

Optimized AI-Enabled STATCOM Control for Power Quality Enhancement in Hybrid Solar–Wind Grid-Connected Systems

Anjana Rajpoot¹, Mrs. Akansha Mercy Steele² and Mr. Santosh Verma³

¹Research Scholar, Department of Electrical Engineering, University Institute of Technology Rajiv Gandhi Proudhyogiki Vishwavidyalaya Bhopal (M.P.) India

²Assistant Professor, Department of Electrical Engineering, University Institute of Technology Rajiv Gandhi Proudhyogiki Vishwavidyalaya Bhopal (M.P.) India

³Assistant Professor, Department of Electrical Engineering, University Institute of Technology Rajiv Gandhi Proudhyogiki Vishwavidyalaya Bhopal (M.P.) India

¹anjanarajpoot19@gmail.com, ²anjanarajpoot19@gmail.com

* Corresponding Author: Anjana Rajpoot

Abstract: *Low-voltage (LV) distribution networks are undergoing rapid transformation due to the large-scale deployment of rooftop solar photovoltaic (PV) systems and the growing trend of residential electrification [1]. Networks that were originally designed for unidirectional power flow, predictable load profiles, and balanced phase operation are now experiencing bidirectional and highly variable power flows arising from distributed PV generation, electric vehicles, and smart appliances [3,4]. These developments have introduced significant operational challenges, including voltage rise, phase imbalance, neutral overloading, and overall deterioration of power quality, particularly in feeders with clustered single-phase PV installations. During periods of high solar irradiance, excess PV generation can exceed local demand, leading to reverse power flow and localized overvoltage conditions, while intermittent cloud cover causes rapid voltage fluctuations that conventional regulation devices cannot effectively manage [4,5]. Traditional voltage control equipment such as tap changers and capacitor banks are inherently slow, rigid, and rule-based, making them unsuitable for responding to fast and stochastic PV dynamics [2]. Consequently, utilities require advanced control strategies capable of real-time voltage regulation, dynamic current balancing, and coordinated power flow management to maintain system reliability and power quality under high renewable penetration. Power-electronic-based controllers offer fast, flexible, and multi-functional control by enabling reactive power compensation, phase current harmonization, and voltage stabilization, thereby increasing PV hosting capacity, reducing network stress, and deferring costly infrastructure upgrades [6,7]. These evolving challenges strongly motivate the adoption of intelligent, advanced voltage and power flow control solutions for modern LV distribution networks.*

Keywords: *Solar–Wind Hybrid System, STATCOM, Differential Evolution, Power Quality, Harmonic Reduction, Reactive Power Compensation, AI-Based Control.*

I. Introduction

The rapid integration of renewable energy sources like solar Photovoltaic (PV) and wind technology has revolutionized distribution systems of the present day by placing distributed energy resources (DERs) as a prominent solution towards sustainable energy aspirations, diminution of carbon emissions and continued energy diversification. However, due to their intermittent and variable nature, DERs pose great challenges on voltage regulation, power quality, and overall system stability within the LV and MV distribution levels [1,2]. At very high penetration, solar PV and wind generators may escalate the problem of the overvoltage, voltage fluctuation, harmonic content, and unbalance in power flows making it highly inadequate for the operation of grid feeders or end-users [3,4]. Thus, advanced control and power electronic devices should add value in sustaining and enhancing the quality of power delivered to end-users.

Within this multifaceted ocean of power electronic solutions, the importance of the static synchronous compensator (STATCOM, henceforth) has especially emerged for dynamic reactive power compensation, voltage regulation, and power quality issues in power system applications with high renewable energy penetration [5,6]. STATCOM allows rapid correction of voltage support to dips and swells, so the grid voltage can be stabilized, and the system reliability improved by STATCOM. Moreover, coordinated operations with the other control systems like OLTC and energy storage devices could provide further enhancement to voltage regulation and unbalance mitigation in the LV distribution feeders [2,7,8]

Collective strategies are critical in networks with a large percentage of PV and wind penetration, as the traditional voltage-regulation strategies have been greatly ineffectual. AI tools and cutting-edge optimization techniques are together looking to enhance STATCOM operational performance and power quality management. AI-based controllers constitute reinforcement learning, deep learning, and predictive algorithms, to smartly alter STATCOM control signals in the face of various network states, thereby leading to minimizing voltage deviation and enhancing reactive power support [9,10]. For example, model predictive control with neural networks and deep reinforcement learning strongly succeeded in managing voltage sags within LV networks with higher levels of penetration by PVs, thus demonstrating that system stability and adaptability are enhanced even in the presence of uncertain operating conditions [10,11]. Likewise, hybrid control strategies that couple AI and conventional control methodologies have shown good potential, in particular, for active and reactive power balance, efficiency improvement owing to loss avoidance, and grid reliability maintenance [12,13].

Native based control strategies like current- and power injection-based methods eliminate these issues, thereby improving electrical quality without the need for drastic infrastructure upgrades [5,14,15]. Moreover, other researchers have developed graph-based reinforcement learning and consensus-based coordination for optimal DG Volt/Var control, optimizing stability and efficiency in hybrid AC/DC distribution systems [16,17]. This approach is particularly applicable to grid-connected solar-wind energy systems, where different intermittent power sources occupy spaces in complicated networks.

