TPM Vol. 32, No. S8, 2025
ISSN: 1972-6325
https://www.tpmap.org/

ARTIFICIAL INTELLIGENCE TECHNIQUE TO ENHANCE POWER QUALITY AND STABILITY OF THE GRID-CONNECTED PHOTOVOLTAIC SYSTEM

BHUMIKA SHRIMALI[1], VIKRAMADITYA DAVE[2], KAMLESH JAT[3]

[1,3] RESEARCH SCHOLAR, DEPARTMENT OF ELECTRICAL ENGINEERING, CTAE, UDAIPUR, INDIA
[2]PROFESSOR, DEPARTMENT OF ELECTRICAL ENGINEERING, CTAE, UDAIPUR, INDIA
* CORRESPONDING AUTHOR: bhumikashrimali1997@gmail.com

ABSTRACT

Massive deployment of grid-connected photovoltaic (PV) systems has raised considerable issues pertaining to the power quality, stability of voltages, and fault ride-through. Harmonic distortion, voltage sag on grid faults, and inadequate dynamic response under variable irradiance conditions remain among the issues that limit reliable penetration of PV to the modern power networks. In this paper, an artificial intelligence (AI) control system has been introduced, which uses an 'Artificial Neural Network (ANN)' to improve the quality of power and stability in a grid-connected PV system. The suggested solution combines an ANN-based fault detection unit and a Distribution Static Compensator (DSTATCOM) to deliver rapid voltage support in case of grid disturbances. An elaborate mathematical model of the PV array, DCDC 'boost converter, voltage source inverter (VSI), and grid' interface is designed and simulated. The ANN is trained under a supervised learning method to effectively differentiate between normal and faulty operating conditions. Simulation outcomes show great enhancement of voltage stability, harmonic reduction, and fault ride-throughs. ANN has a regression accuracy rate of 99.8% and is able to detect faults very quickly to implement a reactive power compensation in a timely manner. The solution suggested is a very efficient and smart way of enhancing the quality of the power and providing a resilient grid integration of the photovoltaic systems in the smart grid setup.

KEYWORDS: Artificial Intelligence; Artificial Neural Network; Grid-Connected Photovoltaic System; Power Quality; Voltage Stability; Harmonics

1. INTRODUCTION

The growing world needs to access clean and sustainable energy, which has increased the immense movement 'of renewable energy sources, especially solar photovoltaic (PV) systems'. The reason why grid-connected PV installations are popular is that the installations are scalable, the cost has reduced, and it offers a lot of environmental benefits (Kundur, 1994). Among the most significant issues that can be linked to grid-connected PV systems, the quality of power deterioration can be noted. Problems like voltage sags and swells, harmonic distortion due to switching of inverters, frequency variations, and poor dynamic response to grid disturbances can impair system stability and can even cause the disconnection of PV units to the grid. These problems of power quality disruption have been widely discussed in the classical and contemporary literature on power systems, with their negative effects on sensitive loads and network stability being the focus (Bollen, 2000; Mahela et al., 2019). Moreover, the growing infiltration of renewable energy sources has exacerbated these worries, especially within weak grids and large-scale installations (Ullah et al., 2025; Eltamaly and Mohamed, 2018). More complex control and modeling methods are thus needed to provide stable operation and improved power quality in the renewable-abundant power systems (Gulzar et al., 2023). This paper presents an ANN-based intelligent control scheme that incorporates a Distribution Static Compensator (DSTATCOM) to improve voltage stability, minimize harmonic distortion, and 'fault ride-through' operation of 'a grid-connected PV system'. The suggested solution will help to make sure that the updated grid codes will be adhered to and to enhance the general quality of power and dynamic performance considerably (Mahela et al., 2019; Ullah et al., 2025).

2. System Description and Modeling

The system under investigation consists of a utility-scale photovoltaic (PV) array that is connected to the electrical grid using an aligned power electronic interface to enable smooth conversion of energy and stable interaction with the grid (Eltawil and Zhao, 2010). The PV array is the main source of DC power, which converts 'solar irradiance into electrical power. A DC-DC boost converter' is used to adjust and scale up the variable PV output voltage to a constant DC-link voltage, which can be used by the inverter.

