Enhancing Power Quality with PDO-FOPID Controller in Unified Power Quality Conditioner for Grid-Connected Hybrid Renewables

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ABSTRACT: Addressing the pressing research problem of power fluctuations and grid harmonics in the integration of renewable energy, our proposed control strategy utilizes the Prairie Dog Optimization Fractional Order Proportional Integral Derivative (PDO-FOPID) controller within a Unified Power Quality Conditioner (UPQC) system. This innovative approach is tailored to mitigate harmonics and meet load requirements in grid-connected hybrid renewables. The UPQC system is instrumental in regulating coupling point voltage, countering voltage and current harmonics to enhance overall power quality. The PDO-FOPID controller dynamically adapts control parameters to system dynamics and load changes, ensuring a stable power supply despite the variability of renewable sources. Simulations in MATLAB/Simulink confirm its superiority over traditional control strategies, such as PI, sliding mode, and fuzzy control, in harmonics mitigation, load fulfilment, and power stability. By effectively addressing these challenges, our proposed solution not only contributes to resolving a critical research problem but also advances the seamless integration of Hybrid Renewable Energy Sources (HRES) into power systems, thereby enhancing overall grid performance and the efficacy of renewable energy integration.

KEYWORDS: Renewable energy sources, PDO, FOPID, UPQC, Power Quality

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I. INTRODUCTION

Distributed generators powered by renewable energy sources are becoming important as a result of technological advancements, concerns about the environment and the massive demand for power on the electrical grid (Nagaraju *et al*., 2022). Numerous optimization strategies have been created to regulate different power electronics and control technologies with more flexibility while incorporating a variety of alternative energy sources, such as solar, wind, and other kinds of batteries etc., which are becoming more important in supplying the enormous power needs (Youssef *et al*., 2023).

Distribution generation is very important since it provides more reliable, best-quality, and productive electricity to the commercial deliveries that need constant management owing to the drawbacks of producing power from traditional sources of energy (Ishaq *et al*., 2022). Due to the rising population and demand, it is now difficult to generate enough electricity from conventional sources alone, as a result, distribution generators typically use alternative energy sources including solar, wind, and batteries. (Li *et al*., 2022).

The proposed study's DG system has a source connected to the DC connection of a grid-connected controlled via an inverter by an approximated search algorithm that is tightly regulated so as to feed actual DG power to the grid (Guha *et al*., 2022). If the load is linked at the common coupling point, which is non-linear, unbalanced, or both, even in situations when the supply voltage is distorted, the recommended solution corrects harmonics and unbalances (Rodríguez-Pajarón *et al*., 2022). In addition to grid-interfacing inverters and actual power injection from renewable energy sources (RES), we also wanted to account for load wattage power, current harmonics, and current imbalance (Azmi *et al*., 2023).

Presented paper would significantly benefit from a more thorough analysis of the limitations and uncertainties associated with the ANFIS application, transparent reporting of experimental setups, and a balanced evaluation of the proposed control strategy against existing methods. These enhancements are crucial for establishing the credibility and generalizability of the proposed approach in the broader context of power quality enhancement in photovoltaic-integrated systems. (Dheeban *et al*., 2021). The paper could greatly improve by offering a more thorough elucidation of how the algorithm specifically addresses power quality challenges. Additionally, a nuanced exploration of parameter selection and a more rigorous evaluation, encompassing detailed quantitative results and statistical analyses, would enhance the overall quality of the paper. These enhancements are essential for establishing the method's reliability and applicability in diverse power system scenarios (Mahaboob *et al*., 2019). While the proposal of a modified hybrid Unified Power Quality Conditioner (UPQC) system based on PV-wind-PEMFCS is innovative, the paper lacks a clear

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explanation of the system's effective operation as a combined Dynamic Voltage Restorer (DVR) and Static Synchronous Compensator (STATCOM) for harmonic compensation. The potential benefits of power quality enhancement from grid-connected renewable sources are promising, but the paper falls short in exploring integration challenges and thoroughly addressing potential limitations of the suggested system (Sarker *et al.*, 2021). While the introduction of a hybrid controller design for a football league optimization-based Unified Power Quality Conditioner (UPQC) with solar and battery integration is intriguing, the paper lacks detailed insights into the specific mechanisms of how this controller effectively addresses voltage sag, swell, and harmonic distortion. The promised benefits for enhancing electricity quality are promising, but the technical feasibility of integrating football league optimization into a UPQC system requires more elaborate explanation (Srilakshmi *et al.*, 2022).

The proposed work's principal contribution is the following:

i. To provide a unique controller-based UPQC to reduce harmonics, sag, and swell in HRES under varied situations.

ii. To create a HERS system with three-phase loads on the distribution side, together with solar, wind, and batteries on the source side.

iii. An UPQC, which controls both current and voltage changes, is connected between the load and source sides to regulate the power flows.

iv. A FOPID controller that analyses PCC power variation to provide command signals has been created to enhance the mitigation performance of UPQC.

v. The FOPID controller must solve the optimal problem in order to create the proper command pulse. Here, the FOPID controller problem is solved via prairie dog optimization (PDO).

In MATLAB/Simulink, the suggested framework is created and analyzed. The other sections of the study are organized as follows: section 2, Methodology; section 3, PDO; section 4, Results and Discussion; and section 5, Conclusion.

II. METHODOLOGY

A. Proposed HRE System with Prairie Dog Optimization

Structure of integrated UPQC (Lei *et al.*,2022) using solar PV, wind, and BESS is shown in Figure 1, with external assistance provided by BESS with DC/DC BBC, solar PV system and wind system with DC/DC BC (Addagatla *et al.*,2023) coupled to DC-link. For making the most of FOPID that has been tailored to perfection, this article suggests PDO. The source phase voltages are VS_a, VS_b, and VS_c, and the grid voltages are Va, Vb, and Vc. Source-side resistance and inductances are Rs and Ls.

The series and shunt converters that make up UPQC are linked together by a DC-Link (Han *et al.,* 2022). The Series Active Power Filter (SAPF) removes the distortions and imbalances caused by supply voltage by infusing the appropriate compensating voltage Vse through an isolating transformer. It is made up of a series capacitor Cse, a series inductor Lse, and a series resistor Rse.

The Shunt Active Power Filter (SHAPF) is made up of three components: a shunt-resistance Rsh, a shunt-interfacing inductor Lsh, and a shunt-capacitance Csh. By injecting an appropriate compensating shunt current, it lowers the harmonics in the current waveform and maintains the DC-link capacitor voltage (Vdc) steady during load and irradiation fluctuations.

The Battery Energy Storage System (BESS) is designed to store energy and provide supplies in the event of system breakdowns. Photovoltaic (PV) and wind power are harnessed using the perturb and observe (P&O) Maximum Power Point Tracking (MPPT) method (Hafeez *et al.*, 2022). A reference DC link voltage is generated from the PDO. During the absence of solar energy, the reference DC link voltage is set to its default setting. Consideration is given to the power quality problems with the HRES, which are mostly caused by grid-side faults, non-linear loads, and unexpected loads (Rekha *et al.*, 2020). The suggested system is built with UPQC, which uses control methods with the aid of series and shunt controllers to make up for the faults and ensure stable performance. By giving the optimal gain settings to the FOPID controller, which filters and injects the necessary power, power compensation under sag conditions may be accomplished. PDO, which is intended to pick the necessary values to run the control procedure during PQ circumstances, is used to operate FOPID controllers (Ezugwu *et al.*, 2022).