Long-term planning of renewable energy factors should also cater for the minimization of curtailment while maintaining acceptable voltage profiles. Moment difference analysis, space-time coordination, and the predictive control strategies have been identified as suitable potential areas to reduce the curtailment of wind energy and PV partially in the network and to meet the adequate security standards, along with voltage stabilization [18,19,20]. These works confirm the obvious need for intelligent, adaptable, and cooperative control schemes to improve overall performance and use of renewable energy in grid-connected hybrid systems. The slowing of carbon in the broad use of solar pv and wind into operational power systems design sees AI-controlled STATCOM being optimistically seen as assisting in the mitigation of bus voltage ramifications, enhancing power quality, and maintaining system stability. In an intelligent and anticipatory manner, STATCOM may level the real-time compensation of reactive power, maintain voltage balances, and alleviate disturbances usually induced by the integration of intermittent renewable forces. Thus, because AI-empowered STATCOM control solutions contribute to ensuring reliable, resilient, and high-quality electric power services in photovoltaic–wind–energy hybrid integrated system environments.

II. Related Work

The rapid integration of photovoltaic (PV) systems in low-voltage (LV) distribution networks has introduced significant challenges, particularly in voltage quality as well as stability. Chathurangi [1] determined the PV hosting capacities of LV networks and proposed different measures for improving voltage rise management, and advanced control techniques are highly recommended for handling high PV penetrations. Using coordinated operation between on-load tap changer (OLTC) with energy storage controllers, it shows a robust framework for voltage management that is more applicable for large grid systems. [2] The high penetration of rooftop PV installations on radial feeders somewhat causes voltage imbalances, requiring proper application of an adaptive voltage regulation technique for their corresponding networks; [3] transient overvoltage problems can be dealt with in high-PV-penetration networks through V-Iq controls, which adjust the inverter output dynamically, maintaining voltage stability in case of rapid fluctuations in the solar generation. Voltage imbalance is another problem with decentralized current control strategies [5] offering a solution on unbalanced feeds. Linear power flow compensated with voltage control devices [6] puts forward practical solutions for handling unbalance.

Further complicating the picture of voltage profiles are the growing presence of electric vehicles (EVs). Hence, charging operation of EVs distributed in space is instrumental for both reducing voltage rise and imbalance in modern distribution networks [7]. Centralized voltage coordination involving OLTCs or D-STATCOM operated through IoT communication protocols is highly beneficial for maintaining voltage stability [8]. Bipolar configuration in DC microgrid opens another but different road to power sustainability [9].

Powerful control methodologies, such as predictive control based on tube model predictive control, human-in-the-loop deep reinforcement learning, lead to a more stable Volt/Var control in LV networks that is robust to uncertainties and unbalances [10,11]. Hybrid AC/DC network planning [12] and decentralized community energy storage deployment [13] provides more SPD success stories in the improvement of PV penetration for browsing through various voltage violations. Spatial-temporal coordinated Volt/Var control [14], stable consensus-based group coordination of PV and storage systems [15], and conservation voltage reduction [16] have altered landscape efficiently in energy efficiency and system reliability enhancement. On the other side, decentralized power injection [17], evaluations of PV-wind integration [18], graph reinforcement learning strategies [19,20] are strategies for minimal PV curtailment and higher operating network performance. Corresponding technologies, which include UPFC for power quality enhancement [21], robust energy storage control [22], smart transformer-fed networks [23], and flexible transfer converters [24] address practical hindrances powering an integration. Optimum distributed generation coordination [25], intelligent controllers for microgrid disturbances [26], series–parallel soft open point techniques [27], and hybrid PV-BESS controllers [28] emerge with further back-up plans to support voltage and reactive power management common in PV-dominant distribution network systems [29,30].

Table 1 Voltage Regulation and Advanced Control in PV-Rich Distribution Networks

Ref.	Focus Area	Methodology	Key Results	Limitations
[13]	Decentralised control strategy for community energy storage in PV-rich LV networks	Effective utilization of distributed energy storage	Improved voltage profile and PV utilization	Centralized coordination not considered
[14]	Spatial–temporal Volt/Var	Network-wide coordinated control	Reduced voltage violations	Centralized computation burden
[15]	Robust voltage control	Consensus-based coordination	Improved robustness	Slower convergence in large systems
[16]	Conservation Voltage Reduction	Comprehensive review	Identified CVR benefits with PV	Limited quantitative comparison
[17]	Voltage imbalance mitigation	Decentralized power injection	Improved phase voltage balance	No global optimization
[18]	PV & wind impact on LV networks	Field data and simulation	Voltage fluctuation identified	No mitigation techniques proposed