The controlled DC power is then inverted to 'three-phase AC power' by a three-level 'voltage source inverter' (VSI), which has better voltage quality and lower harmonic distortion than the traditional two-level inverters. A phase-locked loop (PLL)-based control scheme makes it possible to achieve grid synchronization, allowing the accurate phase and frequency regulation with the utility grid and to operate the power factor unity (Lai et al., 2017). It also includes a Distribution Static Compensator (DSTATCOM) at the common coupling point to add dynamic reactive power compensation, thus improving the voltage stability, reducing the voltage sag during faults, and improving the overall quality of the grid-connected PV system (Sirjani and Jordehi, 2017). This setup enables the effective extraction of power, managed grid injection, and dynamic voltage support during disturbances.

This paper will use a 50-kW solar array connected to the 25-kV grid using a boost converter with an MPPT controller, a voltage source inverter (VSI) with a current control loop to effectively synchronize the inverter voltage and frequency with the grid voltage and frequency, a coupling transformer, and the load and utility grid. This DSTATCOM of six pulse converters is linked to a 25-kV line in order to ride through faults. They learn how the presence of a fault on the system affects the system with and without DSTATCOM using the suggested model. In order to check how the implemented control scheme works with the system, a simulation has been conducted with the help of the software MATLAB R2017a. This section provides the general simulation model of the grid-connected solar system with DSTATCOM and discusses the results of the simulation.

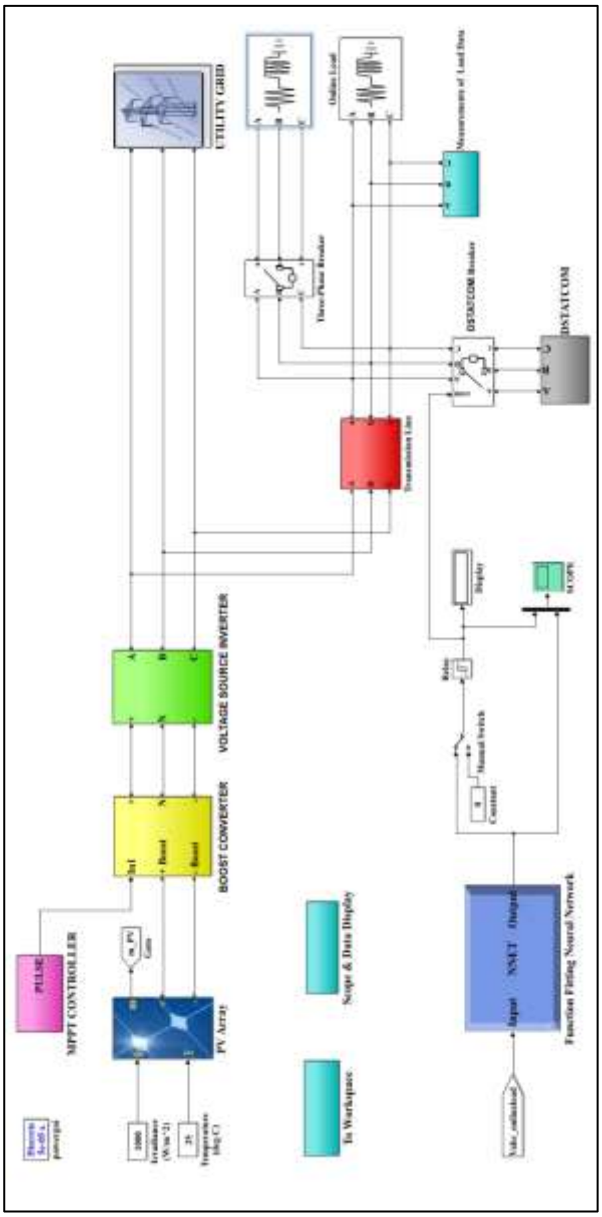

Fig. 1 shows the Simulink model of a grid-connected solar system with a neural network for fault detection and a DSTATCOM for fault ride-through of the system

3. ARTIFICIAL INTELLIGENCE TECHNIQUE

3.1 ANN-Based Controller Design

An Artificial Neural Network is used to detect faults in real time and coordinate fault control. The ANN takes in system voltage, current, irradiance, and change of load as input features, and the output provides switching and control signals to protection and compensating devices. A network architecture is made up of 'an input layer, one or more hidden layers, and an output layer' (Jasim et al., 2022). The training is performed by the Levenberg-Marquardt backpropagation algorithm on a well-prepared dataset (normal and fault conditions). The strong generalization capability without overfitting is validated and tested.

