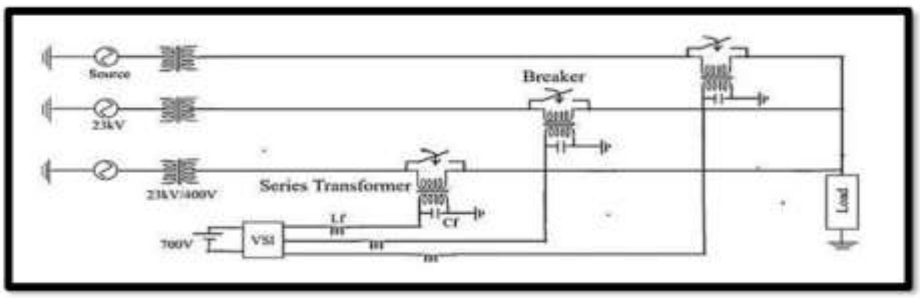

Figure 2: Voltage Sag, Swell and Interruption with out controller

The above figure(2) shows the proposed system presents a Dynamic Voltage Restorer (DVR) for mitigating voltage sag, swell, and interruptions without using any conventional or intelligent controllers. Unlike existing DVR systems that rely on PI, PID, fuzzy logic, neural networks, or optimization algorithms, the proposed system uses Direct–Quadrature–Zero (DQ0) transformation theory to generate switching pulses directly.

The proposed DVR is installed immediately after the distribution transformer to protect sensitive loads from supply voltage disturbances. The system consists of a battery bank as an energy storage device, a Voltage Source Inverter (VSI), LC filter, series injection transformer, breaker, and control circuitry. The three-phase supply voltages are continuously measured and converted into DQ0 components using Clarke and Park transformations.

Under normal operating conditions, the DQ0 components match the reference values (Vd= 1, Vq = 0, V0 = 0). Therefore, no error signal is generated, PWM pulses are not produced, and

the VSI does not inject any compensating voltage. During voltage sag, swell, or interruption, the DQ0 components deviate from their reference values, producing error signals. These error signals are converted back into three-phase quantities using inverse DQ0 transformation and are used to generate PWM pulses for the VSI. The compensating voltage produced by the VSI is injected through the series transformer to restore the load voltage to its rated value.

The proposed system is simple, robust, and cost-effective because it eliminates the need for complex controllers and algorithms while still achieving 100% compensation of balanced and unbalanced sags, swells, and outages.

CONTROL ALGORITHM:

The supply voltage from the grid is continuously monitored by the control circuit. The proposed DVR and the control circuits are installed immediately after the distribution transformer. The control system's job is to continuously monitor and identify any disruptions in the supply voltage by comparing it with the predetermined reference value and synthesis the required PWM switching pulses for VSI in order to generate the required compensating voltage. It is very well known that the three phase voltages can be expressed in direct quadrature voltages using Clarks and parks transforms. It is also known that when the three phase voltages are at rated value, their corresponding direct axis voltage and the quadrature axis voltage will have the values as 1 and zero. So, the reference values in DQ0 frame are 1 for Vsd and 0 for Vsd and Vs0. Based upon these very well known facts, the supply voltages Vsa, Vsb, and Vsc are first transformed to the Vsd,Vsq andVs0

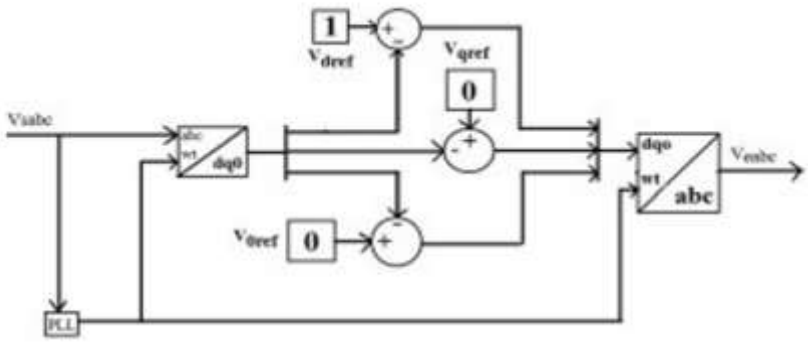

Figure 3: Control Circuit Block Diagram

Whenever a voltage sag swell or interruption occurs, the supply voltages are unbalanced and not at rated value. So, neither Vsd will be equal to 1, nor Vs0 and Vsq will be equal to 0. So, an error voltage will be generated when compared with the reference DQ0 values. This error DQ0 voltages are Ve0, Ved and Veq. The error voltages Ve0, Ved and Veq in DQ0 frame, will again convert into three phase voltages Vea, Veb and Vec using equation bellow.

