# Power Quality Analysis of a Hybrid MATLAB/Simulink Using a DSTATCOM and Comparison with a Real Plant

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**Abstract:** Addressing power quality issues in today's modern electrical systems have become a significantly important topic for all consumers. Power quality issues play a vital role for reliability and efficiency of electrical networks. With distributed generations and mainly solar and wind energy installations power quality issues become a challenge to tackle. Power quality issues such as voltage sag, voltage swell, load changes and harmonics can cause financial losses, distributions in the operations and damage devices and equipment that is used in facilities and in daily life. There are custom power electronic devices that can overcome these power quality issues and improve stability. To ensure stability of voltage and reduce Total Harmonic Distortions (THD), Distribution Static Synchronous Compensators (D-STATCOM) is used in this paper simulate a hybrid electrical system in MATLAB/SIMULINK as well as compared with real site data. D-STATCOM is widely used in distribution systems due to their capabilities in voltage fluctuation mitigation, reduce THD, rapid response to reactive power support and improving system efficiency. In this study, P&O control algorithm is used and D-STACOM is integrated in the work to enhance power quality in total. With the current control technic and simulation THD is reduced significantly in hybrid electrical system. The simulation result also checked with real plant data and it is clear that D-STATCOM can support plant to reduce THD and improve power quality in electrical systems.

**Keywords:** power quality, DSTATCOM, THD, control systems, photovoltaic (PV), wind turbines

## 1. Introduction

In today's world, to ensure a reliable of power to all consumers is essential. However, ensuring an efficient power to all users it is not that simple and smooth from generation to end users. With increase of capacity and distributed generations, power quality becomes a more significant issue than ever. In the last decade, PV and Wind power is the main renewable energy sources that is installed significantly in global level and it is expected to increase in coming decades too [1].

This means more transmission and distribution systems to be installed as well as having more decentralised networks in the electricity infrastructure. Small and large scale of these distributed generations have good impacts on the grid for stabilisation of the load and voltage.

On the other hand it brings up some power quality issues that needs to be optimised in to provide more efficient power to consumers, avoid delays and financial losses in the industrial facilities and reduce damaging devices and losses that is wasted in a power systems [2].

The most common power quality issues are voltage fluctuations, frequency and harmonics in the system. As the grid systems getting more complicated and generation moving to decentralised significantly, Power quality is an emerging challenge that need to be examined. There are technical solutions to minimise these issues to deliver better results. Installing power electronic devices, implementing advance control systems and advance real time analysing and monitoring will support to minimise the power quality issues [3]. Besides, grid regulations and standards also help for reliability of power. In this study, PV and Wind power with DSTATCOM is examined and positive effect of it has been demonstrated in simulation and with real site data.

### *1.1 Motivation*

In recent years, the world is investing in renewable energy sources dramatically and many countries support energy mix diversifications [4]. As more clean energy sources are installed such as solar, wind and storage systems, it brings up power quality challenges in the power networks. This issue will become more crucial moving towards to distributed generations. Therefore, the motivation behind this study is to focus on reducing power quality issues and increase stability.

### *1.2 Literature Review*

Power quality issues have been discussed extensively in some studies which is especially focused on PV, Wind power and Storage systems [5]-[6]. In [5], mitigation of power quality is examined extensively with using Static Synchronous Compensator (STATCOM) in power system and its positive effects to power systems and increasing voltage control stability. In [7], a comprehensive review is done for power electronic devices as well as an overview for control strategies in the distributed systems. There are recently some studies that is focused on improving the control systems in Hybrid renewable energy systems [8] to optimize power quality issues with dynamic load variations in grid with power electronic equipment and validate the simulation on MATLAB/Simulink [9].

As control strategies play a vital role in mitigation of power quality issues and especially Inverters has a critical role in the plants, [10] focused on control strategies of Photovoltaic inverters. In [11], a review on control and optimization for solar inverters have been considered to improve performance. In [12] An Atom Search Optimization (ASO) and Unified Power Quality Conditioner (UPQC) is examined for improvement of Power Quality for various loads in grid, maintain voltage stability and reduce THD.

Most of these studies have raised the emerging power quality issues in hybrid renewable energy systems. In order to minimize power quality issues different power electronic devices and control systems used and optimization of PV inverters addressed.

### *1.3 Contributions*

The main contributions of the current paper as follow:

- Linear and non-linear loads are connected in the simulation and results were examined and validated with real plant installations.
- D-STATCOM has been integrated to system to reduce THD and increase voltage stability and provide more reliable power to system.
- Improvements have been done in control strategies to increase output and create more reliable hybrid system
- Perturb and Observe (P&O) algorithm is used for optimization as it is one of the most widely used MPPT techniques because of its simplicity and effectiveness.
- MATLAB/Simulink results have been compared with real site data and the results are verified that the proposed control systems and implementing of D-STATCOM can significantly reduce THD.

Integrating photovoltaic (PV) systems with wind turbines, along with a D-STATCOM, can significantly enhance the power quality of distributed generation systems, creating a sustainable level of power quality. The following describes how each component contributes to the overall MATLAB/Simulink system that has been used in this study. Common used energy sources, components and power quality issues are described.

*1.4 Photovoltaic (PV) System*

PV systems convert sunlight into electricity, generating DC power. When integrated into a power system, they can help reduce reliance on traditional fossil-fuel-based electricity, thus contributing to sustainability and lowering carbon footprints.

*1.5 Wind Turbines*

Wind turbines simply harness wind energy and convert it into electricity with their blades, which turn around a rotor and spin a generator that produces energy. Similar to PV systems, wind turbines contribute to the generation of renewable energy and can be particularly useful in areas with consistent wind patterns. The control structures of wind turbines include blades, a generator, and converters with an induction generator or a PMSG [13].

*1.6 Distribution Static Synchronous Compensator (DSTATCOM)*

A D-STATCOM is a shunt-connected power electronic device used for mitigating power quality issues in distribution systems. Renewable energy sources, such as solar and wind power, can introduce fluctuations. A D-STATCOM helps maintain stability and quality in the context of variable power generation. It can rapidly inject or absorb the demanded reactive power to balance the grid and make many improvements that enhance the power quality's parameters, such as voltage stability, flicker reduction, and harmonic suppression, as well as reliability in a hybrid electrical system [14].

*1.7 Power Quality Improvement Strategies*

*Voltage Regulation:* PV and wind systems, both of which rely on intermittent energy sources, can cause voltage fluctuations in a distribution grid [15]. D-STATCOMs can help regulate voltage levels by injecting or absorbing reactive power as required by the grid.

*Harmonic Suppression***:** Power electronic converters used in PV and wind systems can introduce harmonics into a grid, leading to power quality issues [16]. D-STATCOMs equipped with harmonic filtering capabilities can mitigate these harmonics, ensuring cleaner power delivery to consumers.