B. UPQC's control structure: series and shunt active power filter

1) Control technique for a series active power filter

The reference voltage is examined with the assistance of a PLL. Eqn. (1)'s (Goud *et al.*, 2020). Clarke transformation is used to translate the three-phase voltages from all of the calculations into d-q axes, and Figure 2 shows a series active power filter (Fei *et al.,* 2022).

$$\begin{bmatrix} V^0 \\ V^d \\ V^q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \sin(\boldsymbol{\alpha}t) & \sin(\boldsymbol{\alpha}t - \frac{2\Pi}{3}) & \sin(\boldsymbol{\alpha}t + \frac{2\Pi}{3}) \\ \cos(\boldsymbol{\alpha}t) & \cos(\boldsymbol{\alpha}t - \frac{2\Pi}{3}) & \cos(\boldsymbol{\alpha}t + \frac{2\Pi}{3}) \end{bmatrix} \begin{bmatrix} V^a \\ V^b \\ V^c \end{bmatrix} \quad (1)$$

V^d stands for direct axis voltage, V^q for quadrature axis voltage, and V^a, V^b, and V^c for 3-ø voltages. A low-pass filter can be used to smooth the D-axis voltage, which is mathematically represented by Eqn. (2) (Goud *et al.*, 2020).

$$Vd(dc) = Vd - Vd(ac) \quad (2)$$

$V^{d\,(ac)}$ is the component voltage for AC. The component voltage for DC is $V^{d\,(dc).}$ The voltage is then divided into 3 stages:

$$\begin{bmatrix} V^{Ra} \\ V^{Rb} \\ V^{Rc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\boldsymbol{\alpha}t) & \frac{1}{2} & 1 \\ \sin(\boldsymbol{\alpha}t) & \sin(\boldsymbol{\alpha}t - \frac{2\Pi}{3}) & 1 \\ \cos(\boldsymbol{\alpha}t) & \cos(\boldsymbol{\alpha}t - \frac{2\Pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} V^{d(dc)} \\ V^q \\ V^0 \end{bmatrix} \quad (3)$$

The 3-ø reference voltages are designated as V^{Ra}, V^{Rb}, and V^{Rc} Eqn. (3) (Goud *et al.*,2020).

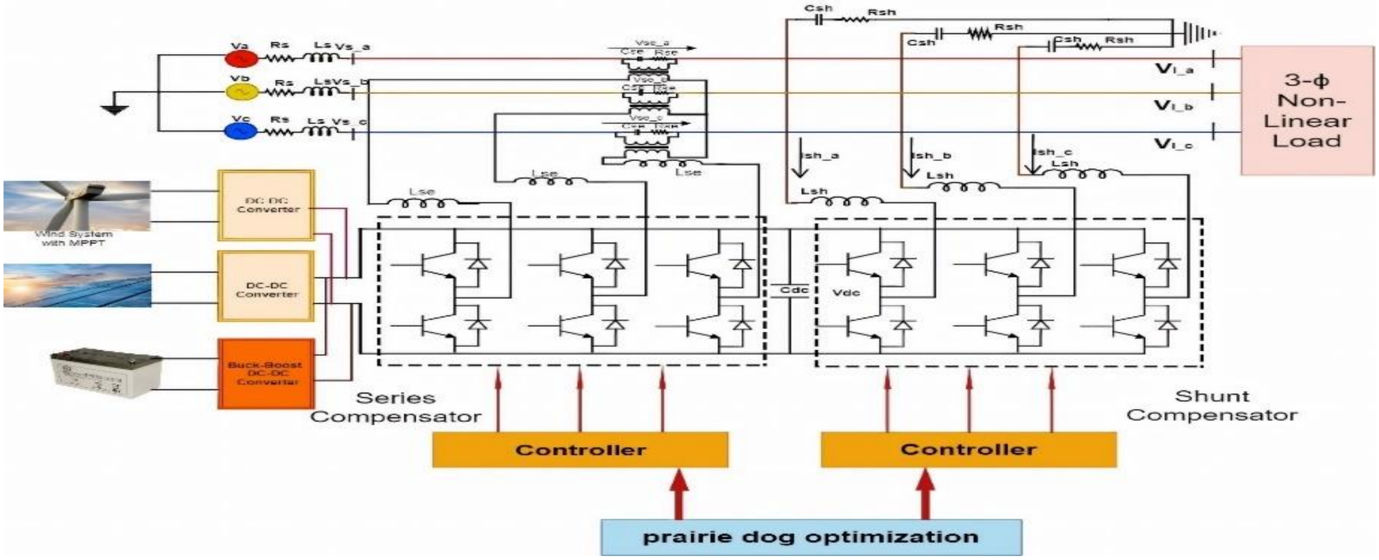


Figure 1. Structure of integrated UPQC using solar PV, wind, and BESS.

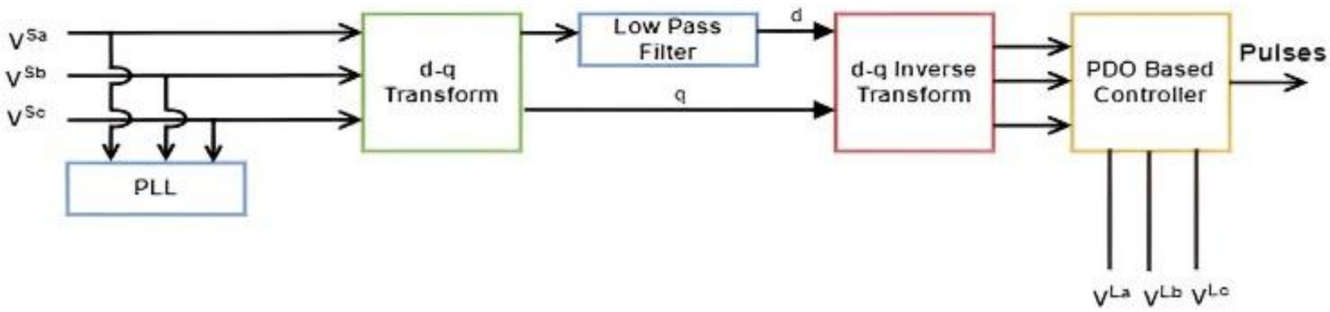


Figure. 2 Series active Power filter

2) *Control technique for a shunt active power filter*

3-ø voltages and currents are transformed into α and β as given in Eqns. (4-5) (Goud *et al.*, 2020), and the construction of a SHAPF (Aljafari *et al.*,2022) is shown in Figure 3.

$$\begin{bmatrix} V^{s0} \\ V^{s\alpha} \\ V^{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V^{sa} \\ V^{sb} \\ V^{sc} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} I^{l0} \\ I^{l\alpha} \\ I^{l\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I^{La} \\ I^{Lb} \\ I^{Lc} \end{bmatrix} \tag{5}$$

Phase-neutral currents $I^{l\alpha}$, $I^{l\beta}$ The 3-ø load currents I^{la}, I^{lb}, and I^{lc}, $V^{s\alpha}$ and $V^{s\beta}$ represent phase neutral voltages, whereas V^{sa}, V^{sb}, and V^{sc} represent three-phase supply voltages. Eqns. 6-7 (Goud *et al*., 2020) are used to compute real and reactive power.

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V^{s\alpha} & V^{s\beta} \\ -V^{s\beta} & V^{s\alpha} \end{bmatrix} \begin{bmatrix} I^{l\alpha} \\ I^{l\beta} \end{bmatrix} \tag{6}$$

The reference currents expression is given as

$$\begin{bmatrix} I^{Ra} \\ I^{Rb} \\ I^{Rc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I^{R\alpha} \\ I^{R\beta} \end{bmatrix} \tag{7}$$

The SHAPF reference currents are I^{Ra}, I^{Rb}, and I^{Rc}. The error current is calculated by comparing reference currents, and FOPID-based controller using PDO is to be used to help rectify it, which develops the pulses needed by the SHAPF.

III. PRAIRIE DOG OPTIMIZATION ALGORITHM

The Prairie Dog Optimization Method (PDO) is a recently suggested nature-inspired method for tackling optimization challenges. It is based on the behaviours of prairie dogs in the wild, where they live in vast communities and interact with one another through vocalizations and movements.

A prairie dog population depicts the possible solutions to the optimisation issue in PDO. The programme is based on prairie dog social interaction and communication concepts. To efficiently explore the search space, the algorithm employs a combination of local and global search algorithms.

One of PDO's benefits is its ability to handle both continuous and discrete optimization challenges. It has been used to solve a variety of optimization issues, including feature selection, picture segmentation, and structure optimization, among others.

