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Original Article

PRc-PID with Grey Wolf Optimization based UPQC for Power Quality Enhancement in Standalone Microgrids

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Abstract *- Microgrids that are self-sufficient and powered by renewable energy sources like solar and wind are necessary for the electrification of less-populated areas. When it comes to power quality, however, they are susceptible to problems because of the nonlinear load behaviors and the variable nature of the generation. A solution that is effective in addressing voltage and current disturbances is the Unified Power Quality Conditioner (UPQC), which is a combination of series and shunt APF. Precise resonance frequency and proportional-integral gain adjustment are critical to the PRc-PID controller's performance. Instability or poorer harmonic rejection performance could result from minor parameter variations. Grey Wolf Optimization (GWO), a metaheuristic method inspired by nature, is given in this paper to prevent these parameter variations. The purpose of this approach is to optimize the tuning of UPQC controllers in order to improve power quality in standalone microgrids. A MATLAB/Simulink model of a standalone microgrid is used to implement the GWO-based technique, and the performance of this new approach is compared to that of the TLBO version. The results demonstrate considerable improvements in Total Harmonic Distortion (THD), voltage Sag/Swell, and Current distortions, which validate the usefulness of GWO in adaptive UPQC management.*

Keywords *- UPQC, Microgrid, PRc-PID controller, Grey wolf optimization, THD, MATLAB/Simulink.*

1. Introduction

Energy consumption has been on the rise, leading to a buildup of atmospheric greenhouse gas emissions in recent years. Renewable energy resources are seen to be the greatest way to cut down on emissions of greenhouse gases and boost power production [1]. Power generation from renewable energy sources does not release harmful gases into the atmosphere. Photovoltaic (PV), Wind Energy Conversion Systems (WECS), biomass, tidal, geothermal, and hydropower are just a few examples of the numerous renewable energy sources that are readily accessible today [2]. The most cutting-edge and ubiquitous renewable energy resources are Photovoltaics (PV) and Wind Energy Conversion Systems (WECS). The PV and WECS have evolved into convenient and useful tools due to qualities like being beautiful and cost-effective [3, 4]. Weather and climatic shifts are two examples of environmental factors that have a significant impact on WECS and PV generation. When the climate changes, PV and WECS systems employ Maximum Power Point Tracking (MPPT) methods to boost their performance [5]. To maximize the benefits of each DG unit's complementary and distinctive capabilities, a hybrid power system known as a freestanding microgrid incorporates a diverse range of them [6]. The standalone microgrid system improves power supply dependability, energy utilization rate, and energy efficiency [7]. In addition, renewable energy sources are linked to standalone microgrid systems in order to offset demand. Problems with power quality and volatility may arise in an independent microgrid system due to the interconnection of renewable energy sources. The variable nature of renewable energy sources' climatic circumstances also makes load side instability more common [8]. Problems with Power Quality (PQ), such as disturbances, sags, harmonics, and swells, can arise in standalone microgrid systems as a result of the random fluctuations in renewable energy sources and changes in loads, such as imbalanced, non-linear, and critical loads [9]. As a result of power quality problems, the load voltage varies, causing the load to trip. The ongoing development of isolated microgrids impacts the system's reliability. The correct operation of the system depends on preventing tripping on it [10].

2. Literature Review

Avoiding power quality problems improves the system's stability and reliability. Flexible Alternating Current Transmission system (FACT) filters and power electronics devices typically aid with these issues. To solve power quality-based problems and ensure system stability and dependability, FACT devices are utilized in standalone microgrids [11]. Microgrids connect series and shunt FACTS devices to compensate for PQ problems. The microgrid's voltage problems can be addressed by connecting the DVR [13] and SSSC [12] devices in series. In order to regulate and compensate the system voltage, the shunt FACT device uses TCR [14] and DSTATCOM [15]. If there are voltage issues, the DSTATCOM can fix them, but it won't cut down on harmonics [16]. Additional capacitors or storage elements were needed for the DVR to compensate for voltage difficulties. Minimizing power quality concerns and ensuring stable, reliable operation in a standalone microgrid system are the primary foci of this research. Following is a rundown of the suggested design's primary goals. The rise of standalone microgrids integrated with renewable energy sources has created new challenges for power quality management. Voltage sags/swells, harmonic distortion, and load imbalances are common in such systems. UPQC, integrating series and shunt active filters, offers a robust solution but requires precise control. This paper explores the use of Grey Wolf Optimization (GWO) to fine-tune UPQC control parameters for enhanced power quality performance. The literature reviews the current approach. It has to be enhanced and fixed in the right way because it has certain restrictions. The next parts detail the design of the suggested approach with the appropriate control technique.