*Power Factor Correction:* D-STATCOMs can improve the power factor of a system by injecting reactive power as needed. This helps in reducing line losses and optimizing the utilization of a distribution system's infrastructure.

*Flicker Reduction:* Variations in power generation from renewable sources, such as wind and solar power, can cause flickering in systems with a weak current and sensitive equipment [17]. Voltage flickers are a challenge in hybrid systems, because the inverters in these systems rapidly change the active power and cause unstable loads [18]. D-STATCOMs can smooth out such fluctuations, ensuring stable voltage levels and minimizing the effects of flickering.

## 2. Solar Power

The working principle of PV system, MMPT logic and Perturb and Observe (P&O) algorithm is stated in this section. A circuit diagram of a sun-oriented photovoltaic cell is presented in Figure 1, demonstrating the working principle of solar panels [19]. Figure 2 shows the working principle of a PV cell, which is the ability of a semiconductor to absorb photons and release electrons [20].

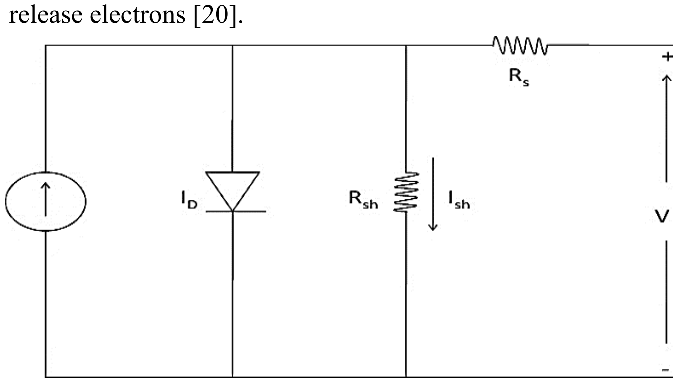



*Figure 1. Circuit diagram of a solar panel*

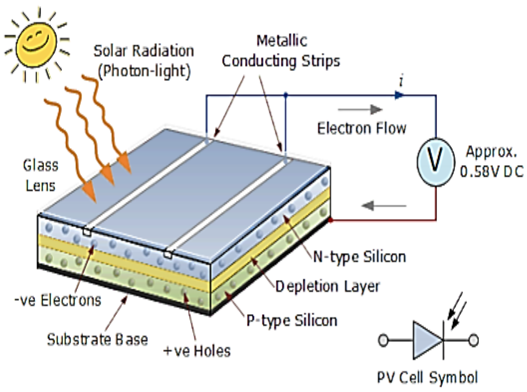



*Figure 2. Basic working principle of a PV cell.*

*2.1 Maximum power point tracking (MPPT) method*

Maximum Power Point Tracking (MPPT) is a technology used in photovoltaic (PV) systems to optimize the output of energy from solar panels and the efficiency of the inverters. Our system ensures that photovoltaics (PV) in panels operate at their maximum level of power output under varying environmental conditions, including sunlight intensity and temperature. MPPT performance is affected by some weather factors such as cloud, trees, shading, dust etc. To minimize these effects too, most widely used MPPT method is the Perturb and Observe (P&O) algorithm, which is used in the MATLAB/Simulink simulation in this paper [21].

MPPT is essential because the maximum power point (MPP) of a solar panel varies with factors such as temperature and irradiance. The MPPT is the point on the voltage–current curve (I–V curve) of the PV panel at which the production of the voltage and current is at the maximum. Operating a PV panel at this point ensures the highest efficiency and maximum power output. MPPT is a special optimization algorithm that mainly controls systems in PV systems [22]-[23].

*2.2 Perturb and Observe (P&O) Algorithm*

The Perturb and Observe (P&O) algorithm is one of the most widely used MPPT techniques because of its simplicity and effectiveness. It is a very effective standard algorithm for the optimization of power output in PVs [24]. It works in the following ways:

*Power Observation:* After a perturbation, the algorithm observes the change in the power output by comparing the power output at the new operating point with that at the previous point.

*Direction Determination:* The algorithm determines whether the perturbation moves the operating point closer to or farther away from the MPP based on the change in the power output.

*Optimization:* The algorithm is a simple but effective method for maximum power point tracking (MPPT) in photovoltaic (PV) systems. We optimized the P&O algorithm by addressing its inherent limitations. We also enhanced its performance by tuning some parameters. Depending on whether the power increases or decreases significantly, the P&O algorithm may change the direction of the perturbation. Until the maximum point of the power is achieved, this process is repeated.

*Convergence:* The algorithm iteratively adjusts the operating point until it converges to the MPP, where further perturbations result in a decrease in the power output. MPPT uses dc-dc converter to receive maximum output from PV and this process is a continues process via Duty cycle control to check irradiance and send command to inverter to check voltage and current in the system till peak power output is reached. Figure 3 below demonstrates block diagram of the MPPT [25].

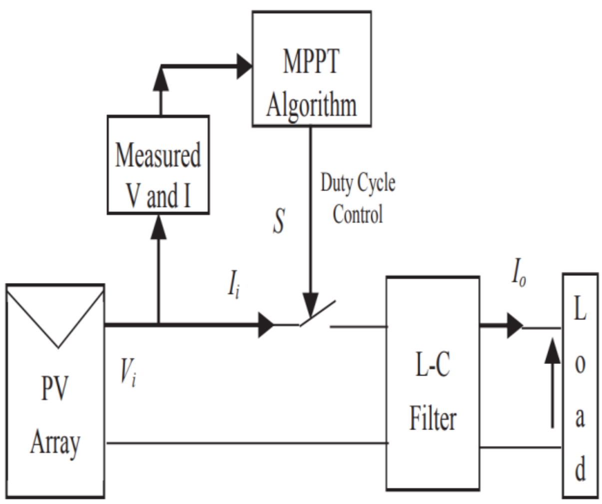



*Figure 3. Block diagram of the MPPT algorithm*

As solar is one of main driven renewable energy source and it is intermittent, the control algorithm has various effects on the power system. Therefore P&O algorithm is proposed to have more efficient output and reduce power quality issues.

## 3. Wind Turbine Model with PMSG

A wind turbine with a permanent magnet synchronous generator (PMSG) is a common configuration in modern wind power systems. The reason is commonly used due to their promising high efficiency, low maintenance and flexible in providing variable wind speeds. PMSG have a good control on the output power and can optimize the power flow in the grid systems as well as reduce power quality issues such as reducing losses in the grid system and stabilizing the voltages [26]. Figure 4 below shows wind energy conversion system using a PMSG that is used in the simulation. Due to its efficiency and a reliability this type of turbine is selected. The PSMG has a single control loop that keeps checking the active and reactive powers [27]. This gives an advantage for overall control system and fast responds to setpoints and changes whenever is required.

Figure 5 below shows a turbine power characteristic [28] according to Turbine speed and output power.

Table 1 below demonstrates the wind turbine parameters that is used in the MATLAB/Simulink simulation.