A Function Fitting 'Neural Network trained via the Levenberg-Marquardt back-propagation algorithm' was deployed for online fault detection on the AC side of the system. Training converged after 345 epochs, yielding a best validation mean-squared error of 1.3092×10^{-4}. The regression analysis across all data splits, training, validation, and test, returned an overall R-value of 0.99852, confirming 99.8% detection accuracy. Close agreement between the validation and test curves throughout training ruled out over-fitting. Under normal operating conditions, the network output is held at 1 (no-fault), transitioning sharply to 2 upon fault inception to trigger the DSTATCOM relay.

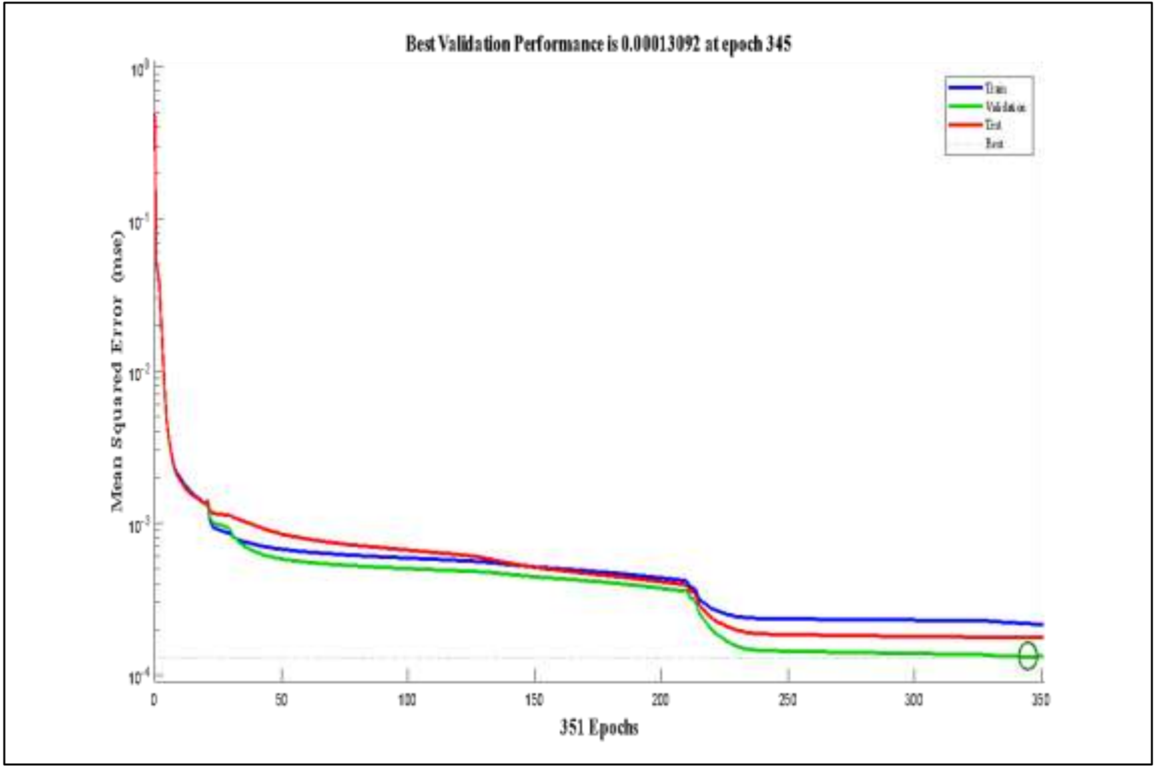

Fig. 2 Validation Performance Plot of Function Fitting Neural Network (Best MSE = 1.3092×10^{-4} at epoch 345)

4. RESULTS AND DISCUSSION

4.1. PV Array Characteristics and MPPT Performance

The experiments were conducted under 'Standard Test Conditions (STC) of 1000 W/m2 irradiance and 298K module temperature' with the SunPower SPR-305E-WHT-D array (33 parallel strings, five series modules, with an approximate 50.4 kW rated power). The characteristic curves validated previously known photovoltaic properties: the voltage output decreased significantly with cell temperature, and the short-circuit current increased approximately linearly with incident irradiance.