3. Research Gap

According to earlier studies, microgrid power quality is greatly impacted by unbalanced loads and intermittent generation. Under dynamic circumstances, traditional UPQC control approaches utilizing PI or PID controllers sometimes do not respond optimally. Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) are two examples of recent metaheuristic optimization developments that have demonstrated potential for enhancing control performance. Developed by Mirjalili et al., GWO provides effective worldwide search capabilities by emulating the hunting behavior and hierarchical structure of grey wolves. Research using GWO for controller tuning in power systems has demonstrated improved accuracy and faster convergence. But there isn't a ton of data on how to use it to improve UPQC for independent microgrids. The following is the setup of the study manuscript: a correlated effort centered on improving power quality in independent microgrid systems. In Section 3, the suggested system design is detailed in detail, with an emphasis on a freestanding microgrid system. The 4 section provides a comprehensive approval of the UPQC-based control mechanism, including shunts and series active power filters. The proposed technique aims to enhance the efficiency of the electrical grid. Section 5 provides the necessary background information and a flow diagram of GWO. Section 6 details the findings and discussion. Section 7 wraps up the manuscript with the Conclusion.

4. System Model of Standalone Microgrid

Power protection, climate change, increased demand, and ecological issues are all on the rise these days. Because it links renewable power sources with energy storage devices, a standalone microgrid is believed to be the best answer to these problems-an attractive layout for controlling renewable power sources and load demands on the load side of independent microgrids. Solar panels, wind turbines, and other renewable energy sources are integrated into a self-sufficient microgrid [17]. Solar Photovoltaic (PV) systems harness the energy of the sun and the wind to produce electricity; these systems have several benefits, including not requiring fuel, being quiet, and not emitting any harmful pollutants. Power quality issues such as surges, disturbances, oscillations, and sags can arise in standalone microgrid systems due to the interconnection of distributed resources and loads [18]. The stability and collapse dependability of freestanding microgrid systems are PQ concerns. By integrating UPQC into the system, the PQ issues were reduced. Thanks to UPQC, we were able to reduce sag, swelling, voltage, and current disturbances. In order to minimize PQ issues, UPQC relies on proper control. The UPQC-designed coordinated PQ theory dampens oscillations in the independent microgrid. An enhanced coordinated PQ theory controller for UPQC in freestanding microgrid systems is presented using the PRc-PID controller with GWO. The research involves modeling a standalone microgrid in MATLAB/Simulink, including renewable sources (PV and wind), dynamic loads, and nonlinear elements. A UPQC is designed with series and shunt converters to mitigate power quality issues. GWO is used to optimize controller parameters (e.g., Kp and Ki of PI controllers). The objective function minimizes THD, voltage deviation, and reactive power compensation. The performance of the GWO-optimized UPQC is compared with that of a conventional PI-based UPQC.

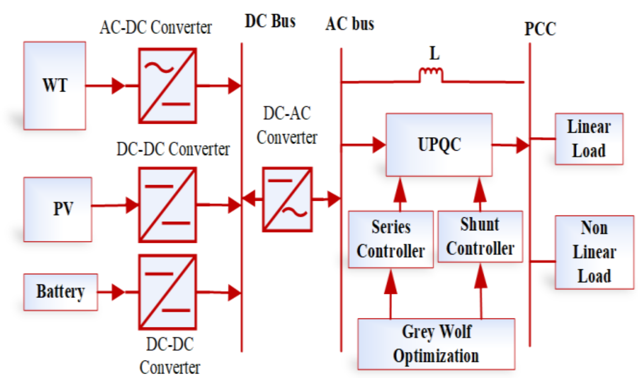


Fig. 1 System architecture

The expected method's system architecture is depicted in Figure 1. In a standalone microgrid, the power generation and storage are all working together. The generation sources that make up a standalone microgrid system are typically responsible for producing enough power to satisfy the load demand.

Depending on the environmental conditions, PV and WT systems can either be more or less productive. When wind and photovoltaic power were not enough to cover the load, the batteries were drained to generate electricity.

In a similar vein, any excess power produced by WT and PV can be stored in the battery during the charging process. Using UPQC to fix PQ problems in independent microgrid systems is the main objective. Series and shunt APFs implemented the UPQC with coordinated PQ theory. PRc-PID with Grey Wolf Optimization, developed in the context of coordinated PQ theory, enhances the control architecture of the suggested approach to addressing power quality issues such as interruptions, disturbances, swells, sags, and oscillations. The following section presents the mathematical models of the components used for microgrid generation and storage that operate independently.