$$\begin{bmatrix} V_{ea} \\ V_{eb} \\ V_{ec} \end{bmatrix} = \frac{2}{3} \begin{vmatrix} \frac{1}{2} & \sin wt & \cos wt \\ \frac{1}{2} & \sin\left(wt - \frac{2\pi}{3}\right) & \cos\left(wt - \frac{2\pi}{3}\right) \\ \frac{1}{2} & \sin\left(wt + \frac{2\pi}{3}\right) & \cos\left(wt + \frac{2\pi}{3}\right) \end{vmatrix} \begin{bmatrix} V_{e0} \\ V_{ed} \\ V_{eq} \end{bmatrix}$$

Vea, Veb and Vec error signals are compared with the carrier signals and the PWM switching pulses are generated for the VSI. A phase locked loop circuit is used to track the phase of the supply voltages in order to generate the compensating voltage according to the three different phases of the supply voltage. The compensating voltage generated by the DVR is injected in the line along with the supply voltage through the series transformer in order to maintain the load voltage at rated condition at all the time.

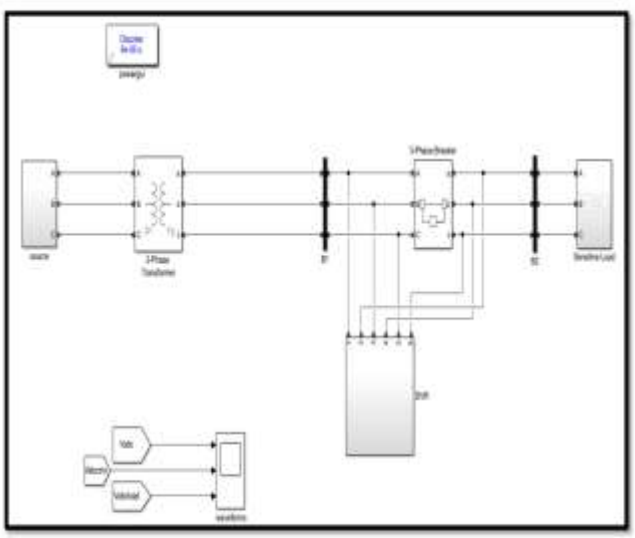

Figure 4: Simulink Diagram

V SIMULATION DIAGRAM AND RESULTS:

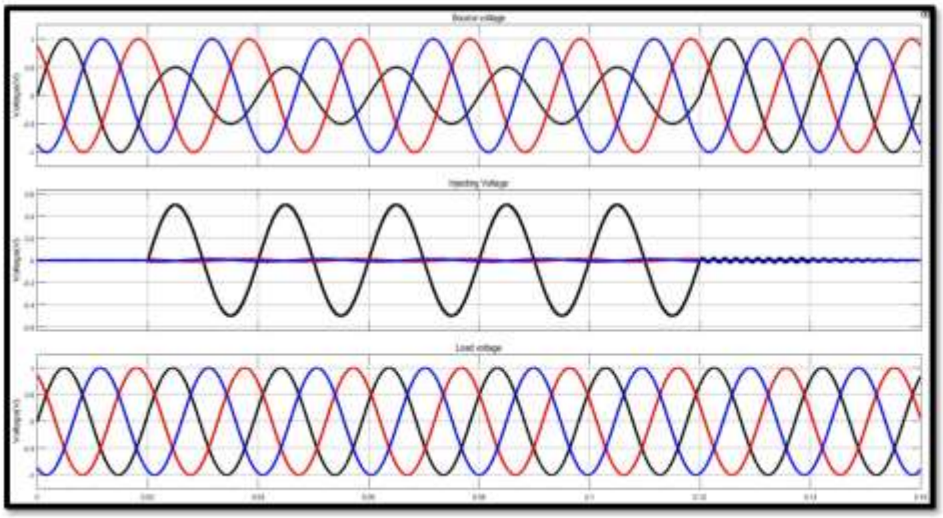

Figure 5: Single phase voltage sag mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit**.**