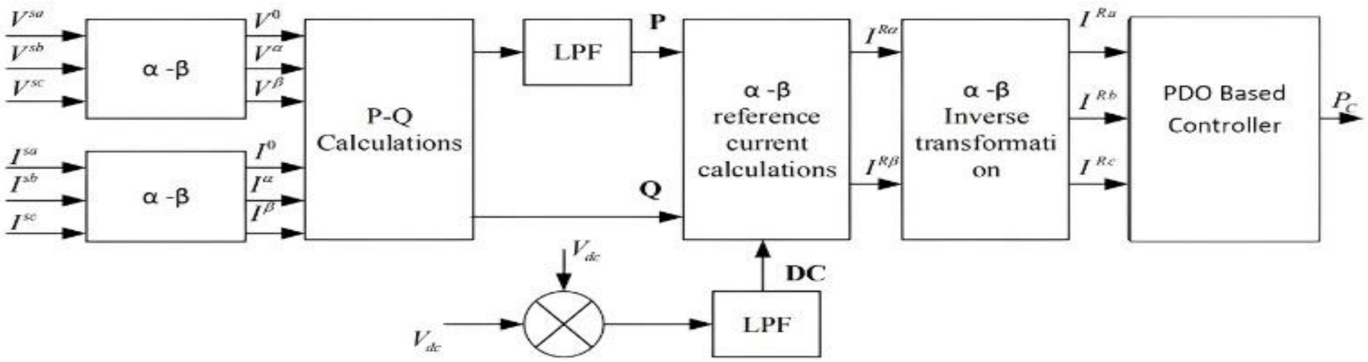


Figure.3 Shunt active power filter (SHAPF)

A. PDO pseudo-code

Algorithm provides the pseudocode for the PDO optimization process. PDO begins by producing a set of evenly distributed, random potential solutions. The programme then employs its established procedures to iteratively examine all potential sites for near-optimal solutions. Based on the stated rule, the algorithm chooses the best answer replaces the prior as of right now obtained solution each time. To achieve exploration and exploitation, the algorithm that is being presented uses four prairie dog actions. When iter<Maxiter/2 is reached, PDO begins the exploring stage, and when iter >Maxiter/2 is reached, the exploitation phase begins.

Finally, when the end criteria are fulfilled, the suggested algorithm comes to a halt. In the literature, several stopping criteria have been used, containing the maximum number of repeats, maximum execution time, and function tolerance. In this study, the PDO algorithm's termination criterion is the number of iterations at its most. The maximum number of iterations, though, needs to be carefully set since if it's too high or too low, it might lead to a bad solution and a waste of computer resources, respectively. Figure 4's flow chart shows the suggested PDO algorithm's straightforward and thorough optimization approach.

B. FOPID controller

Figure. 5 depicts the fundamental diagram of FOPID. The e (s) error signal aids in the generation of the u (s) control output Eqn. (8) (Goud *et al*., 2020). The FOPID with PDO optimization is intended to reduce problems with power quality caused by voltage and current oscillations in the HRES platform. The FOPID controller's signal of control is mathematically stated as follows:

$$\mathrm{u}(s) = K_P + K_i D^{-\lambda} e(s) + K_d D^{\mu} e(s) \quad (8)$$

During the controller design process, the following actions must be taken:

1. K_P is controlled to minimise steady-state error and rising time.
2. K_d is controlled to reduce settling time and overshoot.
3. K_i is adjusted in order to eliminate the steady-state error.
4. The parameters for fractional orders $D^{-\lambda}$ and D^{μ}.

IV. RESULTS AND DISCUSSION

The suggested UPQC was tested on a 3-ø AC distribution system that is grid-connected. Figure.6 depicts the simulation model created in Matlab R2022b.

Eqn. (9) (Srilakshmi *et al.*, 2020) calculates voltage fluctuations with PDO.

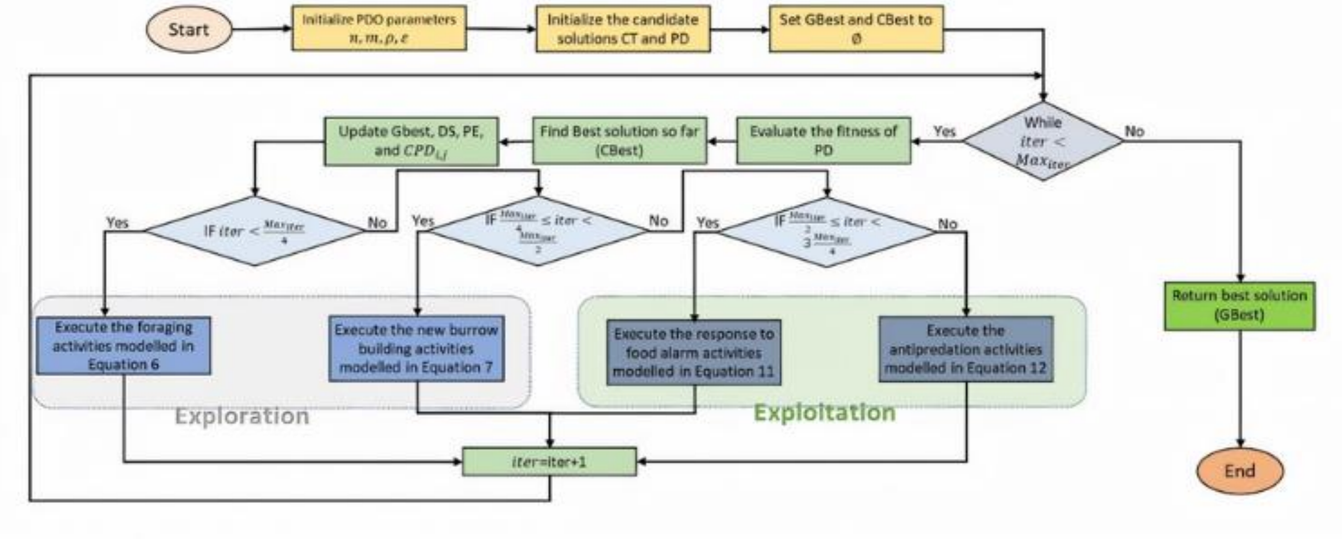


Figure. 4 Flowchart for the PDO method.

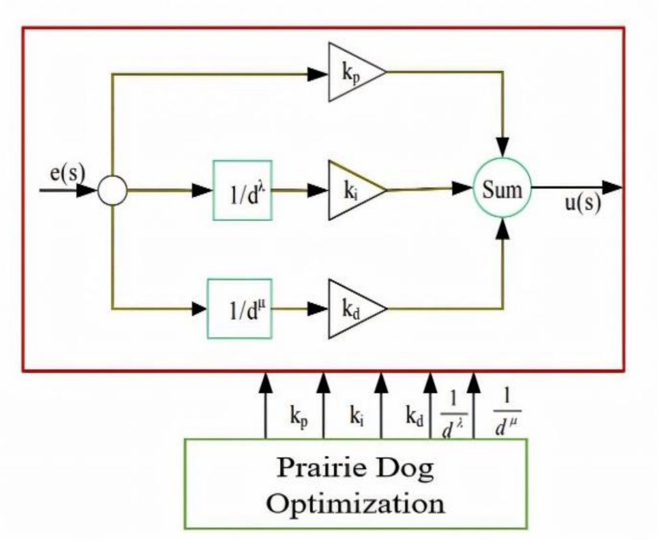


Figure.5 Controller for fractional order proportional integral derivative (FOPID).

$$V_{sag/swell} = \frac{V_l - V_s}{V_l} = \frac{V_{se}}{V_l} \tag{9}$$

The series compensator injected voltage to adjust for voltage sag/swell and UPQC disturbance is provided by Eqn. (10) (Srilakshmi *et al.*, 2020).

$$V_{se} = V_l - V_s \tag{10}$$

The shunt compensator's injected current is provided by Eqn. (11) (Srilakshmi *et al.*, 2020).

$$i_{sh} = i_l - i_s \tag{11}$$

In general, traditional approaches produce more precise findings, although they are time-consuming and have significant limits. Meta-heuristic algorithms can be used for speedier processing.