4.1. Mathematical Modelling of PV

A solar cell is fundamentally a p-n junction fabricated on a thin semiconductor wafer. In solar energy, electromagnetic radiation can be converted directly into electricity via the photovoltaic effect. The output power of PV is given below:

$$P_{PV} = \eta_g N_{PV} A_m G_i \quad (1)$$

Where N_{PV} and η_g Represent the PV modules and generation efficiency. $G_i$andA_mIndicates the total irradiance from the PV panel and the area of one module.

4.2. Mathematical Modelling of WT

Wind turbine technology uses rotor blades to collect the kinetic energy of the wind as water flows. WT blades capture the wind's kinetic energy and convert it into mechanical energy. The numerical design of the wind turbine is crucial for determining its operation. The Mechanical power of this unit is:

$$P_W = \frac{1}{2}\rho C_P \pi R^2 V_W^3 \quad (2)$$

Where C_pRepresent the coefficient of performance, $\rho$is the air density, V_wIndicates wind speed and $R$is the blade length.

5. Unified Power Quality Conditioner

A UPQC is a flexible tool that simultaneously reduces grid-side voltage disturbances and load-side current disturbances. The proposed MG system is built to operate loads using multiple feeders and linear loads. In UPQC, a custom power device connected between the feeders is used to mitigate the issues brought on by these various loads. Figure 2 depicts the design of the interline UPQC. It has a series and shunt active power filter that are connected by a common DC-link. Shunt active power filters are reconnected in reverse, and the DC link is connected to a series of capacitors.

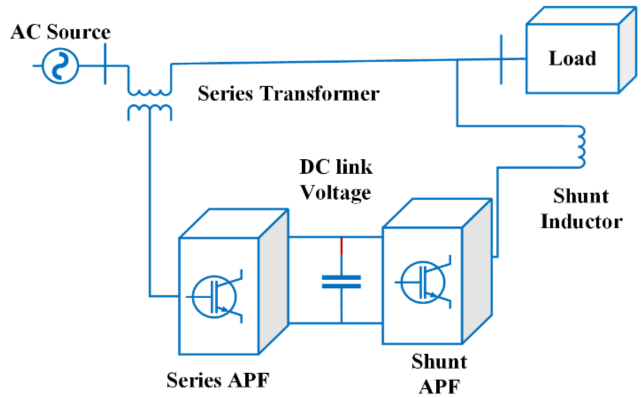


Fig. 2 Line diagram of UPQC

Figure 2 shows a series converter that connects the load and the supply through transformers. Another method for connecting shunt converters in parallel is the Point of Common Coupling, or PCC. The UPQC layout utilizes a series active power filter to generate voltage and a shunt active power filter to produce current. To compensate for power quality issues with voltage and current signals, UPQC can be employed in standalone microgrid systems. A shunt coupling inductor is an integral part of the UPQC architecture, used to link the converter to the power line. By boosting the DC-link voltage to the required value, this design can compensate for power quality concerns. Harmonic reduction in the load current and regulator of the DC-link voltage are the principal functions of a shunt converter. A shunt converter is an undeniable tool for mitigating supply-side voltage surges and dips caused by renewable energy sources. It is recommended to use a low-pass filter to reduce switching ripple at high frequencies. To bridge the gap between the converter and the electrical connections, a transformer is attached to the converter's output. To fix PQ problems and modify switching impulses, shunt and series APFs use IGBTs with anti-parallel semiconductor diodes. According to surveys, voltage power quality and voltage problems can be mitigated with the use of the UPQC design [19]. When the series converter is switched off and the shunt active power filter is turned on, the voltage inside the shunt converter acts as a current source. By using this method, power quality issues and voltage harmonics are reduced. The shunt filter controls the voltage of the DC-link capacitor and, at the same time, muffles the harmonics of the current. Switching to the series filter, the voltage sock and swell harmonics are activated. An adequate control structure should be implemented to minimize PQ difficulties with current and voltage signals in order to maximize the performance of the UPQC device in standalone microgrid systems. In a self-contained microgrid system, the suggested coordinated PQ theory is implemented, thereby eliminating power quality problems and controlling the DC-link voltage. Signals are also efficiently managed by coordinated PQ theory with the help of a PI controller and GWO optimization. Here, we present the synchronized PQ theory and the PI controller with the GWO description that has been presented.