[19]	PV curtailment minimization	Moment difference analysis	Reduced PV curtailment	High computational effort
[20]	Volt/Var control	Knowledge-enhanced graph reinforcement learning	Faster convergence, better voltage	Data-intensive training
[21]	Power quality enhancement	UPFC-based control	Reduced sag, swell, harmonics	Simulation-only study
[22]	Grid-forming ESS control	Topology-aware robust control	Improved voltage resilience	Control complexity
[23]	Smart transformer networks	Transformer and DER coordination	Enhanced voltage flexibility	Cost and protection issues
[24]	Series flexible converter	Reduced-cost converter topology	Fast voltage support	Reliability not assessed
[25]	DG coordination	Optimization-based control	Improved voltage balance	Computational burden
[26]	PQ disturbance mitigation	Intelligent adaptive controller	Improved PQ under dynamic loads	No experimental validation
[27]	Feeder impedance detection	Series-parallel soft open point	Enhanced observability	Additional hardware required
[28]	PV-BESS stability	Coordinated inverter control	Improved transient stability	Tuning complexity
[29]	Reactive power compensation	Review of matrix converters	Fast and flexible VAR support	Limited practical adoption
[30]	UPFC industrial application	UPFC-based arc stability control	Improved power stability	Not focused on LV PV feeders

III. Research Objectives

- To design a simple but highly viable compensator for a grid connected solar wind hybrid system that is capable of feeding less distorted voltage to the load along with enhancement in power output.
- Designing of a compensating device and compare it with the basic STATCOM with voltage regulation control for active power output enhancement in the system
- The compensating device control has to be designed with an AI based optimization algorithm where in this case differential evolutionary algorithm is selected for analysis algorithm to obtain a smooth voltage and current waveform.
- Reduction in the distortion level of the voltage output at the grid system is to be done by using the proposed optimizer.

IV. Research Methodology

Different surveys by different researchers have been collated systematically in Chapter 2 for an all-embracing understanding of the basic layout of solar-wind hybrids. The compiled literature gives way to the operational properties, control strategies, and grid integration challenges surrounding off-grid hybrid renewable energy systems. Again, a new segment in the chapter is established for a thorough exposition on the utility, merits, and classifications of artificial intelligence-based schemes for control, optimization, and power quality enhancement in hybrid systems. From the research presented, it can be concluded that more advanced and intelligent approaches will contribute significantly to enhancing the all-around performance, efficiency, reliability, and stability of solar-wind hybrid systems.

In mega solar-wind hybrid farms, the wind and the photovoltaic generation units are combined separately from the grid by a booster station for proper voltage level control. The hybrid system consists of a collective technology of wind energy conversion system and photo-voltaic, and these two energies work in tandem. Enhanced transient voltage stability balances the coordination with varying load and generation conditions, reacting-power control devices such as STATCOMs can be attached to PCs at the point of common coupling. The proposed compensator is meant to enhance performance under the system, minimising voltage fluctuations, lessening the total harmonic distortion (THD) in both voltage and current, and increasing active-power output. This connected system is desired to assimilate power quality improvement, greater operational reliability, and grid code compliance for a mega hybrid renewable energy system.

A. STATCOM compensator operation

In the cascaded multicell inverter structures, the two-arm converters are arranged in series for all three phase legs, and the voltage of the phase is achieved by adding the voltages of the converters of the same phase. Such a structure, though so simple, was not possible as in the case of diode and capacitor-clamped solar inverter configuration.

The STATCOM can be included with the H-bridge cascaded, which constitutes a series of H-bridge, with its connection both in a triangle and star mode. The conventional cascade H bridge multilevel converter needs H bridge cells in huge abundance to keep low current distortions whenever proper stepped waveform modulation for the same is chosen.

The control strategy proposed in this paper regulates a generic single-phase Cascaded H-Bridge multilevel converted, composed by N H-Bridges connected in series as shown in Fig. 4.9 where N=2. The connection of the STATCOM device to the power grid is made using a coupling inductance. Assuming that the grid voltage and output current expressions are:

The active power reference is driven largely by the DC Bus voltage control loops. So as to make it brief enough to view the mechanism of action of the active power controllers, we shall provide here an example by intentionally adding random error to the input signals to hint as to their functions. Privacy compliances restrict any microwording to base the idea. If the DC-Bus voltage of one (or more) of the series-connected H-Bridges show(ing signs of its voltages) goes lower than the reference

voltage, then it means that this H-Bridge should come into active power service and charge the capacitor to elevate the voltage level. On the contrary, if the DC-Bus voltage goes beyond the voltage reference, the power should be drawn out of the Bus capacitor to drop the voltage. As such, the output of each DC-Bus voltage regulator is an active power reference for a particular Bridge.

Differential Evolution has also been used in seeing the scheme functioning in optimal mode. Load power becomes its objective function in terms of the balancing of all sorts of quality with the load changes in "DE" approach. Figure below shows the flowchart of this algorithm and it has been implemented in MATLAB as governing equations and codes for producing pulses for the phase converter and boosting.