In Case 1, 30% of the source voltage dropped during 0.25-0.35 sec; the suggested UPQC injects a sufficient quantity of needed voltage to enhance the load voltage, as illustrated in figure. 7(a). Furthermore, as shown in figure. 7(b), the load current was found to be non-sinusoidal but balanced, with a THD of 27%.

Figure.7 clearly shows that the proposed UPQC efficiently eliminates sag by injecting an appropriate compensating voltage and enhancing source current that is sinusoidal. However, improvements in current waveforms are reflected in THD levels. As a result, by injecting suitable shunt currents, the load current's THD was lowered from 27% to 2%.

In Case 2, a voltage swell was created between 0.4 and 0.5 s; the suggested method successfully removes the voltage swell by injecting a sufficient compensatory voltage, as illustrated in figure 8(a). During steady state, however, a tiny quantity of voltage always escapes across the series converter. Figure 8(b) shows that the non-sinusoidal load current existed yet balanced with a THD of 15%. The UPQC was capable successfully control swell and lower THD from 15% to 2.4% by injecting appropriate shunt currents.

In Case 3, a substantial voltage fluctuation at the source voltage was introduced. The load current in this case was imbalanced and non-sinusoidal, with a 33% THD. The UPQC was capable to minimize voltage anomalies extremely successfully by using the appropriate compensatory voltage and reducing THD from 33% to 2.4% while also enhancing the sinusoidal waveform's appearance, as illustrated in figures 9(a)–9(b).

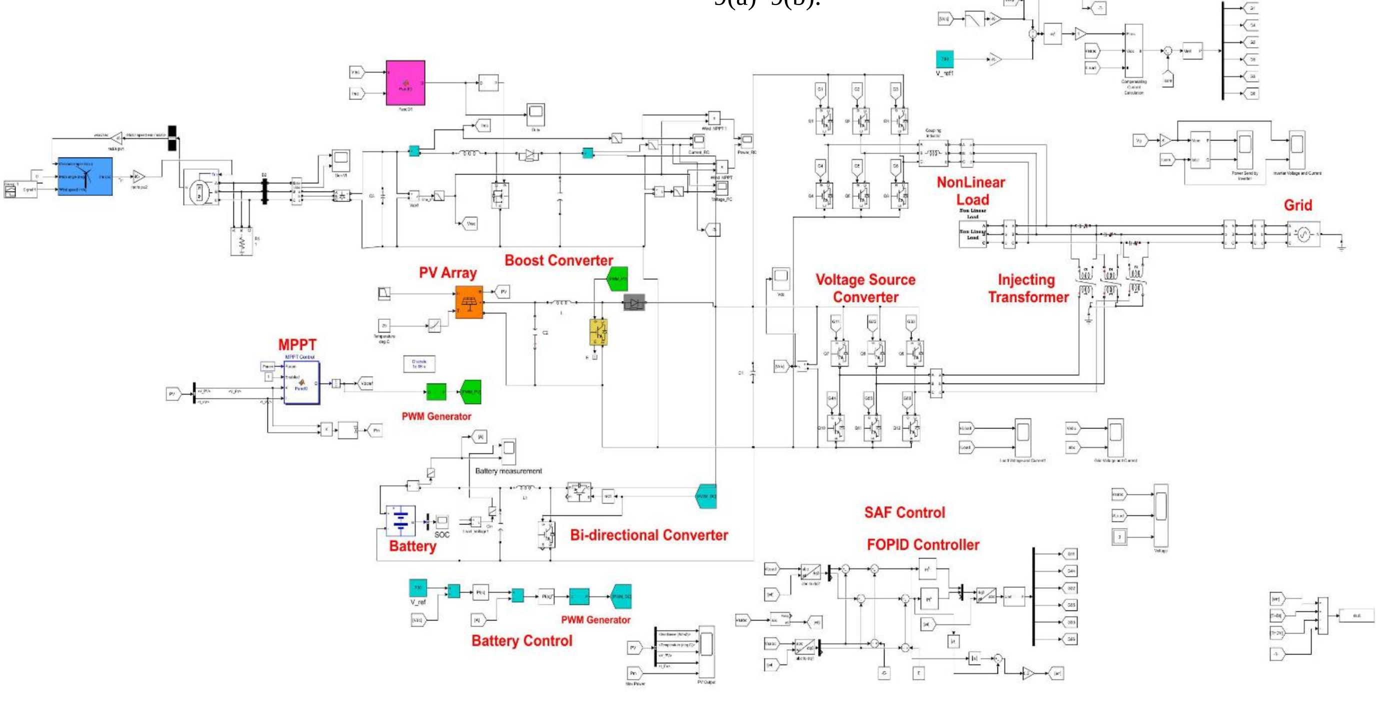


Figure.6 Simulink model of an HRES-integrated UPQC with loads.

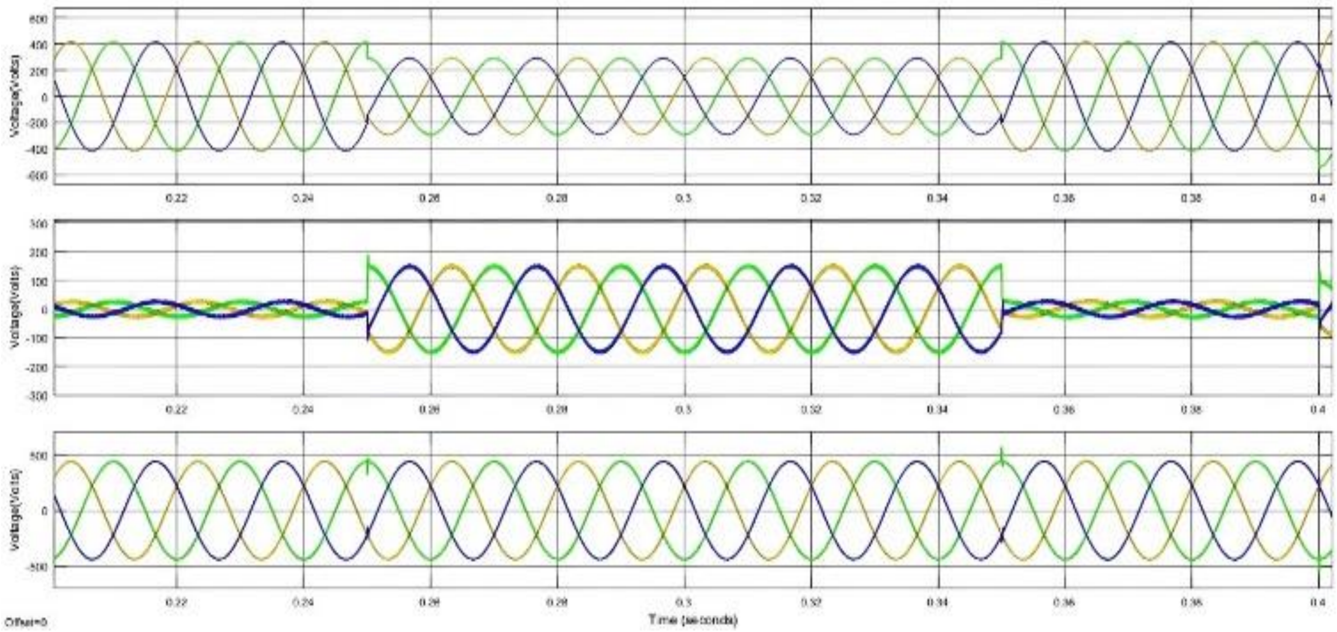


Figure.7. (a) (Vs), (Vse), (Vl)