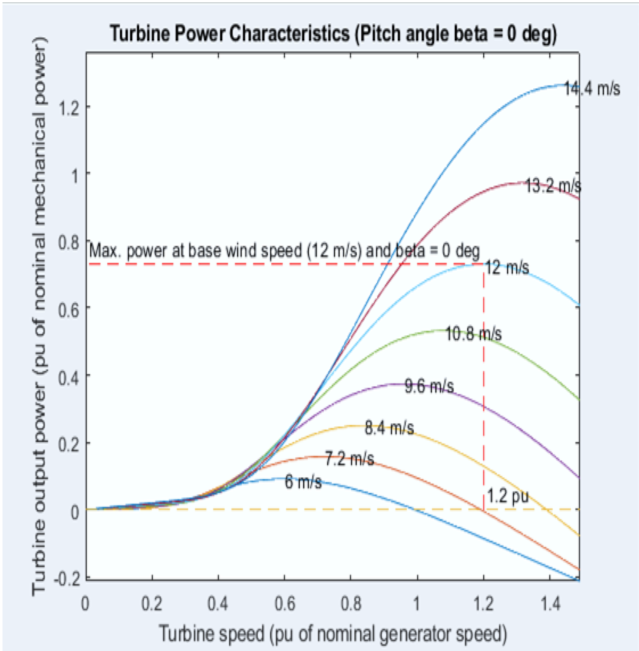



*Figure 5. Turbine power characteristics*

Table 1. Wind turbine input parameters.

| | |
|---|---|
| Nominal mechanical output power | 1.5e6 |
| Base power of electrical generator | 1.5e6/0.9 |
| Base wind speed | 12 |
| Maximum power at base wind speed | 0.73 |
| Base rotational speed | 1.2 |
| Pitch angle | 0 |

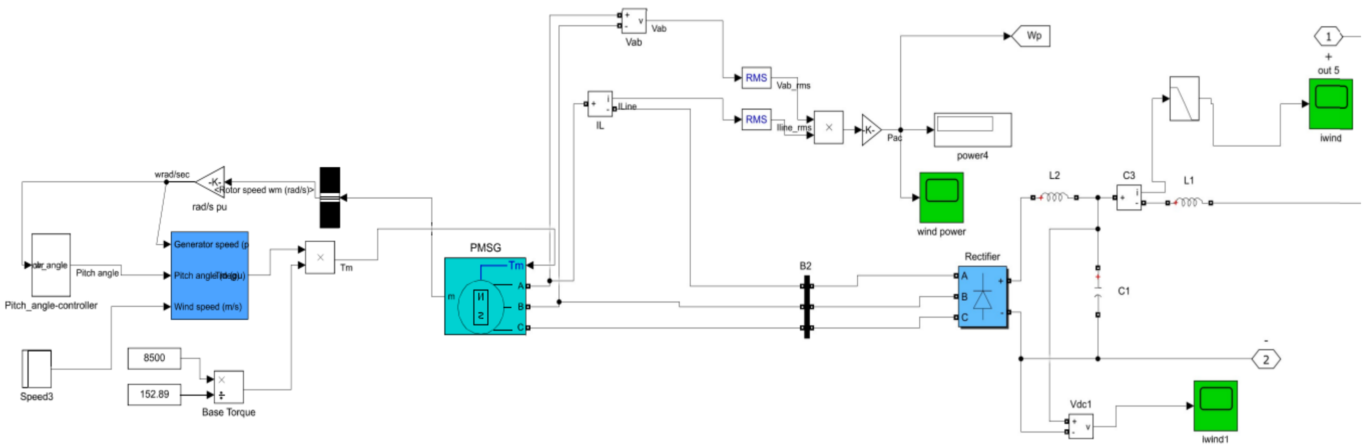



*Figure 4. Wind energy conversion system using a PMSG.*

## 4. PV Array

PV panel configuration and inverters are important in the design in order to optimize the inverter output. PV systems has a significant role in improving the power quality such as voltage support, grid stability, THD mitigations, frequency regulation etc. [29]. The implemented solar array comprised 10843 equal parallel strings. Every string consisted of 24 Tiger Pro 72HC-BDVP (Jinko) solar PV panels with a 535 Watt specification for each panel and all coefficients were used from panel datasheets to create a the PV simulation. Table 2 presents the modules and the parameters used to plot the I–V and P–V outputs which is presented in results.

The maximum DC input of PV is designed to be 1500V and inverter AC output is designed to be 800V and increased to 33kV via transformers to be injected into the grid.

Table 2. PV panel input parameters

| | |
|---|---|
| Parallel strings | 10843 |
| Series connected modules per string | 24 |
| Module type | Jinko Solar Panel Tiger Pro 72HC-BDV 535 Watt |
| Maximum power | 535 |
| Open circuit voltage | 49.54 |
| Cells per module | 144 |
| Short circuit current | 13.83 |
| Current at maximum power imp | 13.07 |

## 5. D-STATCOM

The D-STATCOM is a power electronic device that is widely used in power systems for many years. They play a significant role for improving of power quality issues. They are widely used in distributed generations and transmission networks to minimize power quality issues especially in voltage regulation and controlling reactive power as well as increase the reliability of the network. The D-STATCOM is used in the simulation on the grid side to mainly reduce the THD in the hybrid system. To control the load-side disturbance in the distribution system, we installed solid-state devices connected in parallel, known as a D-STATCOM. The first D-STATCOM, an SVC with a voltage source converter, was utilized in 1999. It has overtaken the simultaneous condenser on account of its lower venture cost, no latency etc. during the time. A force VSC that is dependent on high-force electronic innovations is at the heart of the DSTATCOM's responsive force remuneration in AC systems [30]. The voltage source converter controls the exchange of reactive power between a DC voltage storage device and an AC framework through the spillage reactance of a transformer. The DSTATCOM continuously checks the line waveform to obtain a reference for the AC signal and then it commands the DSTATCOM to respond to the required adequate or reference AC signal with an adequate responsive current remuneration to decline or adjust the variance in the voltage. A DSTATCOM is like a STATCOM, with the distinction that the STATCOM is utilized at the transmission level to control the principal responsive power and to maintain the voltage, and a DSTATCOM is utilized at the appropriation level for voltage guidelines and remedying the force factor [16]. A DSTATCOM can, likewise, be utilized to eliminate all total harmonic distortions, voltage sags, and swells. Applied control block diagram of it is as shown below in figure 6.