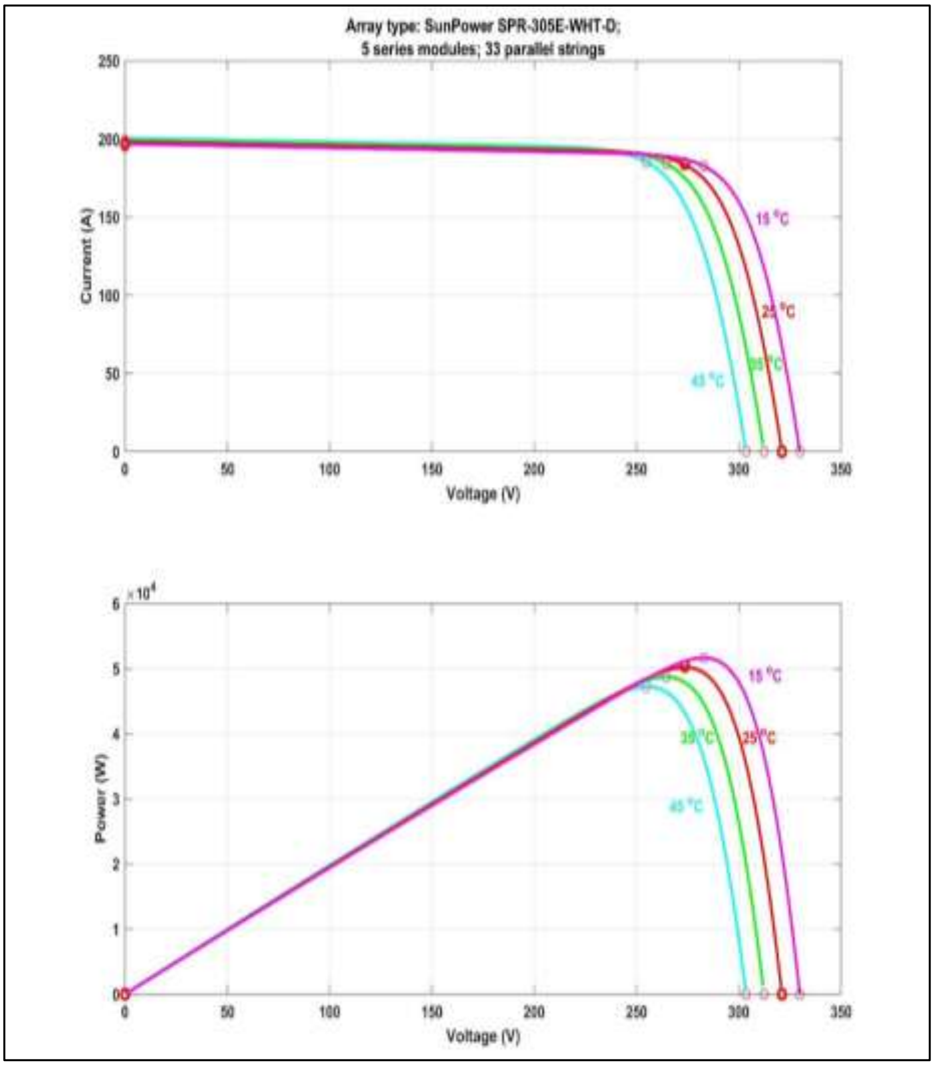

Fig. 3 I-V and P-V Characteristics of PV Array at Constant Irradiance (1000 W/m²) and Variable Temperature

4.2 DSTATCOM Baseline- No-Load Condition

The baseline of the system was recorded prior to fault scenarios being studied when the system was under no load. AC line voltage was maintained at about 304 V (about 1 pu), and the DSTATCOM was left in standby with its output voltage set to zero, ensuring that the compensator does not affect normal operation.