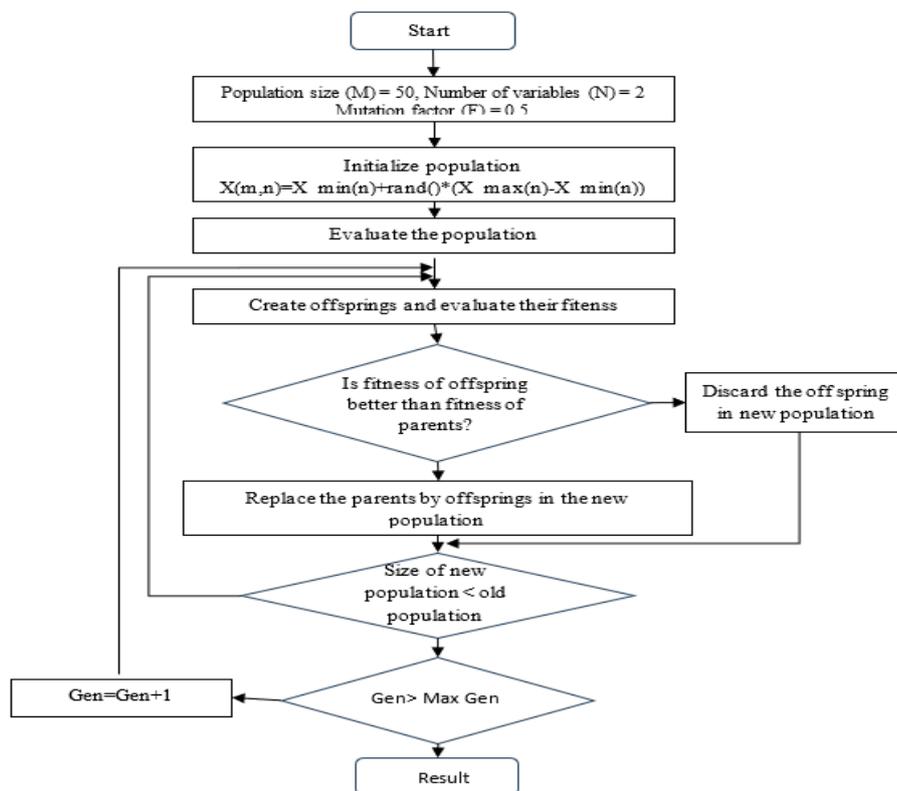


Figure 1: Flow chart of proposed Differential Evolution Algorithm for converters

V. Result and Discussion

This section presents research findings and their discussions. The emphasis here is on the effectiveness of the proposed control strategy on improving power quality and system stability. The intention behind this study was not depicted in a narrow view of the "just see this control system's performance" but to embrace this much of a dynamic solar wind hybrid system whose multiple operations are all interacting with their respective influence over the network behavior. The conceptual framework adopted considered both active and reactive power dynamics in a manner that simulates better replication of performance in power system operations and gives an insight into how both transient and steady-state response can be optimized.

A. Case 1: Hybrid renewable energy model driving heavy loads with STATCOM controlled by basic voltage regulation control.

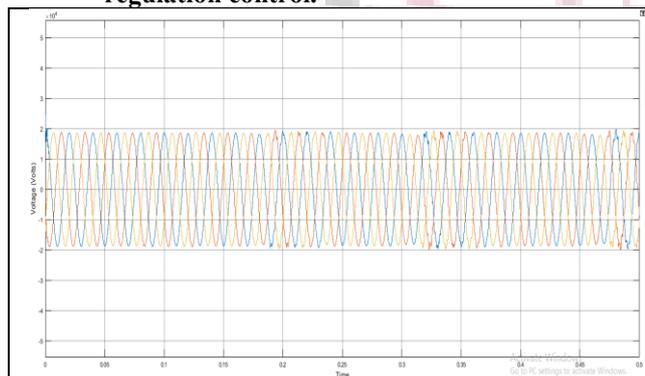


Figure 2: AC Voltage available at the loading point in system having voltage regulation control for compensation

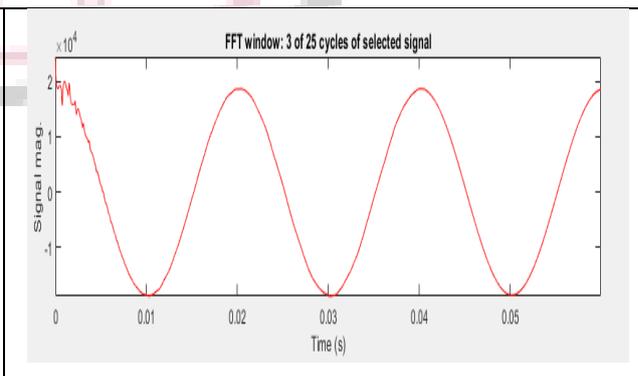


Figure 3: FFT analysis of Voltage in system having voltage regulation control for compensation

Figure 2 shows the AC voltage available at the loading point in the system using a voltage regulation control for compensation. The waveform demonstrates stable voltage with minimal fluctuations, indicating effective voltage regulation and improved power quality at the load. Figure 3 presents the FFT analysis of the voltage in the system employing a voltage regulation control for compensation. The spectrum shows suppressed harmonic components, demonstrating the effectiveness of the control in improving voltage quality and mitigating distortions.