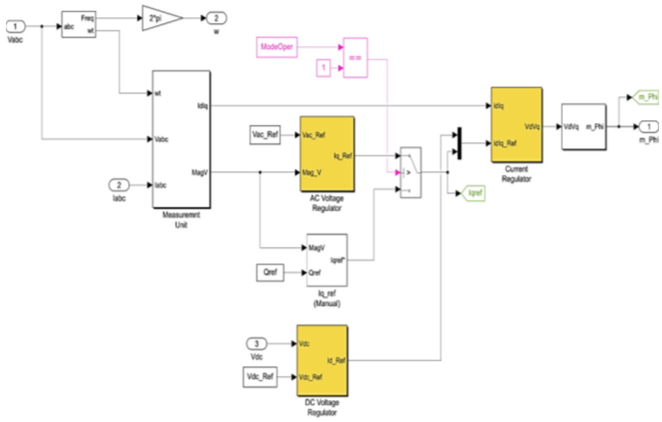


*Figure 6. Control Block diagram of the DSTATCOM*

Figure 7 below shows a basic diagram of DSTATCOM that is installed between loads and generator. The DSTATCOM can act as the shunt active filter to eliminate disturbances that are present in the supplied source current and voltage. The D-

STATCOM mainly triggers the converters to create a closed loop to control the current and voltage at an optimum level [14].

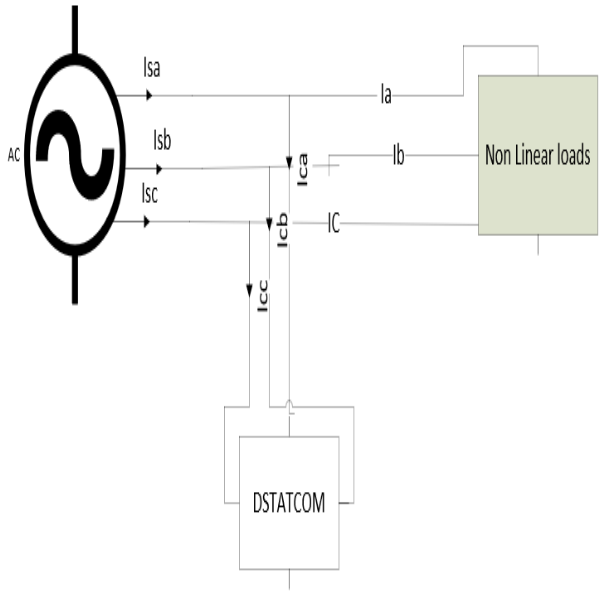



*Figure 7. Basic diagram of a D-STATCOM.*

The main components of the D-STATCOM are as follows:

- Voltage source converter
- L-C filter
- Coupling transformers
- Different control blocks
- Storage device

*Simulation Procedure*

The simulation procedure mainly is based P&O algorithm to receive maximum output with continues control checks on power-voltage curve. As it is shown in Figure 8 [31] it start with measuring the voltage and current and then calculate power *P(n)* with previous perturbation. If the perturbation still allows to increase power the algorithm send new setpoint to increase the power. This cycle is done continuously from zero to maximum point till *P(n)- P(n)=0.* As this techniques is based on some factors such as irradiance and temperature, Even P&O reached to MMPT, it still has to check periodically for power drops. The advantages of this procedure due to its effectiveness, simplicity and reliability.

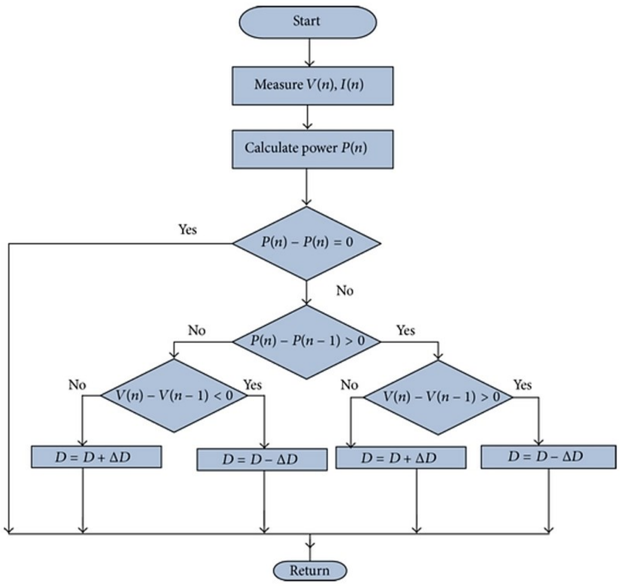



*Figure 8. Flowchart of the P&O technique*

## 6. Results and Discussions

The results are discussed in this section. A grid-connected hybrid system was simulated in MATLAB/Simulink. The MPPT system that we used obtained the maximum power from the PV array, allowing us to achieve a better output of energy by the PV system. The input information of the Simulink on the PV side was based on the irradiance and temperature. As can be seen in Figure 9, the irradiance of the PV array model was started at 1000 W/m2, decreased to 800W/m2 to achieve a drop in the level of production, and then increased

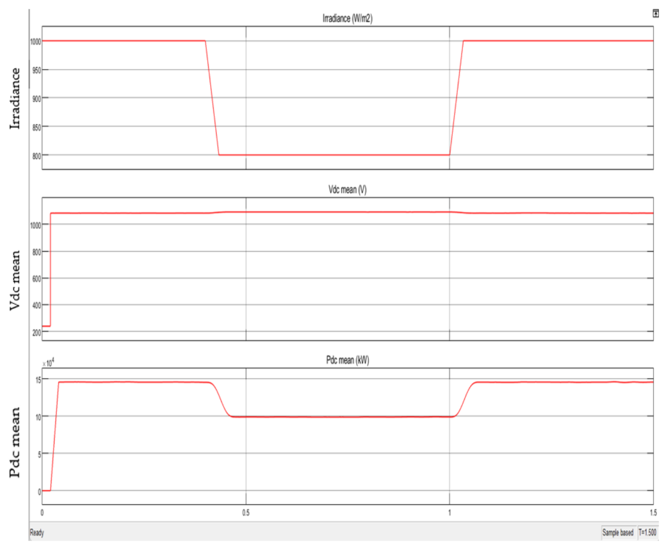



*Figure 9. The irradiance, PV power, and PV voltage graph*

to 100W/m2 again. During this time, the working temperature was kept at 45$^0$C. The steady-state time was considered as t=0.15 sec.At this point, the output power (Pdc_mean-kW) was approximately 14,6e4 Kw, which also meets the PV panel's production requirements. Figure 10 below demonstrates the power and current in different temperatures. As temperature increase the output voltage and power is reduced slightly.