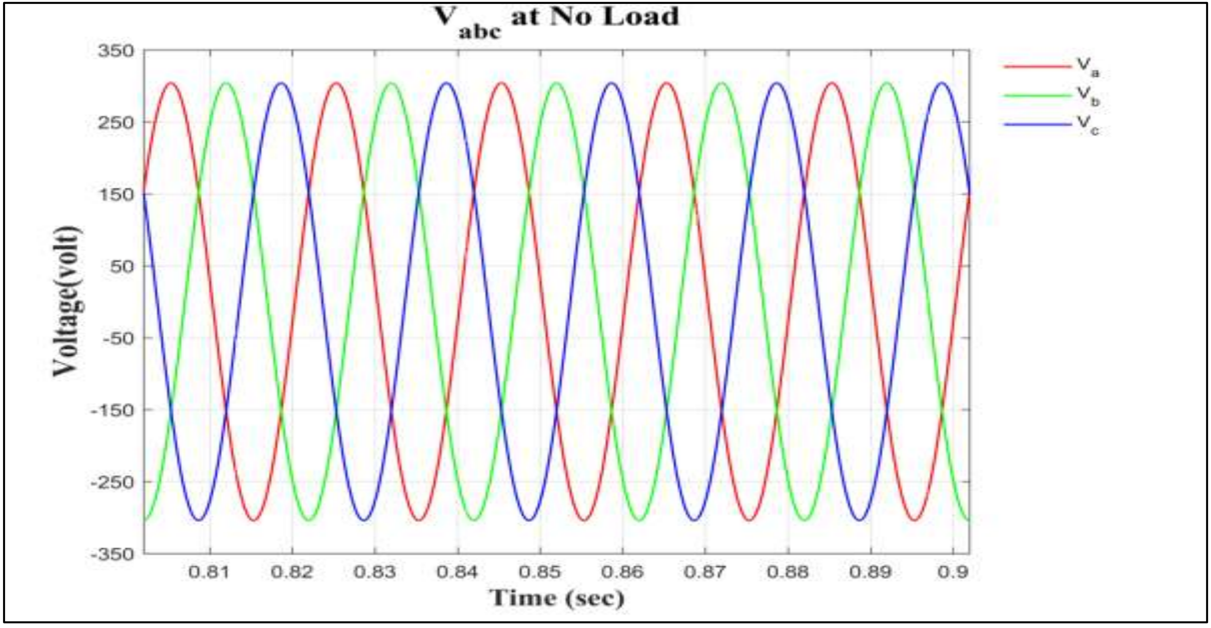

Fig. 4 Three-Phase Voltage Waveform Under No-Load Condition (~304 V)

4.3 Fault Ride-Through (FRT) Analysis – Half Load (P = 5 kW, Q = 1500 kVAR)

A three-phase symmetrical fault was bolted between ‘t = 0.5 s and t = 0.6 s’, and the system was fed with a half-rated RL load. In a real grid, line voltage dropped below 290 V, enough to cause protective relay action and inverter disconnection, without the DSTATCOM.

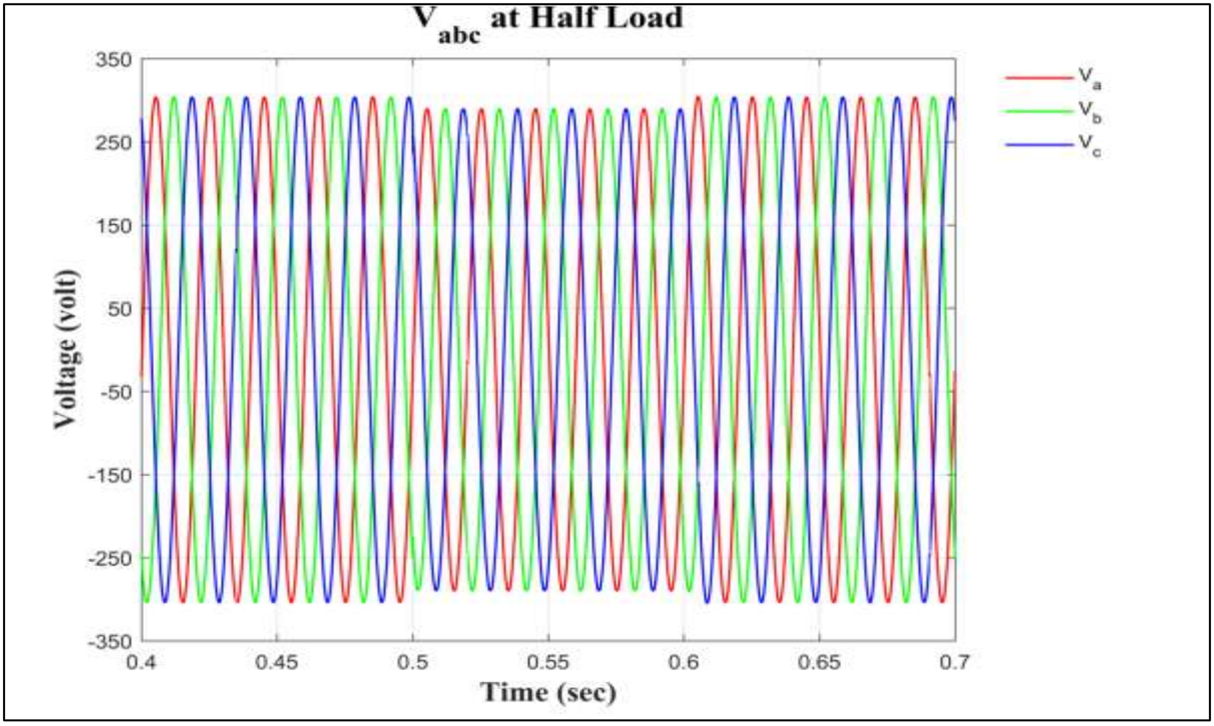

Fig. 5 Three-Phase Voltage Without DSTATCOM — Half-Load Fault (Voltage Sag Visible)