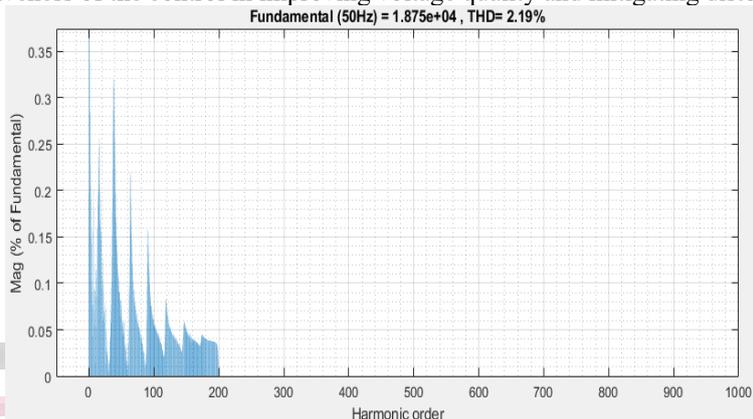


Figure 4 THD % of Voltage in system having voltage regulation control for compensation

Figure 4 illustrates the total harmonic distortion (THD%) of the voltage in the system using a voltage regulation control for compensation. The results show a reduction in voltage harmonics, indicating enhanced voltage quality and effective compensation performance.

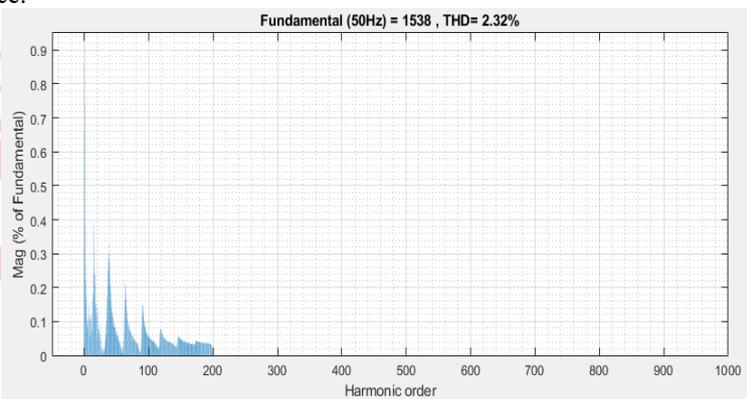


Figure 5: THD% of Current driven at the loading point in system having voltage regulation control for compensation

Figure 5 illustrates the total harmonic distortion (THD%) of the current drawn at the loading point in the system employing a voltage regulation control for compensation. The results indicate a reduction in current harmonics, reflecting improved power quality and effective control action.

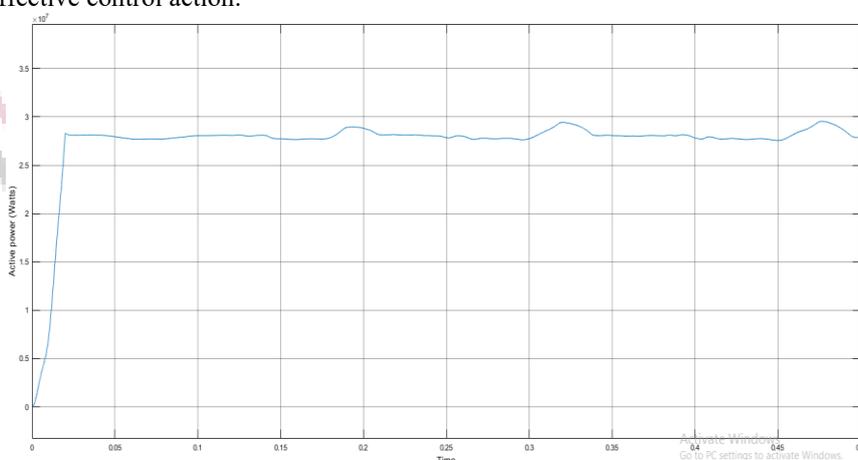


Figure 6 : Active Power at the loading point in system having voltage regulation control for compensation

Figure 6 shows the active power measured at the loading point in the system using a voltage regulation control for compensation. The results indicate stable active power delivery with minimal fluctuations, demonstrating the effectiveness of the voltage regulation control in maintaining reliable power flow.

B. Case 2: Hybrid renewable energy model driving heavy loads with compensation controlled by PQ_PI controller

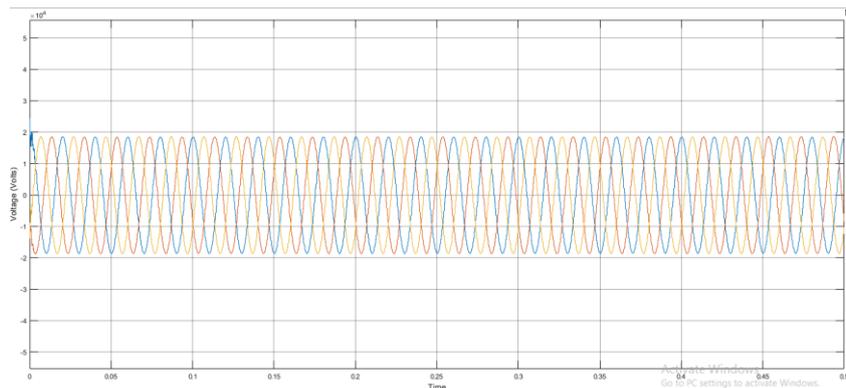


Figure 7: AC voltage available at the loading point in system having PQ_PI controller for compensation

Figure 7 shows the AC voltage available at the loading point in the system using a PQ-PI controller for compensation. The waveform demonstrates improved voltage stability and reduced fluctuations, indicating effective compensation and enhanced power quality at the load.