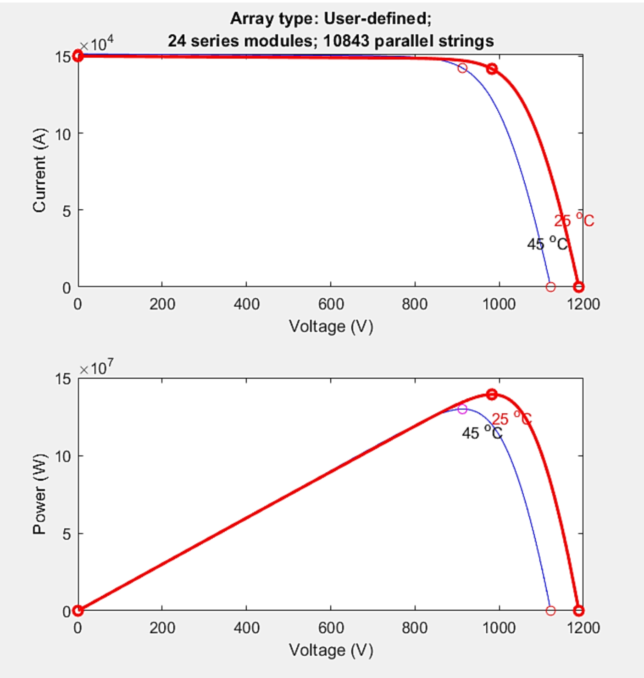



*Figure 10. Photovoltaic system's simulation I–V and P–V curves output for different temperatures*

As it can be seen from Figure 11 a detailed layout of hybrid electrical system demonstrated including PV, wind, D-STATCOM etc.

The main purpose of implementing the use of a D-STATCOM in this system was to regulate the voltage on the grid side at 110 kV. Two feeders had configurations of 21 km and 2 km. These feeders, B2 and B3, supply power to buses. We used shunt capacitors at B2 for the power factor correction. In addition, there was a load at B3 connected to a 110 kV/33kV transformer, which represented a plant that constantly absorbed varying currents and compensated for voltage flickers. The load current frequency was fixed at 50 Hz, causing the power to range from 1 MVA to 5.2 MVA in the distribution system. The power factor was fixed at 0.9 in the design. We can clearly observe in the graphs below that the voltage flickering was mitigated by the D-STATCOM as a result.

As per the function of the D-STATCOM, we observed that the voltage of bus number 3 met the regulated condition for the process of absorbing and generating reactive power [32]. Transfer of the reactive power was conducted, generally, by leakage of the reactance of the coupling transformer by the generation of voltage on the secondary side of the phase network side. As our inverter was a pulse with modulation (PMW) type, it also allowed us to obtain the gain in the output voltage. However, there were conditions under which the secondary voltage was lower than the voltages of the busses. Thus, a D-STATCOM was used in these situations to absorb the reactive power that the system produced. In other words, the D-STATCOM worked as a capacitor to balance the system. In this way, the D-STATCOM exerts real-time control, improves the quality of the voltage, and increases the stability and reliability of the system.

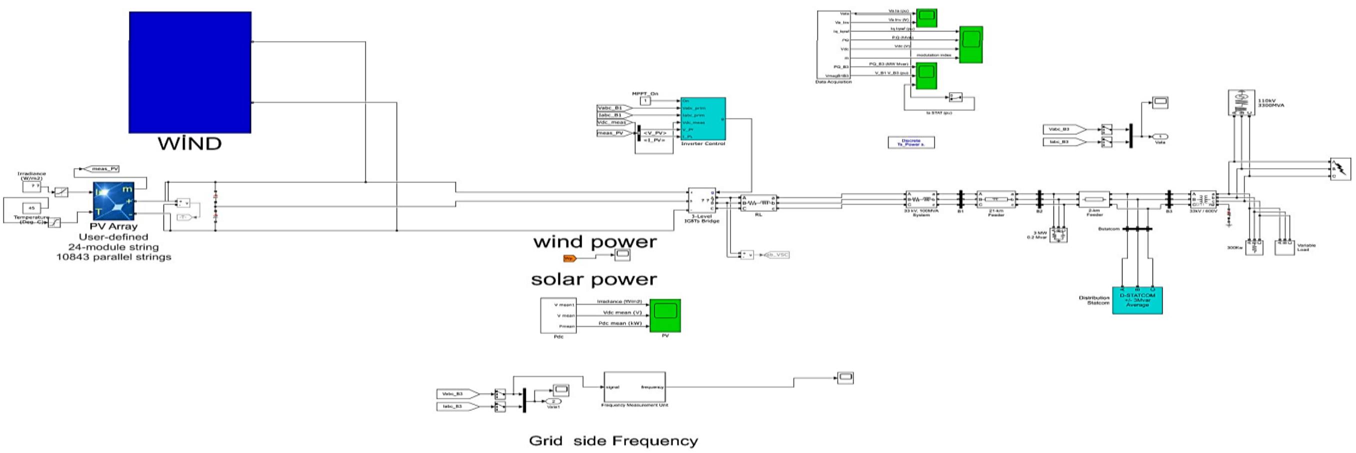



*Figure 11. Layout of the Hybrid Simulink/MATLAB system*

*6.1 Functional Blocks Consist of D-STATCOM*

A transformer's primary voltage is located where its fundamentals are synchronized. We included two measuring components that measure the voltage and current of the d-axis and q-axis components. Their variables are denoted as Vmeas and Imeas. The measurements were conducted using an ABC-dqo transformation of the synchronous reference. The reference was determined using the two following components: sin(wt) and cos(wt). These are provided by a phase-locked loop (PLL), which is an inner current regulation loop. Two PI controllers were used, controlling the d-axis and q-axis currents. The outputs of the controller voltages are represented by the variables Vd and Vq, which were generated by the PMW generator. These voltages were further converted into phase voltages as Va, Vb, and Vc. These phase voltages were used for the synthesis of the PMW voltages. Voltage regulation or qref. imposes the Iq reference. The main function of the PI controller is to control voltages..

*6.2 Dynamic Response of the D-STATCOM*

The dynamic response of the D-STATCOM for power, voltage and current is as fallow below in Figure 12.

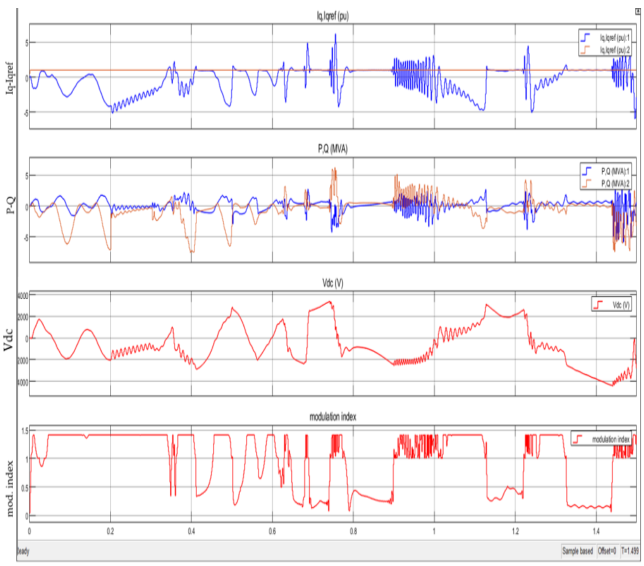



*Figure 12. Dynamic response of the D-STATCOM.*

*6.3Reactive and Active Powers of the D-STATCOM*

The result of active and reactive power of the D-STATCOM as fallow below in Figure 13.