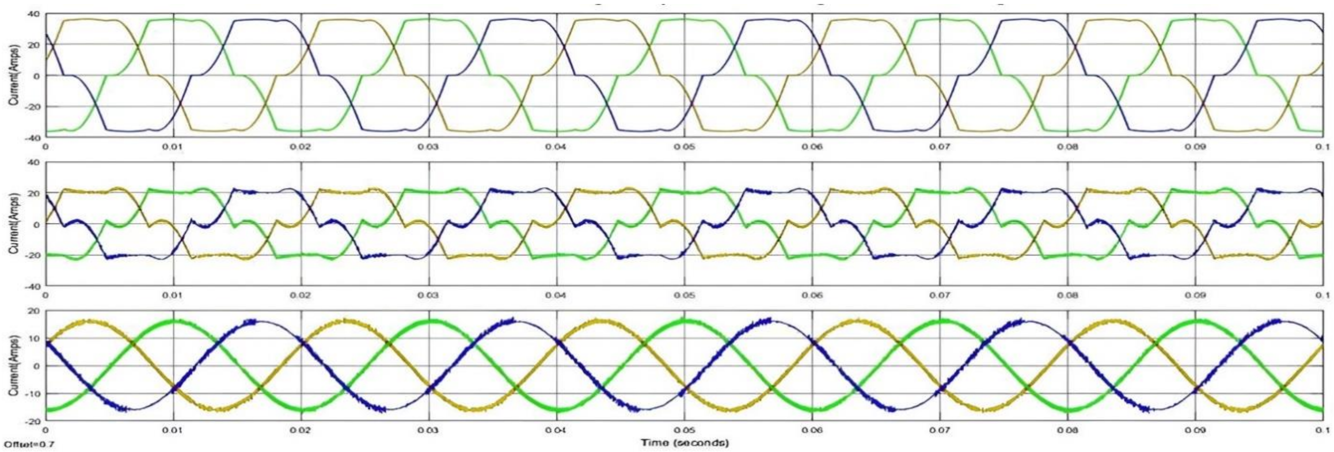


Figure.7. (b) (Il), (Ish

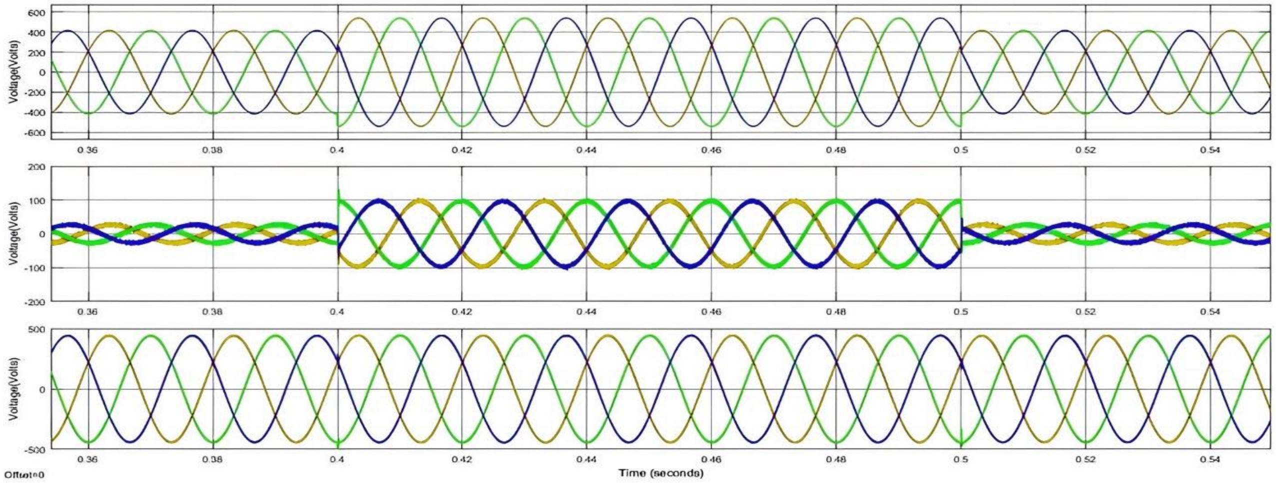


Figure.8. (a) (Vs), (Vse), (Vl)

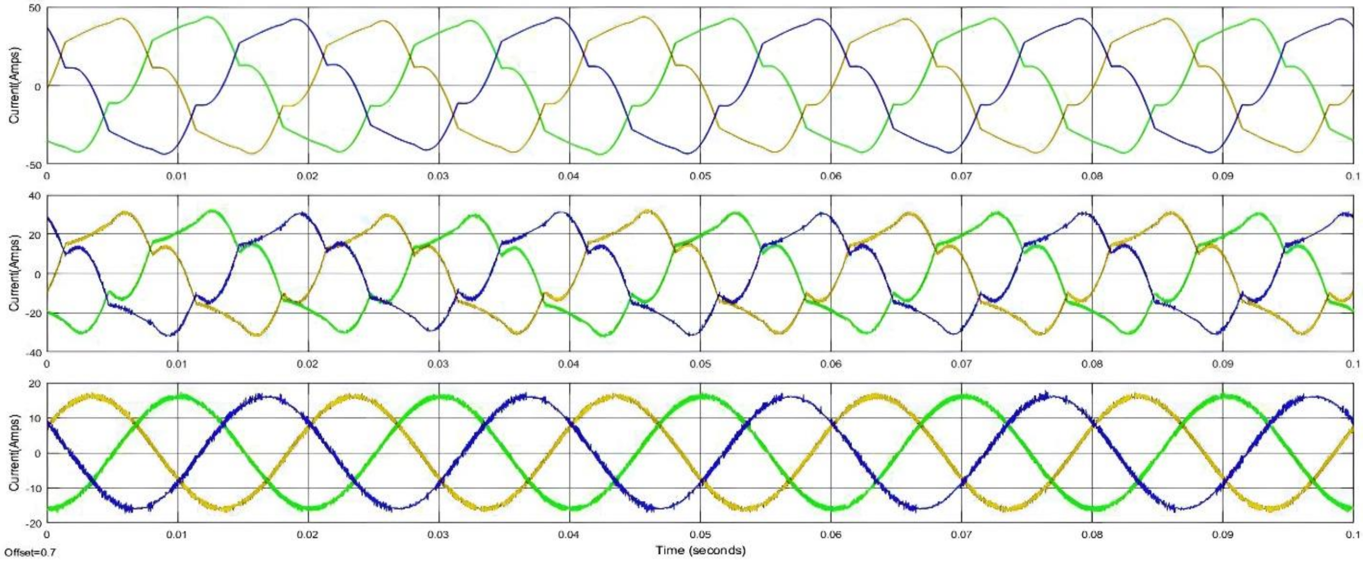


Figure.8. (b) (Il), (Ish), (Is)

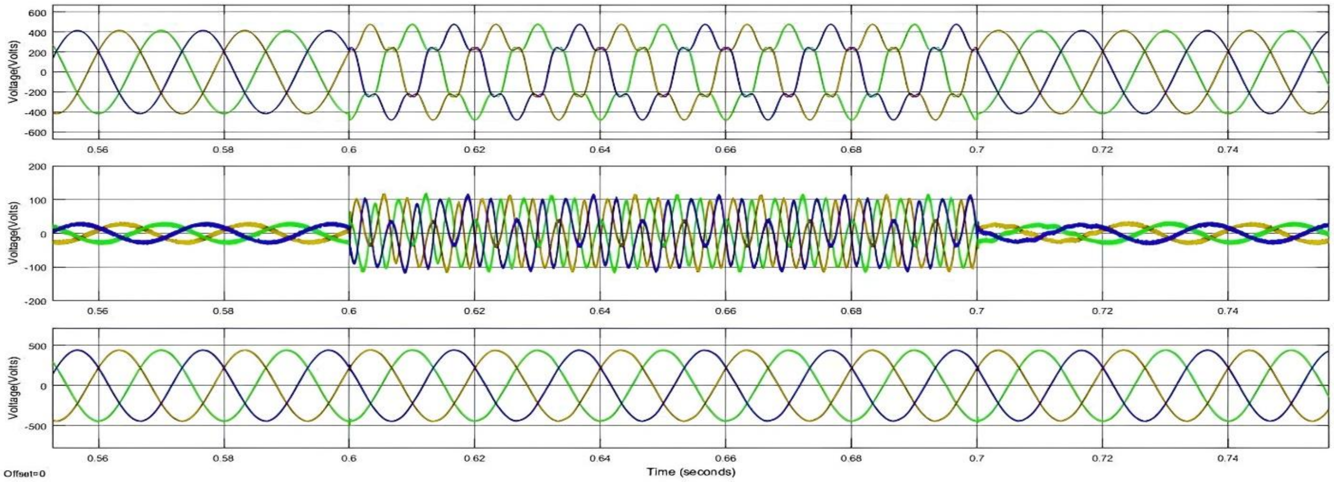


Figure.9. (a) (Vs), (Vse), (Vl)