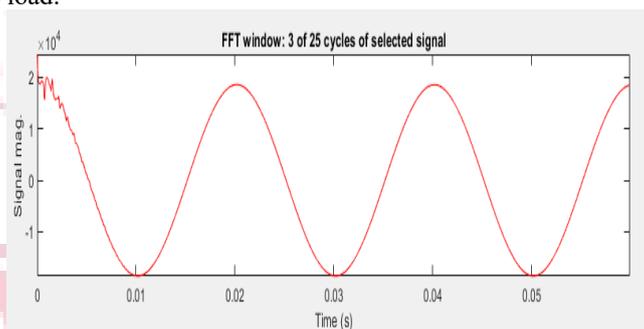


Figure 8: FFT of the AC voltage at the loading point in system having PQ_PI controller for compensation

Figure 8 presents the FFT analysis of the AC voltage at the loading point in the system employing a PQ-PI controller for compensation. The spectrum shows suppressed voltage harmonics, demonstrating the controller's effectiveness in improving voltage quality and mitigating distortions.

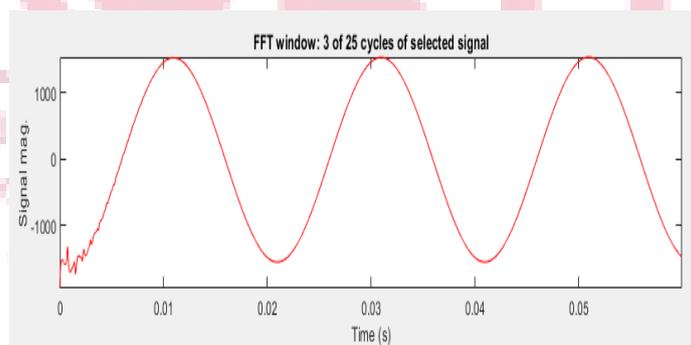


Figure 9: FFT analysis Current driven at the loading point in system having PQ_PI controller for compensation

The result in Figure 9 demonstrates the FFT analysis of the current drawn at the concentrated loading point for the PQ-PI controller for compensation. But controller active compensation seems to enhance improvement in the current's quality and lessening of profits with current distortions, as indicated by a weakened harmonic content on the spectrum.

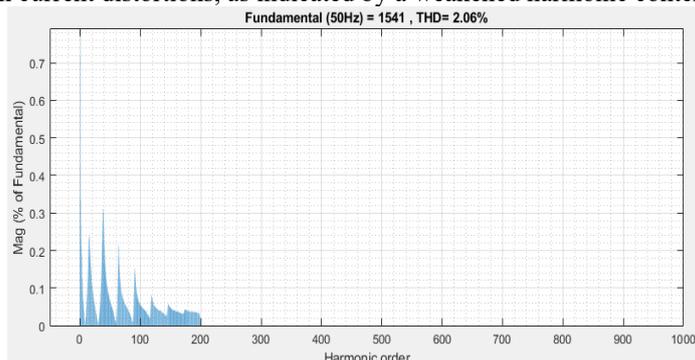


Figure 10: THD% in the Current driven at the loading point in system having PQ_PI controller for compensation

Results shown in Figure 10 infer that a PQ-PI controller may decrease, to a great extent, the current harmonics at the load point, thereby enhancing power quality at the load.

C. Case 3: Hybrid renewable energy model driving heavy loads with compensation controlled by DE optimization controller

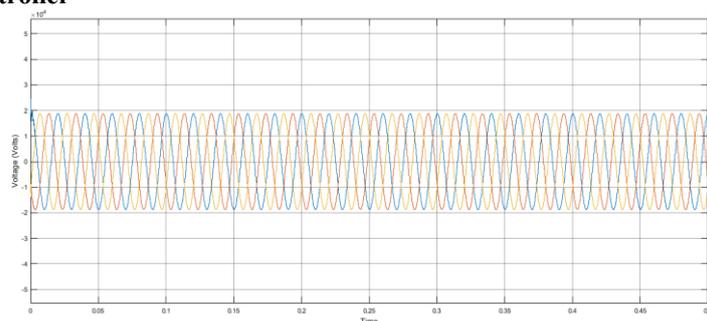


Figure 11: AC voltage available at the loading point in system having DE optimization controller for compensation

Figure 11 presents the AC voltage at the load point in the system using DE-based optimization controller in power loss consideration. The waveforms show greatly improved voltage stability coupled with the much-reduced fluctuations, thus demonstrating effective compensation and enhancement of power quality.

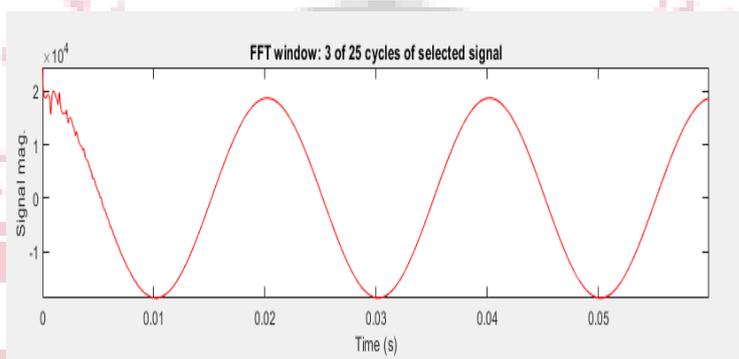


Figure 12: FFT window of the voltage in system having DE optimization controller for compensation

In Figure 12 presents an FFT Window of the system voltage with Differential Evolution (DE)-based control for its compensation purpose. It is confirmed that the harmonic components are being suppressed, indicating that the voltage is truly regulated and good power quality is expected.