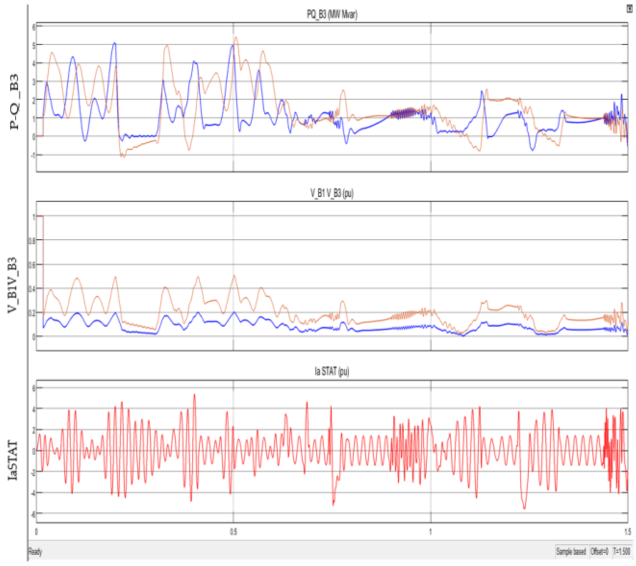



*Figure 13. Reactive and active powers of the D-STATCOM for bus b3.*

*6.4 Mitigation of Voltage Flicker*

The D-STATCOM could mitigate voltage flickering when there was modulation in a variable load. It injects a current modulated at 5 Hz to compensate for voltage fluctuations. Figure 12 demonstrates both the capacitive and inductive voltages where value of was 0.6 p.u the, as demonstrated above in Figure 12. The D-STATCOM is a modern and flexible device that responds rapidly to a grid or control system's needs [33]. For this test, we kept the programmable voltage source constant over the control circuitry and enabled variable load modulation. After this programming, we observed that the D-STATCOM was able to mitigate the voltage flickering. This clearly indicates that the D-STATCOM can make great improvements by mitigating voltage flickering. Scopes could observe the results of the voltage correction under different conditions in our MATLAB/Simulink.

### *6.5 FFT Analysis*

Table 3 presents a comparison of the results of the Fass Fourier Transform (FFT) analysis with/without the D-STATCOM installed in the system in the cases of the variable loads shown in Figures 14 and 15. This simulation was also compared with the real-site THD data that is visible in Figure 16 below from 3rd February 2024 which has been measured from energy analyzer on the grid side.

*Table 3. Comparison of the THDs.*

| | Grid-connected wind PV STATCOM (Mosobi [34]) | Grid-connected wind PV with BESS and Statcom (Frangieh [35]) | Grid-connected wind Statcom (Ashok [36]) | Our system grid-connected with PV and wind |
|---|---|---|---|---|
| Max THD | 1.32%(V), 0.75%(I) | 4.05% | 2.72% | 0.68% |

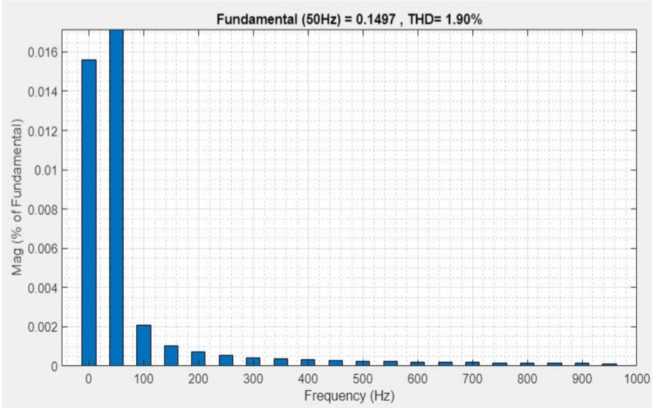



*Figure 14. THD data without the D-STATCOM*

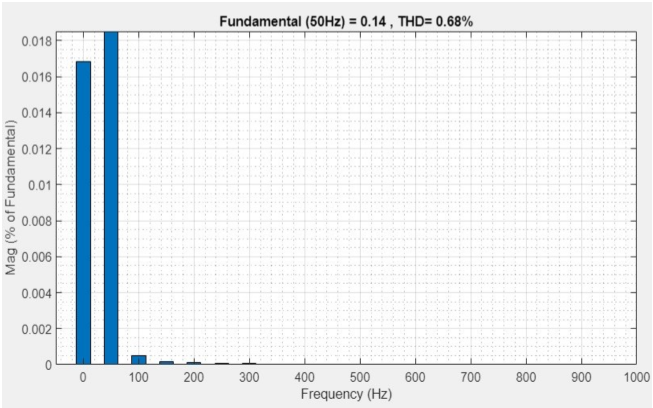
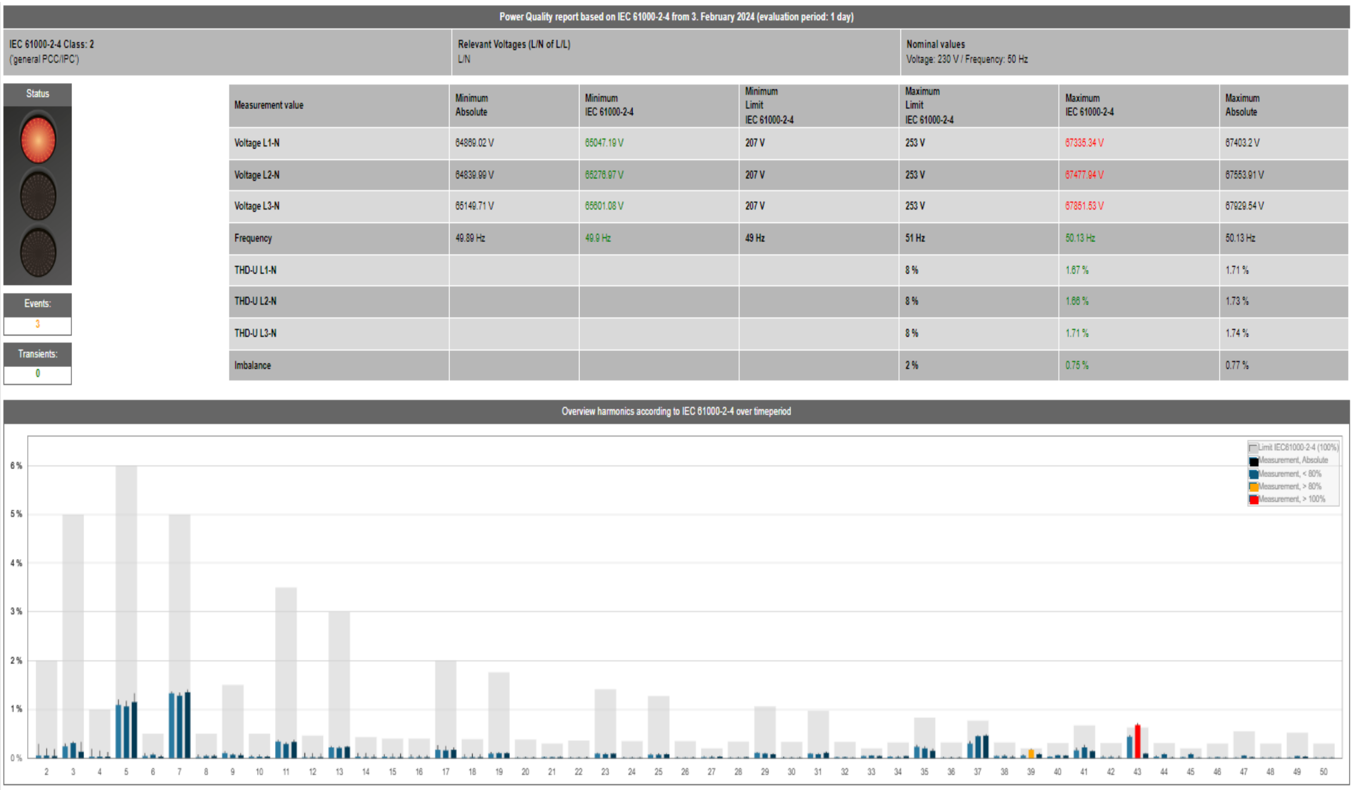