4.4 Fault Ride-Through (FRT) Analysis – Full Load *(P = 10 kW, Q = 3000 kVAR)*

The load was doubled to test the DSTATCOM performance at maximum load. The fault sag, which was not compensated, was further lowered to less than 275 V by the increased reactive current caused by the increased weight load. The above result highlights the inefficiency of passive response strategies during full load.

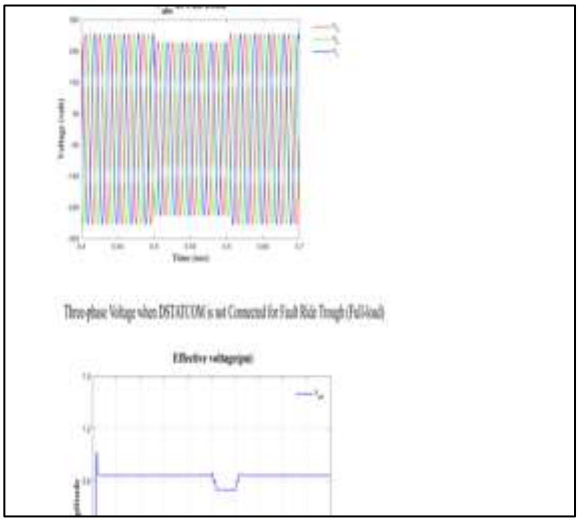

Fig. 6 Three-Phase Voltage Without DSTATCOM — Full-Load Fault (Deeper Sag, < 275 V)

4.5 Comparative Performance Analysis

The discussion has explicitly shown that the uncompensated system is very susceptible to grid outages, especially in fault conditions, where excessive loss of voltage, slow recovery, and poor quality of power are experienced. Without compensation, the level of voltages decreases to unacceptable values (less than 290 V at half load and less than 275 V at full load), which leads to a low fault ride-through and an extreme probability of inverter disconnection. Besides, harmonic content is also quite high because the dynamic reactive power support and intelligent control are not provided, which negatively impacts the power quality.

5. CONCLUSION

This research shows that ANN-based control can greatly improve the quality of power, voltage stability, and fault ride-through of grid-connected photovoltaic systems. The ANN has a good fault detection rate and can quickly coordinate with DSTATCOM to support reactive power. The proposed solution has better dynamic performance and flexibility compared to the traditional control strategies, so it is very appropriate in smart grid applications where the PV penetration is high.

REFERENCES

1. Bollen, M. H. J. (2000). *Understanding power quality problems: Voltage sags and interruptions*. IEEE Press.
2. Eltamaly, A. M., & Mohamed, Y. A. R. I. (2018). Advanced fault ride-through strategies for renewable energy systems. *IEEE Transactions on Power Electronics*, 33(10), 8726–8740.
3. Gulzar, M. M., Gardezi, S., Sibtain, D., & Khalid, M. (2023). Discrete-time modeling and control for LFC based on fuzzy-tuned fractional-order PD μ controller in a sustainable hybrid power system. *IEEe Access*, *11*, 63271-63287.
4. ‘Kundur, P. (1994). *Power system stability and control*. McGraw-Hill.’
5. Mahela, O. P., Gupta, P., Ali, S., & Gupta, N. (2019, February). Power quality improvement in a renewable energy source-based power system using DSTATCOM supported by a battery energy storage system. In *2019, Fifth International Conference on Electrical Energy Systems (ICEES)* (pp. 1-6). IEEE.
6. Ullah, M., Guan, Y., Yu, Y., Chaudhary, S. K., Vasquez, J. C., & Guerrero, J. M. (2025). Dynamic Performance and Power Quality of Large-Scale Wind Power Plants
7. Jasim, A. M., Jasim, B. H., Neagu, B. C., & Alhasnawi, B. N. (2022). Coordination control of a hybrid AC/DC smart microgrid with online fault detection, diagnostics, and localization using artificial neural networks. *Electronics*, *12*(1), 187.