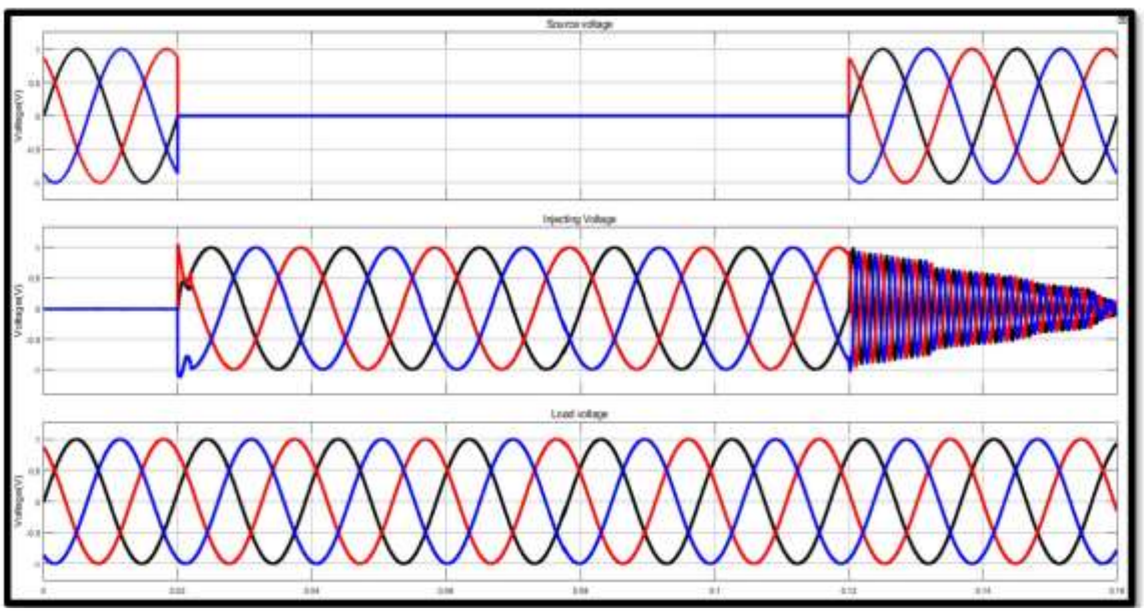

Figure 6: Three phase outage mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit

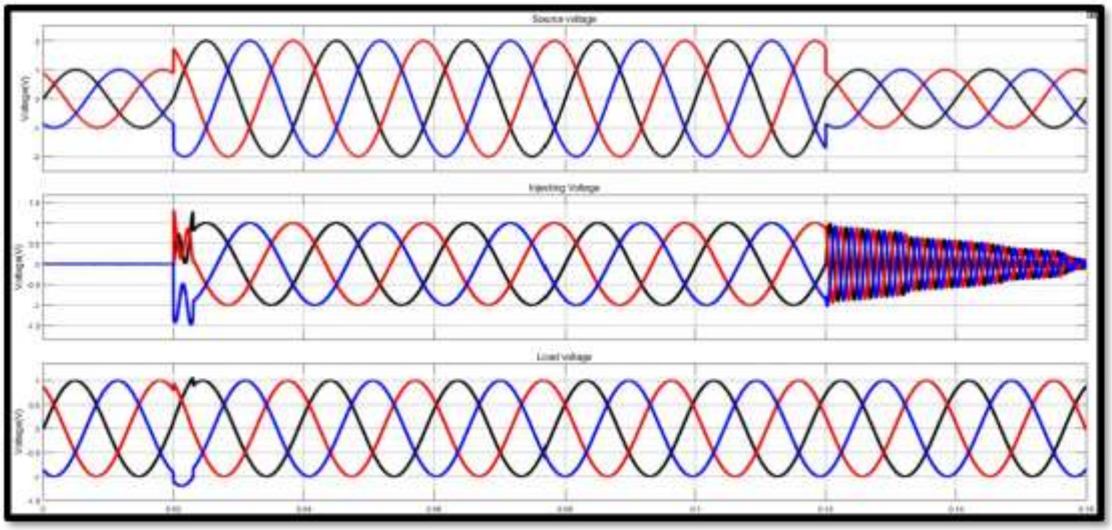

Figure 7: Balanced voltage swell mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.

To verify the proposed algorithm, the supply voltage from the grid is chosen as 23kV. This supply voltage is stepped down using a 6.25 kVA distribution transformer of 23kV/400 V. A RL load of 5 kVA with 0.8 power factor lag is chosen. The DVR is connected immediately after the distribution transformer. The voltage of the battery bank is 700 volts. A voltage source inverter is constructed with 6IGBT switches with anti-parallel diodes. A LC filter of 2 milli Hendry and 15 micro farad is connected at the output of the VSI. The filtered output voltage is added to the supply voltage using a 6.25 kVA series transformer of 1:1 turns ratio. The proposed DVR is able to mitigate voltage sag, swell, single phase outage and three phase outages successfully. The simulation results are presented below in per unit value. As the results are expressed in per unit value, the results are self- explanatory and easy to understand the effectiveness and reliability of the proposed DVR.