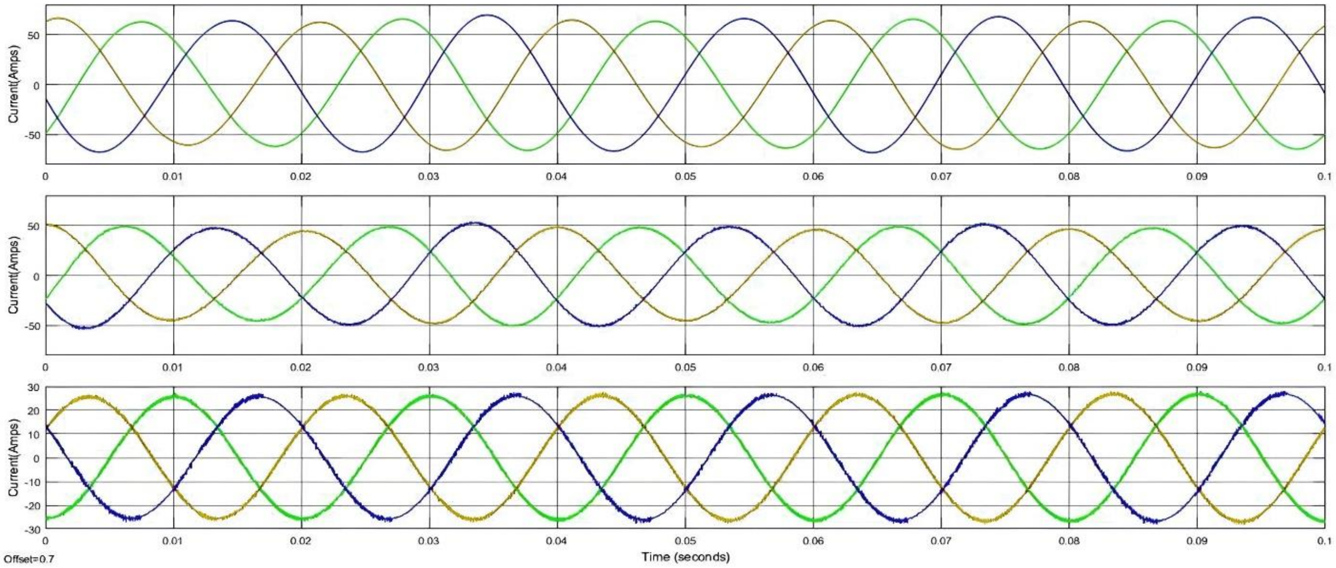


Figure.9. (b) (Il), (Ish), (Is)

In Case 4, the supply voltage that is not balanced was evaluated; however, the suggested UPQC effectively supplies a symmetrical load voltage, as illustrated in Figure 10(a). It appears that the load current is sinusoidal and imbalanced in this case, with a THD of 7.33% figure 10(b).

THD was reduced from 7.3% to 2.3% with the PDO. The suggested method's performance was evaluated using solar irradiation variations of 1000W/m^2 to 800W/ m^2 and 800 W/ m^2 to 1000 W/ m^2 at a consistently warm of 25℃.

It is obvious from figure.11 that the suggested system maintains a steady DC-Link voltage during irradiation fluctuations better than other devices. Additionally, the PV panel's output power, voltages, and duty cycle were reported. Figure. 12 displays the THD spectrum for each of the four test scenarios.

V. CONCLUSION

The proposed novel Unified Power Quality Conditioner (UPQC) System, incorporating an innovative control technique based on the Prairie Dog Optimization (PDO) Fractional Order Proportional Integral Derivative (FOPID) controller. Through extensive simulations using MATLAB/Simulink, the key findings demonstrate the efficacy of the proposed PDO-FOPID controller in mitigating harmonics and compensating for load demand in grid-connected renewable energy sources.

The significance of this research lies in its potential to address critical challenges associated with the integration of hybrid renewable energy sources (HRES) into power systems. The PDO-FOPID controller's ability to adapt control parameters to dynamic system conditions and load fluctuations ensures a stable and reliable power supply.

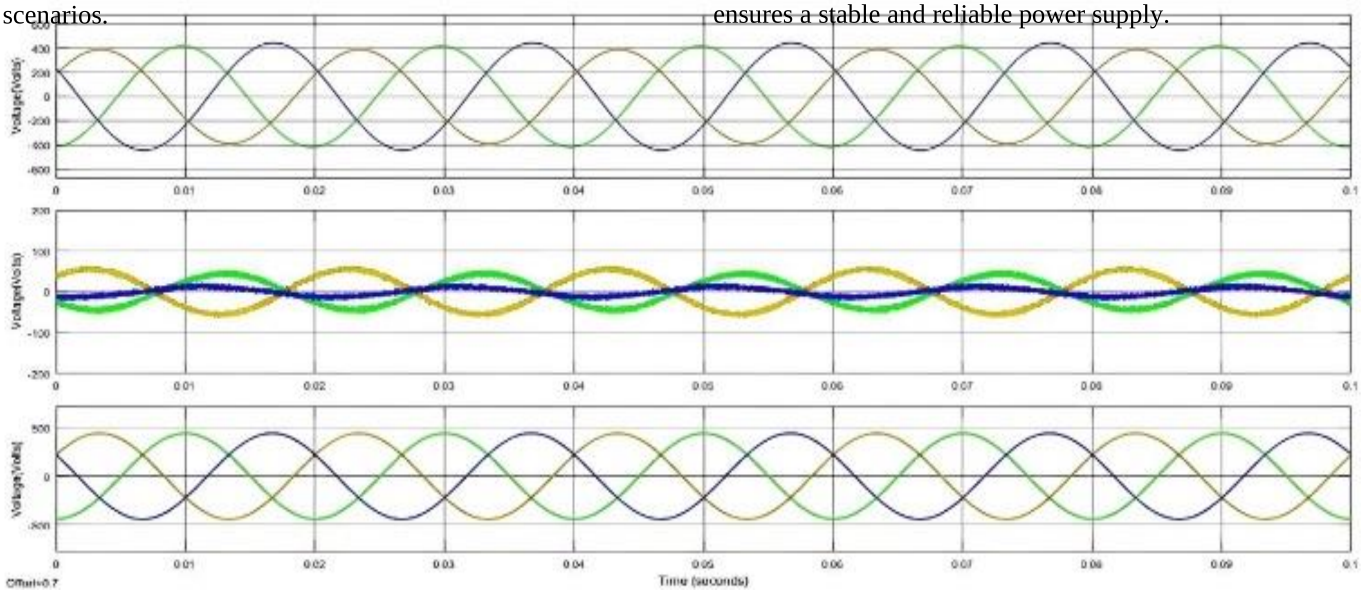


Figure.10. (a) (Vs), (Vse), (Vl)