5.1. Series Active Power Filter

This type of active power filter is designed to rectify voltages. The input to the control block is intended to calculate the instantaneous power PCC phase voltage with line current compensation of non-linear loads. Three-phase voltage $(V^{s(abc)})$ It was altered before the d-q coordinates were created in the series active power filter controller [20].

$$\begin{pmatrix}V^{s0}\\V^{sd}\\V^{sq}\end{pmatrix} = \frac{2}{3}\begin{pmatrix}\frac{1}{2} & \frac{1}{2} & \frac{1}{2}\\ sin(\omega t) & sin\left(\omega t-\frac{2\pi}{3}\right) & sin\left(\omega t+\frac{2\pi}{3}\right)\\ cos(\omega t) & cos\left(\omega t-\frac{2\pi}{3}\right) & cos\left(\omega t+\frac{2\pi}{3}\right)\end{pmatrix}\times\begin{pmatrix}V^{sa}\\V^{sb}\\V^{sc}\end{pmatrix} \quad (3)$$

Three-phase voltage was described as V^{sa},V^{sb} and V^{sc} Correspondingly.V^{sq}, V^{sd}It is denoted for the q-axis and direct voltage. The equation given below is used to find the d-axis voltage.

$$V^{sd} = \hat{V}^{sd} + \overline{V^{sd}} \quad (4)$$

The equation is used to compute the load voltage

$$\begin{pmatrix}VR^{la}\\VR^{lb}\\VR^{lc}\end{pmatrix} = \frac{2}{3}\begin{pmatrix} sin(\omega t) & cos(\omega t) & 1\\ sin\left(\omega t-\frac{2\pi}{3}\right) & cos\left(\omega t-\frac{2\pi}{3}\right) & 1\\ sin\left(\omega t+\frac{2\pi}{3}\right) & cos\left(\omega t+\frac{2\pi}{3}\right) & 1\end{pmatrix}\times\begin{pmatrix}\overline{V^{sd}}\\0\\0\end{pmatrix} \quad (5)$$

Voltage error is considered in Equation (6).

$$E(V) = VR^{labc} - V^{sabc} \quad (6)$$

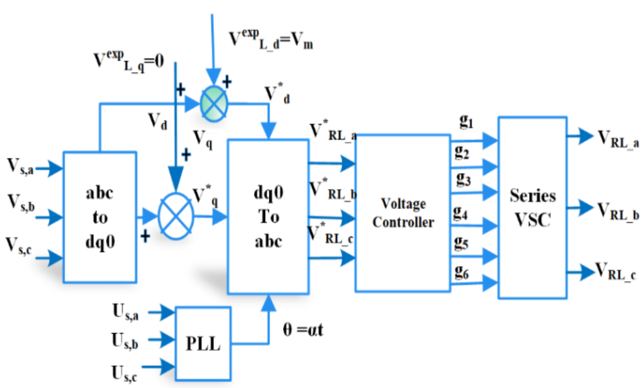


Fig. 3 Control diagram of series APF

5.2. Shunt Active Power Filter

A zero-powered zero-sequence component is produced in a three-phase system without a neutral by using some of the oscillating active load current to supply the shunt power. The system's current harmonics are managed using the notion of instantaneous reactive power. Three-phase voltages and currents are translated using the coefficients α and β. The following formula determines active and reactive power:

$$\begin{pmatrix}P\\Q\end{pmatrix} = \begin{pmatrix}V^{\alpha} & V^{\beta}\\ -V^{\beta} & V^{\alpha}\end{pmatrix}\begin{pmatrix}I^{\alpha}\\I^{\beta}\end{pmatrix} \quad (7)$$

In α-β coordinates, the shunt APF reference current is

$$\begin{pmatrix}IR^{\alpha}\\IR^{\beta}\end{pmatrix} = \frac{1}{V_\alpha^2+V_\beta^2}\begin{pmatrix}V_\alpha & V_\beta\\ -V_\beta & V_\alpha\end{pmatrix}\begin{pmatrix}\bar{p}\_P_0+P_{loss}\\ 0\end{pmatrix} \quad (8)$$

$$E(I) = IR^{sabc} - I^{labc} \quad (9)$$

$E(I)$Used to calculate the current error in the process. After comparing these reference source current signals, three-phase source currents are detected. A hysteresis band PWM controller processes the errors to produce the necessary switching signals for the shunt APF switches.