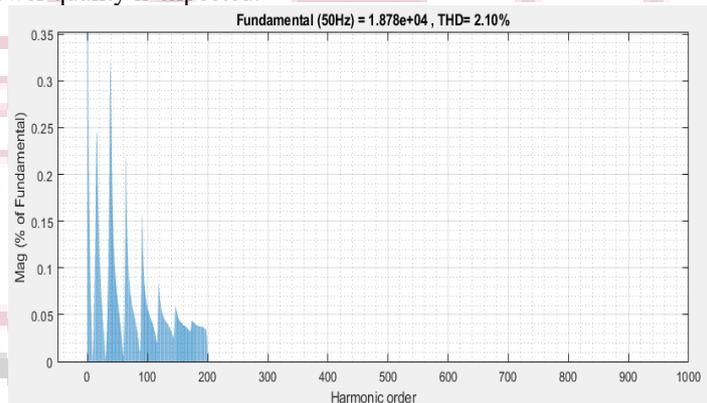


Figure 13: THD% in the voltage in system having DE optimization controller for compensation

The average voltage total harmonic distortion (THD%) for the facility with a compensating differential evolution-based optimizer control is shown in Figure 13. A lower THD value is indicative of efficient voltage harmonic containment and good voltage quality.

D. Validation

This discussion shall focus on comparative results achieved by the compensators. It may be inferred that the outcomes for the compensator implemented with a differential evolutionary algorithm are more likely to surpass any traditional controller employed for STATCOM.

Table 2: Comparison of System Performance for Different Compensation Controllers

Parameters/system	System having voltage regulation control for compensation	System having PQ_PI controller for compensation	DE optimization controller for compensation
Active power output	27.88 MW	27.89 MW	28.1 MW
Line Voltage	20 x 10 ⁴ V	20 x 10 ⁴ V	20 x 10 ⁴ V
THD% in voltage	2.19 %	2.17 %	2.10 %
THD % in current	2.32 %	2.06 %	2.02 %

Reactive Power output	6.2 MVar	6.01 MVar	5.8 MVar
Power factor in the system	0.90	0.90	0.91

The above results illustrate the relative estimates of all parameters. Active power output available has been improved from approximately 27,88MW at the load distribution bus in the system with STATCOM to 28.1 MW in the system built with DE optimisation controller for compensation.

VI. CONCLUSION

The study demonstrates that large-scale wind/solar hybrid systems are highly reliable and efficient compared to standalone wind or solar generation. Simulation results confirmed that the proposed control compensator significantly improves voltage and current waveforms, reducing total harmonic distortion (THD) and enhancing active power delivery. The changes caused by controller redesign and optimization ignored effects on waveforms of voltage and current due to voltage-regulated power systems, changes rendering thereby systems more effective. Upon employment of a different voltage-regulated control system, saving power for cotton crop fields would lie, largely, with a decrease in THDV of 0.02 in both spectral harmonics. In providing rather less absorbing sites, zero-impact torque storage helps push the energy of the others through the centralized vane up with the current loop thereby saving power. The integer capacity under power quality controllers was proved creepy. Indicators with power quality are at the most not satisfactory. The action enabling offline algorithm combining DE merges with PI-PQ effect and favors the compensator by means of current-bearing control over lessening the harmonic content in a large part. Future research can focus on extending this approach to multi-generator configurations and integrating advanced power system devices such as STATCOM, SMES, BESS, SSSC, IPFC, and TCSC to further improve voltage stability, power factor, and steady-state system performance.