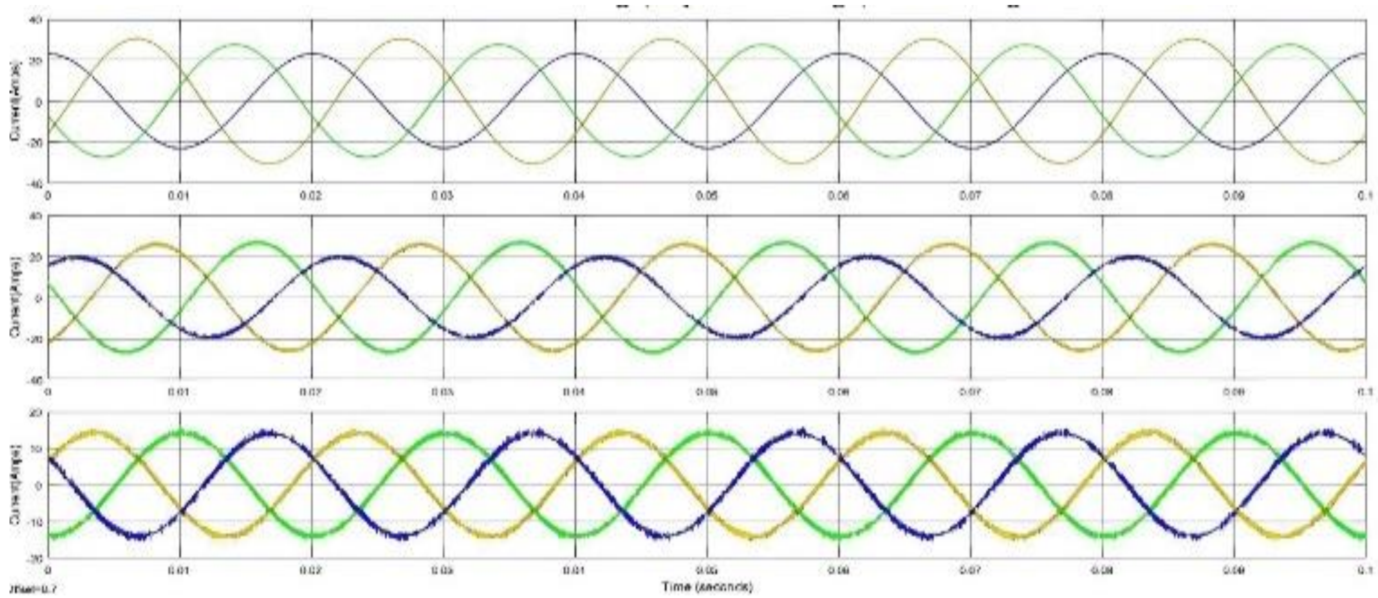


Figure.10. (b) (Il), (Ish), (Is)

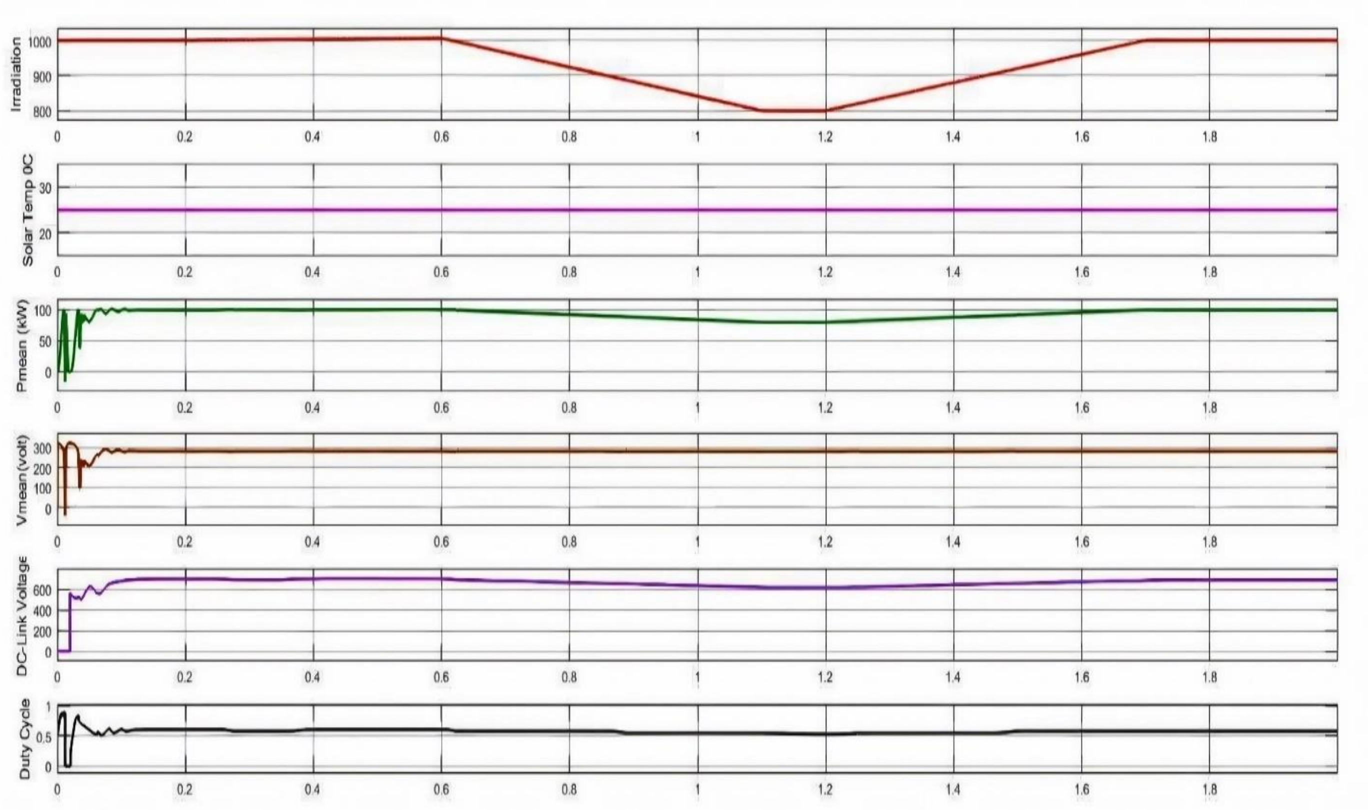
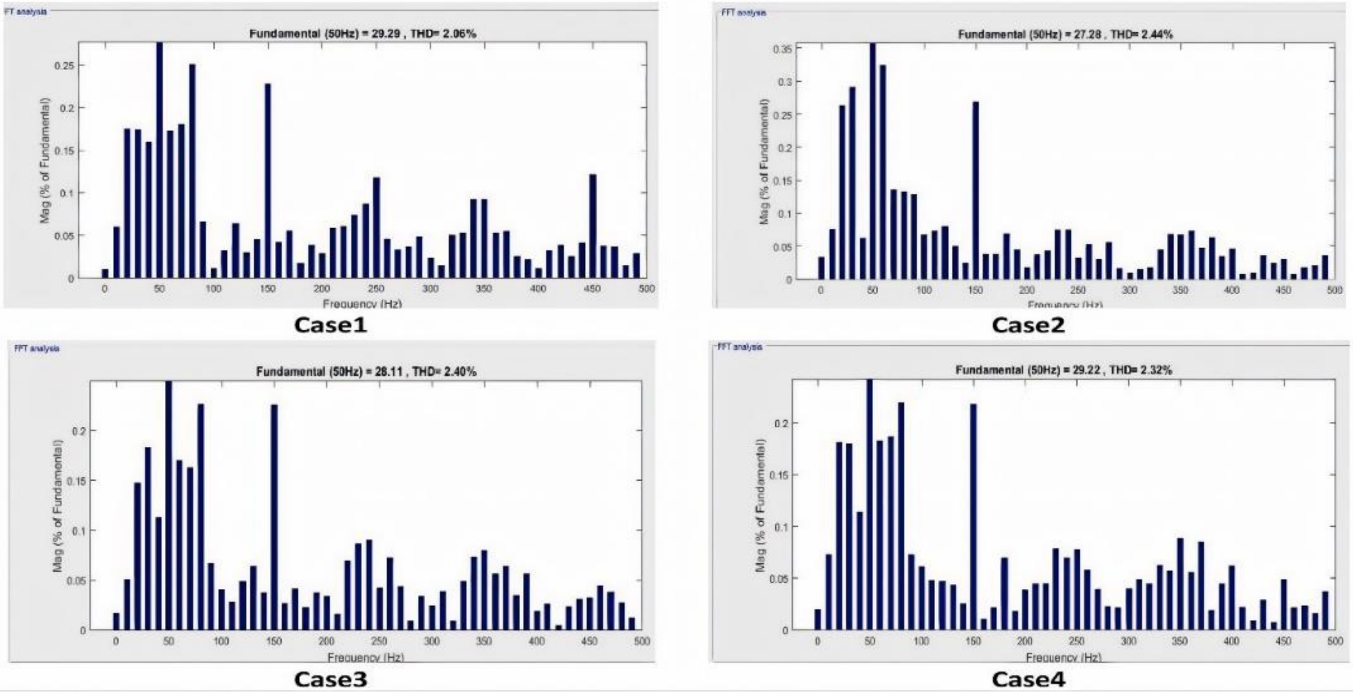


Figure.11: irradiation, temperature, output power, voltage, DC-Link voltage, and duty cycle waveforms.