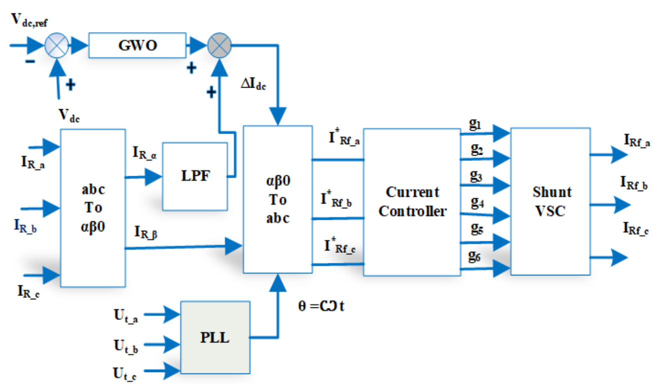


Fig. 4 Control diagram of shunt APF

6. GWO Optimization

The problem was formulated using a limited objective function. Three optimization strategies were used to identify the appropriate gas percentage constraints in order to generate the code tree for exact problem identification. The fitness function measured the diagnostic precision.

6.1. Grey Wolf Optimizer (GWO) Algorithm

The Grey Wolf Optimizer (GWO) algorithm mimics the natural hunting tactics and leadership structure of grey wolves. Grey wolf optimization and GWO creation are based on mathematical models of the wolves' social structure and hunting tactics [21]. This surrounding action can be described mathematically using the formulae given below.

$$\bar{D}=\left|\bar{C}.\overline{X_p}(iter)-\bar{X}(iter)\right| \quad (10)$$

$$\overline{X_p}(iter+1) = \overline{Xp}(iter - \bar{A}.\bar{D}) \quad (11)$$

Where iter is the current iteration and $\overline{X_p}(iter)$ Represents the vector of the target. The $\bar{A}$ and $\bar{C}$ Are factor vectors which are specified by:

$$\begin{cases} \vec{A} = 2.\vec{a}.\vec{r_1} - \vec{a} \\ \vec{C} = 2.\vec{r_2} \end{cases} \quad (12)$$

Where $\vec{r_1}$ and $\vec{r_2}$ They are random vectors with a range of 0 to 1, where a decreases linearly from 2 to 0 over the duration of iterations.

By retaining the top three results in GWO, we can make the other search agents adjust their placements based on where the top search agents are. When creating the GWO algorithm, the population is divided into four groups: alpha(α), beta (β), delta (δ), and omega (ω), which help to define the social hierarchy of wolves. The first three optimal solutions are denoted by and, respectively, over iterations [22]. Figure 5 demonstrates how to modify the positions of a two-dimensional space, respectively.

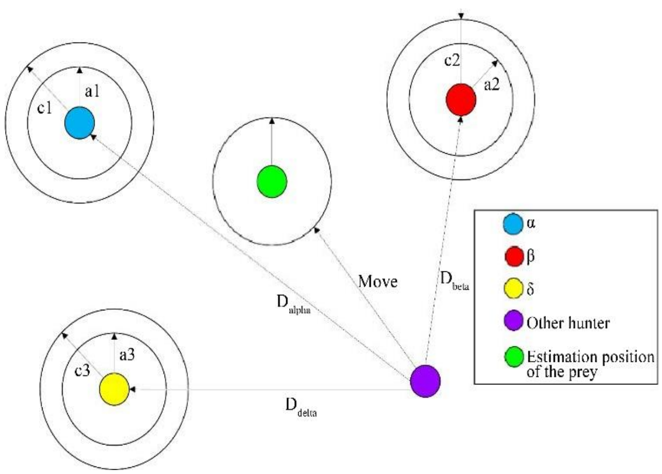


Fig. 5 Position updating in GWO

The remaining potential answers are designated as. The hunting/optimization in this algorithm is controlled by α, β, δ, and to come up with better answers, the wolves must encircle and. Hold on to the first three results and make every other search agent, even the omegas, move to where the top search agent is.