*Figure 15. THD data with the D-STATCOM*



Power Quality report based on IEC 61000-2-4 from 3. February 2024 (evaluation period: 1 day)

IEC 61000-2-4 Class: 2 ('general PCC/IPC') | Relevant Voltages (L/N of L/L) L/N | Nominal values Voltage: 230 V / Frequency: 50 Hz

Status | Events: 3 | Transients: 0

| Measurement value | Minimum Absolute | Minimum IEC 61000-2-4 | Minimum Limit IEC 61000-2-4 | Maximum Limit IEC 61000-2-4 | Maximum IEC 61000-2-4 | Maximum Absolute |
|---|---|---|---|---|---|---|
| Voltage L1-N | 64869.02 V | 65047.19 V | 207 V | 253 V | 67335.34 V | 67403.2 V |
| Voltage L2-N | 64839.99 V | 65276.97 V | 207 V | 253 V | 67477.94 V | 67553.91 V |
| Voltage L3-N | 65149.71 V | 65601.08 V | 207 V | 253 V | 67851.53 V | 67929.54 V |
| Frequency | 49.89 Hz | 49.9 Hz | 49 Hz | 51 Hz | 50.13 Hz | 50.13 Hz |
| THD-U L1-N | | | | 8 % | 1.67 % | 1.71 % |
| THD-U L2-N | | | | 8 % | 1.66 % | 1.73 % |
| THD-U L3-N | | | | 8 % | 1.71 % | 1.74 % |
| Imbalance | | | | 2 % | 0.75 % | 0.77 % |



*Figure 16. Real-site THD data without a D-STATCOM*

Figure 16 shows the measurements from the plant which is a full-day aggregated THD measurement on 3rd February 2024 using the Janitza UMG512 energy analyzer. In the figure 16, the THD is 1.68%, whereas our simulation showed a THD of 1.90%, which is almost the same. Table 4 shows on Simulation and real site measurement results.

*Table 4. Simulation and real-site measurements*

| | | | |
|---|---|---|---|
| 1 | Case | Without DSTATCOM | With DSTATCOM |
| 2 | MATLAB/Simulink | 1.90% | 0.68% |
| 3 | Real-site measurements | 1.68% | - |

## 7. Conclusions

Power quality issues have a large influence in distribution networks. Harmonic distortions, voltage fluctuations and poor power factor creates equipment malfunction, loss of income and operation challenges in the networks. To tackle these concerns D-STATCOM is used in this work which is a customized power device that is reliable and effective for evaluation of THD. The occurrence of harmonics is analyzed with different loads in MATLAB/Simulink. P&O control method is used in hybrid energy system simulation and improvements are made in control systems to increase energy efficiency and reduce THD in the system. The Simulation results show that D-STATCOM significantly reduced THD and regulated voltage as well as compensated reactive power. The simulation showed an improvement from 1.90% to 0.68% in the THD with using D-STATCOM. Further, THD measurement result for the hybrid simulation without the D-STATCOM was 1.90%, whereas the real-site THD measurement was 1.68% for a full day. This is quite an accurate results between the simulation and real site data. In addition, the results of the hybrid system simulation were compared with previous studies for THD and it was well within the expected range at 0.68%. This is a significant improvement over the previously conducted experiment and the model demonstrated to be a promising solution for THD and power quality. Furthermore, the methodology could be extended different scale microgrids as well to improve power quality.

## References

1. International Energy Agency (IEA), “World energy Outlook 2023”. pp. 264-267, 2023.
2. A. M. Colak and O. Kaplan, "A Review on the Efficiency Increment in a Power System Using Smart Grid Technologies," 2021 9th International Conference on Smart Grid (icSmartGrid), Setubal, Portugal, pp. 192-196, 2021.
3. M. Abdou-Tankari, J. Arkhangelski, M. Garba, G. Lefebvre, A. Drame and D. Abdourahimou, "Power Quality Challenges and Urban Microgrid Based Grid Resiliency: Case of Niamey City Electrical Grid," 2023 12th International Conference on Renewable Energy Research and Applications (ICRERA), Oshawa, ON, Canada, pp. 79-86, 2023.
4. A. AlKassem, M. Al Ahmadi and A. Draou, "Modeling and Simulation Analysis of a Hybrid PV-Wind Renewable Energy Sources for a Micro-Grid Application," 2021 9th International Conference on Smart Grid (icSmartGrid), Setubal, Portugal, pp. 103-106, 2021.
5. P. Namdev and R. Singh, "Advances in Power Quality Enhancement: A Comprehensive Review of Custom Power Devices and Mitigation Strategies," 2023 3rd international Conference on Energy, Power and Electrical Engineering (EPEE), Wuhan, China, pp. 761-765, 2023.
6. V. B. Pamshetti, S. Singh and S. P. Singh, "Combined Impact of Network Reconfiguration and Volt-VAR Control Devices on Energy Savings in the Presence of Distributed Generation," in IEEE Systems Journal, vol. 14, no. 1, pp. 995-1006, March 2020.
7. M. R. Bhimraj and D. Susitra, "Mitigation of Power Quality Issues in Power System using Static Synchronous Compensator," 2024 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS), Bhopal, India, pp. 1-6, 2024.
8. C. S. Kumar and G. Mallesham, "A New Dual-Adaptive Inertia Strategy Controller Based UPQC to Improve the Power Quality of Hybrid Renewable Energy System Connected to Grid," 2023 9th IEEE India International

Conference on Power Electronics (IICPE), SONIPAT, India, pp. 1-6, 2023.