Case1

Case2

Case3

Case4

Figure.12. Case studies using the THD spectrum.

This is particularly noteworthy in the context of fluctuating alternatives to fossil fuels, as the suggested control technique surpasses existing methods in terms of harmonic mitigation and load compensation.

The contribution of this research is evident in the development of a promising solution for enhancing the stability and performance of power systems with HRES integration. By effectively addressing the issues related to harmonics and load demand, the proposed control technique contributes to the advancement of environmentally friendly and sustainable power systems. This contribution is significant in the broader context of global efforts to transition towards cleaner energy sources.

Looking forward, further research directions and recommendations could include exploring the scalability of the PDO-FOPID controller for larger power systems and diverse renewable energy configurations. Additionally, investigating the controller's robustness in the presence of uncertainties and its adaptability to different grid conditions would enhance the practical applicability of the proposed solution. Furthermore, real-time experimental validation could provide valuable insights into the performance of the PDO-FOPID controller in actual power system scenarios, paving the way for its practical implementation and widespread adoption. Overall, these suggested research directions aim to deepen our understanding of the proposed control technique and its potential for broader applications in the field of power systems engineering.

As a result, the recommended control method based on the PDO-FOPID controller is a promising solution for the integration of hybrid renewable energy sources (HRES) in power systems, as it effectively mitigates the challenges associated with fluctuating alternatives to fossil fuels while securing a steady and dependable electricity source. The suggested control technique has the potential to contribute to the development of environmentally friendly and sustainable power systems.

AUTHOR CONTRIBUTIONS

S. Nagaraju: Conceptualization, Software, Validation, Writing–original draft. **B. Chandramouli:** Supervision, Writing – review & editing.

REFERENCES

Addagatla, N. and Boini, R. (2023). A High Gain Single Switch DC-DC Converter with Double Voltage Booster Switched Inductors. Advances in Science and Technology Research Journal, 17(2), pp.1-11. https://doi.org/10.12913/22998624/161447.

Aljafari, B.; K. Rameshkumar; V. Indragandhi and S. Ramachandran. (2022). A novel single-phase shunt active power filter with a cost function-based model predictive current control technique. Energies, 15(13), p.4531.

Azmi, S.A.; G.P. Adam; B.W. Williams; N.A. Rahim and S.R.A. Rahim. (2023). Grid integration of multiple PV inverters with reduced number of interfacing transformers—A dedicated controller for elimination of DC current injection. Energy Reports, 9, pp.904-911.

Dheeban, S. and Selvan, N. B. M. (2021). ‘‘ANFIS-based power quality improvement by photovoltaic integrated UPQC at distribution system,’’ IETE J. Res., vol. 6, no. 2, pp. 1–19.

Ezugwu, A.E.; J.O. Agushaka; L. Abualigah; S. Mirjalili and A.H. Gandomi. (2022). Prairie dog optimization algorithm. Neural Computing and Applications, 34(22), pp.20017-20065.

Fei, J.; Z. Wang and Q. Pan. (2022). Self-constructing fuzzy neural fractional-order sliding mode control of active power filter. IEEE Transactions on Neural Networks and Learning Systems.

Goud, B. S. and Rao, B. L. (2020). Power quality improvement in hybrid renewable energy source grid-connected system with grey wolf optimization. International Journal of Renewable Energy Research (IJRER), 10(3), 1264-1276.

Guha, D.; P.K. Roy and S. Banerjee. (2022). Performance evolution of different controllers for frequency regulation of a hybrid energy power system employing chaotic crow search algorithm. ISA transactions, 120, pp.128-146.

Hafeez, M.A.; A. Naeem; M. Akram; M.Y. Javed; A.B. Asghar and Y. Wang. (2022). A novel hybrid MPPT technique based on Harris hawk optimization (HHO) and perturb and observer (P&O) under partial and complex partial shading conditions. Energies, 15(15), p.5550.

Han, J.; X. Li; Y. Sun; S. Gong and S. Huang. (2022). Optimal design and decoupling control of series DC-link voltages for quadruple-active-bridge based UPQC. International Journal of Electrical Power & Energy Systems, 140, p.108038.

Ishaq, S.; I. Khan; S. Rahman; T. Hussain; A. Iqbal and R.M. Elavarasan. (2022). A review on recent developments in control and optimization of micro grids. Energy Reports, 8, pp.4085-4103.

Lei, T.; S. Riaz; N. Zanib; M. Batool; F. Pan and S. Zhang. (2022). Performance analysis of grid-connected distributed generation system integrating a hybrid wind-PV farm using UPQC. Complexity, 2022.

Li, S.; P. Zhao; C. Gu; J. Li; S. Cheng and M. Xu. (2022). Battery protective electric vehicle charging management in renewable energy system. IEEE Transactions on Industrial Informatics, 19(2), pp.1312-1321.

Mahaboob, S.; S. K. Ajithan and S. Jayaraman. (2019). ‘‘Optimal design of shunt active power filter for power quality enhancement using predator-prey based firefly optimization,’’ Swarm Evol. Comput., vol. 44, pp. 522–533.

Nagaraju, S.; C. Bethi; K.V. Kumar; T.V. Muni; N.S.V. Varma and P.R. Kumar. (2022), November. Dynamic Voltage Restorer Based Solar PV System Connected Grid Utilizing UPQC with Fuzzy. In 2022 International Conference on Futuristic Technologies (INCOFT) (pp. 1-6). IEEE.

Rekha, R.; B. Srikanth Goud; C. Rami Reddy; B. Nagi Reddy. (2020). PV-Wind-Integrated Hybrid Grid with P&O Optimization Technique. In: Saini, H., Srinivas, T., Vinod Kumar, D., Chandragupta Mauryan, K. (eds) Innovations in Electrical and Electronics Engineering. Lecture Notes in Electrical Engineering, vol 626. Springer, Singapore. https://doi.org/10.1007/978-981-15-2256-7_53.

Rodríguez-Pajarón, P.; A.H. Bayo and J.V. Milanović. (2022). Forecasting voltage harmonic distortion in residential distribution networks using smart meter data. International Journal of Electrical Power & Energy Systems, 136, p.107653.

Sarker, D.; Chatterjee and S. K. Goswami. (2021). ‘‘A modified PV-wind PEMFCS-based hybrid UPQC system with combined DVR/STATCOM operation by harmonic compensation,'' Int. J. Model. Simul., vol. 41, no. 4, pp. 243–255.

Srilakshmi, K.; N. Srinivas; P.K. Balachandran; J.G.P. Reddy; S. Gaddameedhi; N. Valluri and S. Selvarajan. (2022). Design of Soccer League Optimization Based Hybrid Controller for Solar-Battery Integrated UPQC. IEEE Access, 10, pp.107116-107136.

Youssef, A.A.; S. Barakat; E. Tag-Eldin and M.M. Samy. (2023). Islanded green energy system optimal analysis using PV, wind, biomass, and battery resources with various economic criteria. Results in Engineering, 19, p.101321.