Here are some possible formulas for this:

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1}.\overrightarrow{X_\alpha} - \vec{X}\right| \quad (13)$$

$$\overrightarrow{D_\beta} = \left|\overrightarrow{C_2}.\overrightarrow{X_\beta} - \vec{X}\right| \quad (14)$$

$$\overrightarrow{D_\delta} = \left|\overrightarrow{C_3}.\overrightarrow{X_\delta} - \vec{X}\right| \quad (15)$$

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1}(\overrightarrow{D_\alpha}) \quad (16)$$

$$\overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2}(\overrightarrow{D_\beta}) \quad (17)$$

$$\overrightarrow{X_3} = \overrightarrow{X_\delta} - \overrightarrow{A_1}(\overrightarrow{D_\delta}) \quad (18)$$

$$\vec{X}(iter+1) = \frac{\overrightarrow{X_1}+\overrightarrow{X_2}+\overrightarrow{X_3}}{3} \quad (19)$$

According to α, β, and δ, a search agent revises its location in a multi-dimensional search space by utilizing these equations. Incorporating vectors $\vec{A}$ and $\vec{C}$ These calculations compel the GWO algorithm to traverse and benefit from the search arena. Half of the iterations are used to explore the interval. $\vec{A} \geq 1$, and the other half is used to exploit the interval $\vec{A} < 1$. declines. When $\vec{C} > 1$, the vector $\vec{C}$ Also makes exploration easier, and its range is $2 \leq \vec{C} \leq 0$. When the absolute value of C is less than 1 and the linear drop of A with increasing repeat time is observed, misuse becomes apparent. But $\vec{C}$ It is generated randomly to encourage exploration and exploitation at any level and to sidestep local optima. The fundamental GWO was unable to capture the optimal solution in cases where the simulation kept settling at a local minimum.

The algorithm was tweaked to make GWO better at finding the optimal solution. The convergence performance of the GWO has been improved by utilizing a number of methods.

To improve GWO's ability to locate the search area and determine the optimal solution, several changes were implemented. The PRc-PID controller leverages the strengths of both Proportional-Resonant (PR) and cascaded Proportional-Integral-Derivative (PID) control techniques. It is particularly effective in handling both voltage and current-related PQ issues by employing shunt and series regulators within the UPQC structure.

A schematic depiction of the standard Prc-PID controller design employing GW0 for tweaking is shown in Figure 6. [23, 24]. GWO is a meta-heuristic optimization algorithm that mimics the hunting behavior of grey wolves. It has shown promise in optimizing controller parameters due to its ability to balance exploration and exploitation in the search space. In this context, GWO is used to tune the PRc-PID controller parameters, leading to improved UPQC performance.

6.2. GWO-Based Tuning

The social framework and hunting habits of grey wolves serve as the inspiration for this naturalistic optimization method [24]. Alpha, beta, delta, and omega are the four individual kinds utilized in the grey wolf leader structure and hunting process, which GWO adopts [24]. The steps in the GWO technique for PRc-PID tuning are as follows:

Step 1: To begin, assign random locations to the grey wolf population in their quest area.
Step 2: Next, determine each grey wolf's fitness by classifying them as alpha, beta, and delta wolves.
Step 3: At this point, update each wolf's place.
Step 4: If the results do not meet the requirements, change alpha, beta, and delta after first evaluating the revised positions.
Step 5: Lastly, continue steps 3-4 until the desired outcomes (i.e., number of iterations) are not achieved.