9. B. M. Bellah, B. Tahar and B. Adel, “Adaptive Hybrid MPPT Using Artificial Intelligence for an Autonomous PV System”, International Journal of Smart Grid (ijSmartGrid), Vol.8, No.1, 2024
10. J. Meng, S. Dai, Q. Li and S. Wang, "Control Strategy for Power Quality Governance Based on Remaining Capacity of Grid Connected Photovoltaic Inverters," 2023 13th International Conference on Power and Energy Systems (ICPES), Chengdu, China, pp. 419-423, 2023.
11. Q. Zhang, Z. Zhai, M. Mao, S.Wang, S. Sun, D. Mei and Q. Hu, “Control and Intelligent Optimization of a Photovoltaic (PV) Inverter System: A Review ”. Energies, 17, 1571, 2023.
12. G. S. Rao, B. S. Goud and C. R. Reddy, "Power Quality Improvement using ASO Technique," 2021 9th International Conference on Smart Grid (icSmartGrid), Setubal, Portugal, pp. 238-242, 2021.
13. F. Blaabjerg and K. Ma, "Wind Energy Systems," in Proceedings of the IEEE, vol. 105, no. 11, pp. 2116-2131, Nov. 2017.
14. B. K. Saw and A. K. Bohre, "Hybrid Renewable PV-DG with DSTATCOM Planning in Reconfigured Distribution Network for Techno-Economic Analysis," 2023 IEEE 3rd International Conference on Sustainable Energy and Future Electric Transportation (SEFET), Bhubaneswar, India, 2023.
15. A. Ghosh and G. Ledwich, "Load Compensating DSTATCOM in Weak AC Systems," IEEE Transactions on Power Delivery, vol. 18, p. 1302–1309, 2003.
16. K. N. Choma and M. Etezadi-Amoli, “The Application of a DSTATCOM to an Industrial Facility”, IEEE Power Engineering Society Winter Meeting, Volume 2, pp. 725-728, 2002.
17. A. de Almeida, L. Moreira and J. Delgado, “Power Quality Problems and New Solutions”, International Conference on Renewable Energies and Power Quality, 2003.
18. T. Shoji, N. Sasaki, M. Hasegawa, T. Karasawa, S. Akagi and R. Yamamoto, "Evaluation of Countermeasures against Voltage Flicker in Photovoltaic Inverters," 2023 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE), Grenoble, France, 2023.
19. O.P. Mahela, and S.R. Ola. “Modeling and Control of Grid Connected Photovoltaic System: A Review”. International Journal of Electrical and Electronics Engineering Research (IJEEER). 3. 123-134. 2013
20. G.D Rai, “Non-Conventional Energy Sources,” fifth edition., April, Khanna Publishers, 2011.
21. Z. Reguieg, I. Bouyakoub, F. Mehedi and F. Bouhadji, “Optimizing Power Quality: Simulation of UPQC Integrated PV with Comprehensive Reliability and Performance Analysis”, International Journal of Smart Grid (ijSmartGrid), Vol.8, No.1, 2024
22. S. Suyanto, L. Mohammad, I. C. Setiadi and R. Roekmono, "Analysis and Evaluation Performance of MPPT Algorithms: Perturb & Observe (P&O), Firefly, and Flower Pollination (FPA) in Smart Microgrid Solar Panel Systems," 2019 International Conference on Technologies and Policies in Electric Power & Energy, Yogyakarta, pp. 1-6, 2019.
23. M. Hankins, “Earth Scan Expert Series”, Stand-alone Solar Electric System, 2012.
24. I. Khan, R. Hussain, M. A. Sikander, S. Arif and M. Umair, "Solar-Wind Hybrid Energy Generation System Maximum Power Point Tracking using Perturb and Observe (P&O) Algorithm," 2021 International Conference on Computer & Information Sciences (ICCOINS), Kuching, Malaysia, pp. 109-113, 2021.
25. M. W. Rahman, C. Bathina, V. Karthikeyan and R. Prasanth, "Comparative analysis of developed incremental conductance (IC) and perturb & observe (P&O) MPPT algorithm for photovoltaic applications," 2016 10th International Conference on Intelligent Systems and Control (ISCO), Coimbatore, India, pp. 1-6, 2016.
26. Y. Zhou, S. Yan, Y. Luo, H. Zhang, B. Wang and T. Wang, "Power Coordinated Control of PMSG-WTG Based on Power Flow Calculation in Distribution Network," 2023 5th International Conference on Power and Energy Technology (ICPET), Tianjin, China, pp. 606-611, 2023.
27. A. Mishra, A. S. Mir and N. P. Padhy, "Improving System Inertial Support from PMSG based Wind Turbines with Adaptive Inertial and Damping Control," 2023 IEEE International Conference on Power Electronics, Smart Grid,

and Renewable Energy (PESGRE), Trivandrum, India, pp. 1-5, 2023.

28. C. Lertnuwat, U. Leeton and A. Oonsivilai, "Optimization for Wind Turbine with Permanent Magnet Synchronous Generator (PMSG) Using Optimal Control Design," 2018 International Electrical Engineering Congress (IEECON), Krabi, Thailand, pp. 1-4, 2018.
29. K. N. Siverajan, E.A. Jasmin and B. Jayanand, "Power Quality problems And Mitigation Using D-STATCOM With H-bridge topology In Solar PV Integrated Distribution System," 2020 International Conference on Power, Instrumentation, Control and Computing, Thrissur, India, pp. 1-6, 2020.
30. M. G. Molina and P. E. Mercado, “Control Design and Simulation of DSTATCOM with Energy Storage for Power Quality Improvements”, IEEE/PES Conference on Transmission and Distribution, Latin America, Venezuela, pp. 1-7, 2006.
31. K. E. Vargil, and B.R. Koti, “Integrated Differential Power Processing Converters for PV Systems”, 2023.
32. D. G. Flinn, C. Gilker, and S. R. Mendis, “Methods for Identifying Potential Power Quality Problem”. Conference on Rural Electric Power. 1991.
33. B. Behera, K. C. Rout and R. N. Dash, "Voltage Flicker Mitigation Using VSC-Based STATCOM to Improve Power Quality," 1st International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, pp. 1-5, 2021.
34. R. W. Mosabi, T. Chichi and S. Gao, "Power quality analysis of hybrid renewable energy system," Cogent Engineering , 2015.
35. W. Frangieh and M. Najjar, "Active control for power quality improvement in hybrid power systems," International Conference on Technological Advances in Electrical, Electronics and Computer Engineering, pp. 218-23, 2015.
36. L. Kumar and V. Indragandhi, "Power quality improvement of grid-connected wind energy system using facts device," Int J Ambient Energy , 2018.