VI CONCLUSION

This work presented a Dynamic Voltage Restorer (DVR) based on a battery energy storage system for effective mitigation of voltage sag, swell, and interruption in distribution systems. Unlike conventional DVR topologies that rely on PI, PID, fuzzy logic, neural network, or other optimization-based controllers, the proposed system utilizes DQ0 transformation theory to generate PWM pulses without employing any controller or complex algorithm. The three-phase supply voltages are continuously monitored and converted into DQ0 components, and deviations from the reference values generate error signals that are directly used to control the Voltage Source Inverter (VSI). The compensating voltage produced by the VSI is injected through a series transformer to maintain the load voltage at its rated value during disturbance conditions, while no compensation is provided under normal conditions. MATLAB/Simulink simulation results validate that the proposed DVR can successfully compensate 100% balanced and unbalanced voltage sags, swells, single-phase outages, and three-phase outages. The proposed approach offers a simple, robust, and cost-effective solution with reduced computational complexity, making it highly suitable for protecting sensitive loads in modern power distribution systems.

REFERENCES

1. Y. Han, Y. Feng, P. Yang, L. Xu, Y. Xu, and F. Blaabjerg, ‘‘Cause, classification of voltage sag, and voltage sag emulators and applications: A comprehensive overview,’’ IEEE Access, vol. 8, pp. 1922–1934, 2020, doi: 10.1109/ACCESS.2019.2958965.
2. S. Rahman, S. B. Mule, E. D. Mitiku, G. T. Aduye, and C. Gopinath, ‘‘Highest voltage sag and swell compensation using single phase matrix converter with four controlled switches,’’ Przeglad Elektrotechniczny, vol. 97, no. 4, pp. 134–138, Mar. 2021, doi: 10.15199/48.2021.04.24. Rahman, ‘‘Realization of single phase matrix converter using 4 controlled switches,’’ Int.

3. J. Eng., Appl. Manag. Sci. Paradigms, vol. 54, no. 7, pp. 1–4, 2019.
4. M. A. E. Mitiku, G. Aduye, and S. Rahman, ‘‘Performance comparison of harmonic filters in an industrial power system for harmonic distortion reduction,’’ Przeglad Elektrotechniczny, vol. 98, no. 3, pp. 50–53, Mar. 2023, doi: 10.15199/48.2022.03.12.
5. G. Tan and Z. Wang, ‘‘Stability analysis of recurrent neural networks with time-varying delay based on a flexible negative-determination quadratic function method,’’ IEEE Trans. Neural Netw. Learn. Syst., early access, Nov. 3, 2023, doi: 10.1109/TNNLS.2023.3327318.
6. Doragacharla, V. R. (2026). Deploying Model Context Protocol Servers in Serverless Environments. Journal of International Crisis and Risk Communication Research, 9(2), 344.
7. Mahesh Ganji. (2025). Enhancing Oracle Cloud HR Reporting Through AI-Driven Automation. Journal of Science & Technology, 10(6), 28–36. https://doi.org/10.46243/jst.2025.v10.i06.pp28-36
8. S. A. Rahman, S. Birhan, E. D. Mitiku, G. T. Aduye, and P. Somasundaram, ‘‘A novel DVR topology to compensate voltage swell, sag, and singlephase outage,’’ Iranian J. Elect. Electron. Eng., vol. 17, no. 4, pp. 1–10, 2021, doi: 10.22068/IJEEE.17.4.2036.
9. Marella, V. C., Veluru, S. R., & Erukude, S. T. (2025, September). FedOnco-Bench: A Reproducible Benchmark for Privacy-Aware Federated Tumor Segmentation with Synthetic CT Data. In 2025 4th International Conference on Innovative Mechanisms for Industry Applications (ICIMIA) (pp. 870-876). IEEE.
10. R. S. Abuthahir, S. Periasamy, and J. P. Arumugam, ‘‘Mitigation of voltage sag and swell usingdirect converters with minimum switch count,’’ J. Power Electron., vol. 14, no. 6, pp. 1314–1321, Nov. 2014.
11. J. Hu, G. Tan, and L. Liu, ‘‘A new result on H∞ state estimation for delayed neural networks based on an extended reciprocally convex inequality,’’ IEEE Trans. Circuits Syst. II, Exp. Briefs, vol. 71, no. 3, pp. 1181–1185, Mar. 2024, doi: 10.1109/TCSII.2023.3323834.
12. S. M. K. P. (2025). Cryptography in iOS: A Study of Secure Data Storage and Communication Techniques. International Journal on Science and Technology, 16(1). https://doi.org/10.71097/ijsat.v16.i1.1403
13. S. A. Rahman and P. Somasundaram, ‘‘Mitigation of voltage sag and swell using dynamic voltage restorer without energy storage devices,’’ Int. Rev. Elect. Eng., vol. 7, no. 4, pp. 4948– 4953, 2012.
14. S. A. Rahman, P. A. Janakiraman, and P. Somasundaram, ‘‘Voltage sag and swell mitigation based on modulated carrier PWM,’’ Int. J. Electr. Power Energy Syst., vol. 66, pp. 78–85, Mar. 2015.