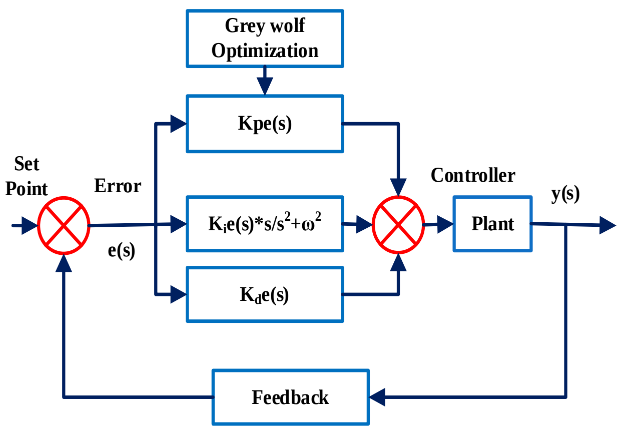


Fig. 6 Control diagram for PRc-PID with grey wolf algorithm

7. Results and Discussion

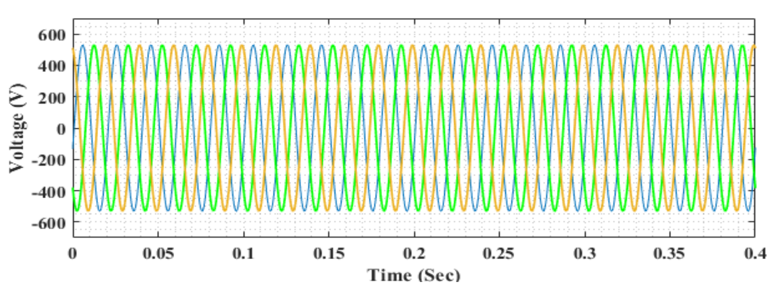
Simulation results indicate that the GWO-optimized UPQC significantly improves voltage stability and reduces THD in standalone microgrids. The system also exhibits better dynamic response under varying load and source conditions. Comparative analysis shows a clear advantage of the GWO approach over classical methods in terms of adaptability, robustness, and convergence speed. In this section, various cases with results are discussed. Simulation is performed using the Simulink environment in order to validate the proposed method. In this paper, PQ problems are reduced by using a controller and optimization methods. This work shows a PQ improvement by reducing the THD when applying the fault. The performance is assessed by measuring the current and voltage with waveforms that are injected, compensating, and creating problems, by comparing the proposed controller with other controllers, to show better performance. Different PQ issues like sag, swell, and harmonics are used to validate the proposed controller with optimization. In this work, PQ is measured in terms of comparing the THD under different cases, also measured by the occurrence of sag and swell while applying a fault in the inputs. For high PQ, it also compares voltage readings between two accurate voltmeters measuring the same system voltage under different cases. Three instances are assessed to show the stability and reliability of the controller, which are tuned with optimization. Three cases are enumerated below:

- Case 1: With PRc-PID controller
- Case 2: With PRc-PID controller and Grey Wolf Optimization Algorithm (GWO)
- Case 3: PRc-PID controller and Grey Wolf Optimization Algorithm (GWO) with fault

To evaluate the performance of the suggested technique, three different cases are used. In the first and second cases, PRc-PID controllers are utilized without optimization methods, PRc-PID controllers using GWO algorithms are used. Finally, the fault is used in the suggested approach to test its validity based on PQ concerns. By including disturbances in the proposed method, PQ characteristics are measured based on harmonics, sag, and rise. The electricity required to meet demand is provided by the PV and WT systems. These scenarios are detailed below, along with a design presentation.

7.1. Case 1: With PRc-PID Controller

In this case, the validation is performed with the PRc-PID controller. The source is kept the same as per case 1. But in this section, the controller is changed from PI-PID to PRc-PID. The voltage and current quality are improved by this PRc-PID controller. The simulation results for current and voltage are shown in Figure 7. The active power is increased from 10×10^4 to 2.5×10^5, and the reactive power is increased from 7×10^4 to 14×10^4as compared to case 1. Figure 8 demonstrates this power in a graphical manner. The ratio of THD is analyzed to evaluate the performance of this controller. With the PI-PID controller, we get a THD of 23.60%, and it is reduced to 22.11% in this case. Figure 9 demonstrates the THD value for voltage and current with the PRc-PID controller. This controller gives the output of THD as better than the PI-PID controller. Compared to the above case, it performs well. The active power is high, and the reactive power is high at the initial stage, but it falls within 0.4 sec. This controller is not very stable and reliable for PQ issues.