References

- [1] Chathurangi, W. LDM. Evaluation and Enhancement of Solar PV Hosting Capacity for Management of Voltage Rise in LV Networks. Diss. University of Wollongong, 2022.
- [2] Khan, Hannan Ahmad, Mohd Zuhair, and Mohd Rihan. "Voltage fluctuation mitigation with coordinated OLTC and energy storage control in high PV penetrating distribution network." *Electric Power Systems Research* 208 (2022): 107924.
- [3] Lucas, J. R., et al. "Voltage Regulation of Distribution Feeders During High-photo Voltaic Penetration Due to Roof-top Solar." (2023).
- [4] Amanipoor, Amin, et al. "V-Iq based control scheme for mitigation of transient overvoltage in distribution feeders with high PV penetration." *IEEE Transactions on Sustainable Energy* 14.1 (2022): 283-296.
- [5] Nour, Ahmed MM, et al. "Voltage imbalance mitigation in an active distribution network using decentralized current control." *Protection and Control of Modern Power Systems* 8.2 (2023): 1-17.
- [6] Di Fazio, Anna Rita, et al. "Linear power flow method for radial distribution systems including voltage control devices." *IEEE Transactions on Industry Applications* 60.3 (2024): 4749-4761.
- [7] Then, Joshua, Ashish P. Agalgaonkar, and Kashem M. Muttaqi. "Coordinated charging of spatially distributed electric vehicles for mitigating voltage rise and voltage unbalance in modern distribution networks." *IEEE transactions on industry applications* 59.4 (2023): 5149-5157.
- [8] Hatata, Ahmed Y., et al. "Centralized control method for voltage coordination challenges with OLTC and D-STATCOM in smart distribution networks based IoT communication protocol." *IEEE Access* 11 (2023): 11903-11922.
- [9] Ren, Quan, et al. "Overview of voltage balancing schemes in bipolar DC microgrids." *IEEE Transactions on Power Electronics* (2024).
- [10] Lv, Yongqing, et al. "Voltage regulation of low-voltage distribution network based on tube model predictive control with the robust positively invariant." *International Journal of Electrical Power & Energy Systems* 158 (2024): 109978.
- [11] Sun, Xianzhuo, et al. "Optimal volt/var control for unbalanced distribution networks with human-in-the-loop deep reinforcement learning." *IEEE Transactions on Smart Grid* 15.3 (2023): 2639-2651.
- [12] Zhang, Bo, et al. "Optimal planning of hybrid AC/DC low-voltage distribution networks considering DC conversion of three-phase four-wire low-voltage AC systems." *Journal of Modern Power Systems and Clean Energy* 12.1 (2023): 141-153.
- [13] Reddy, G. Krishna, and Narayana Prasad Padhy. "Decentralised control strategy for effective utilisation of distributed community energy storage in PV-rich LV distribution network." *Electric Power Systems Research* 234 (2024): 110536.
- [14] Su, Xiangjing, et al. "Spatial-temporal coordinated volt/var control for active distribution systems." *IEEE Transactions on Power Systems* 39.6 (2024): 7077-7088.
- [15] Li, Shengqing, Bowen Liu, and Xin Li. "A robust and optimal voltage control strategy for low-voltage grids utilizing group coordination of photovoltaic and energy storage systems via consensus algorithm." *International Journal of Hydrogen Energy* 78 (2024): 1332-1343.
- [16] Alzubi, Ibrahim, et al. "Conservation Voltage Reduction in Distribution Networks: A Comprehensive Review." *IEEE Access* (2025).
- [17] Tsozbe, Saatong Kenfack, et al. "A decentralized power injection-based approach for voltage imbalance mitigation in three-phase distribution networks." *Scientific Reports* 15.1 (2025): 16162.
- [18] Zdiri, Mohamed Ali, et al. "Impact assessment of photovoltaic and wind energy integration on low voltage distribution networks in Tunisia." *Scientific Reports* 15.1 (2025): 10594.
- [19] Wang, Yi, and Junyong Wu. "Minimum PV curtailment for distribution networks based on moment difference analysis theory." *International Journal of Electrical Power & Energy Systems* 167 (2025): 110654.
- [20] Luo, Fengzhang, et al. "Domain knowledge-enhanced graph reinforcement learning method for Volt/Var control in distribution networks." *Applied Energy* 398 (2025): 126409.
- [21] Gunasekar, T., et al. "Enhancement of Power Quality Under Dynamic Load Conditions Using Unified Power Flow Controller." 2025 3rd International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT). IEEE, 2025.
- [22] Zheng, Shuang, et al. "Topology and Robust Power Flow Control Strategy for Grid-Forming Energy Storage Accessing Low-Voltage Distribution Station." *IEEE Access* (2025).
- [23] Wang, Xiaoyun, et al. "Investigation on Topology and Control for Smart Transformer-fed Active Distribution Network." 2025 IEEE 20th Conference on Industrial Electronics and Applications (ICIEA). IEEE, 2025.
- [24] Song, Zhaoqi, et al. "A Series Flexible Transfer Converter with Reduced Cost while Keeping Functions of Instant Power Support and Auto-Synchronization for Microgrid." *IEEE Transactions on Industry Applications* (2025).
- [25] Kaka, Sanaullah, et al. "Optimal DGs coordination strategy for managing unbalanced and islanded distribution networks." *International Journal of Emerging Electric Power Systems* 26.3 (2025): 437-447.

- [26] Nayak, Niranjana, Anshuman Satapathy, and Satish Choudhury. "Investigation of an Intelligent Controller For Power Quality Disturbance in a Renewable Source Based Micro Grid with Electric Vehicle Integration." Available at SSRN 5269625.
- [27] Lu, Mowei, et al. "Differential detection of feeder and mesh impedances through a series-parallel direct-injection soft open point." IEEE Transactions on Power Electronics (2024).
- [28] Alanazi, Mohana, et al. "Designing a new controller in the operation of the hybrid PV-BESS system to improve the transient stability." IEEE Access 11 (2023): 97625-97640.
- [29] Ishaq, Muhammad, et al. "Reactive power compensation applications of matrix converter: a systemic review." Engineering Research Express 6.4 (2024): 042301.
- [30] Cano-Plata, E. A., A. J. Ustariz-Farfán, and C. Arango-Lemoine. "EAF arc stability through the use of UPFCs." IEEE Transactions on Industry Applications 55.6 (2019): 6624-6632.