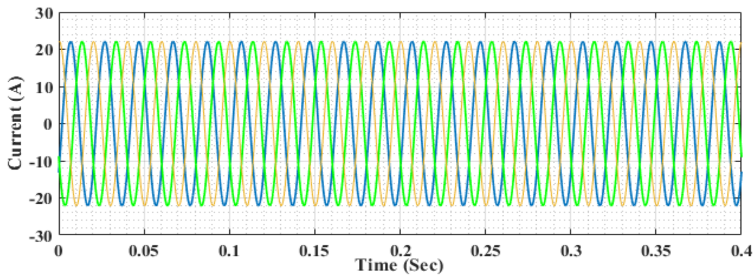


Fig. 7 Simulation result for voltage and current with PRc-PID controller

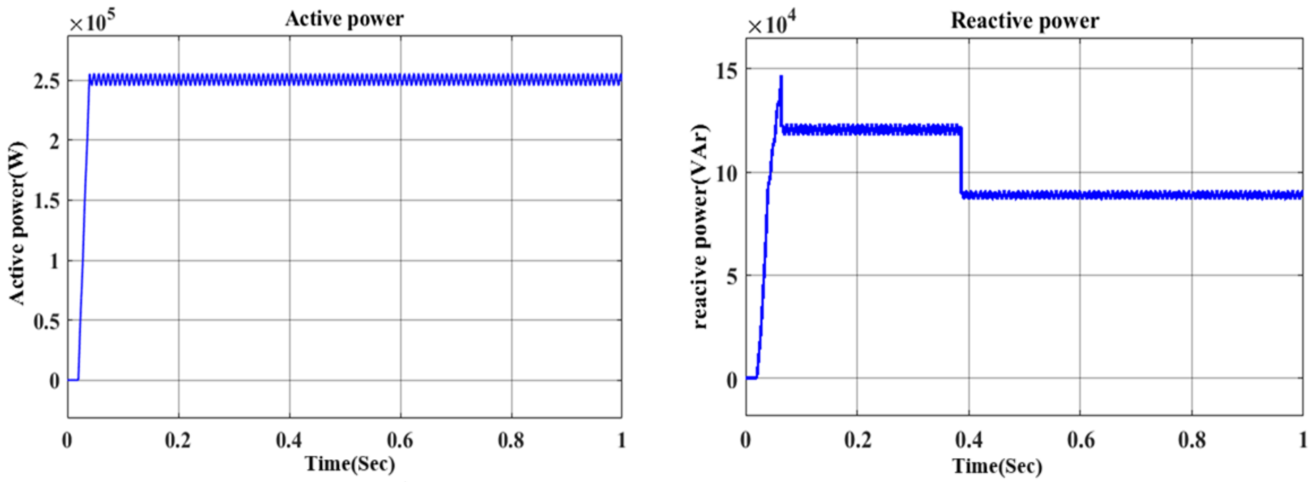


Fig. 8 Active and reactive power with PRc-PID controller

7.2. Case 2: With PRc-PID Controller and GWO Algorithm

The proposed PRc-PID controller with GWO is used to validate this section. The output of UPQC is given to the load. GWO takes the input from the load, and this algorithm provides the input to the controller. This controller minimizes the harmonics and generates pulses with the help of pulse width modulation. The selected pulse is given to the series and shunt active power filters in the UPQC. The range for voltage is 500, shown in Figure 10 (a), and the current is 20A, shown in Figure 10 (b), for the proposed method with optimization.

The time needed to validate the performance is 1s, as for cases (1- 2). Figure 10 shows the simulation output result for voltage and current for this case. The output of this case is best when compared to cases 1 and 2. Figure 11 represents the active and reactive power output for the proposed method. Active and reactive power are 3.8×10^5, and 2.3×10^5respectively, this power is significantly higher than in case 1. PRc-PID controller with optimization provides better THD value than the PRc-PID controller without optimization algorithm. THD for voltage and current is shown in Figure 12.

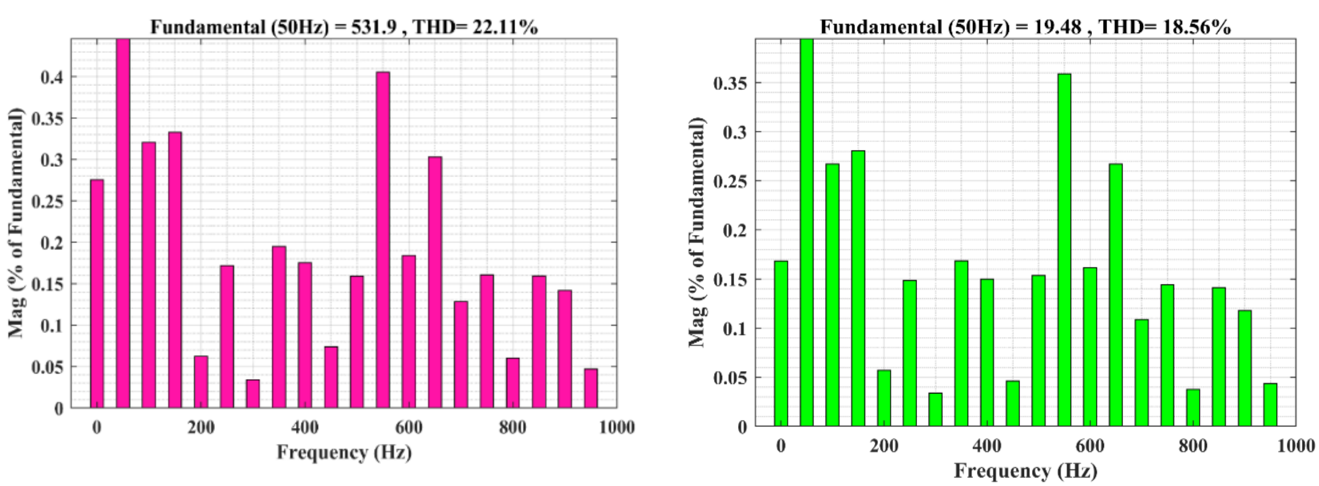


Fig. 9 THD for current in case 1

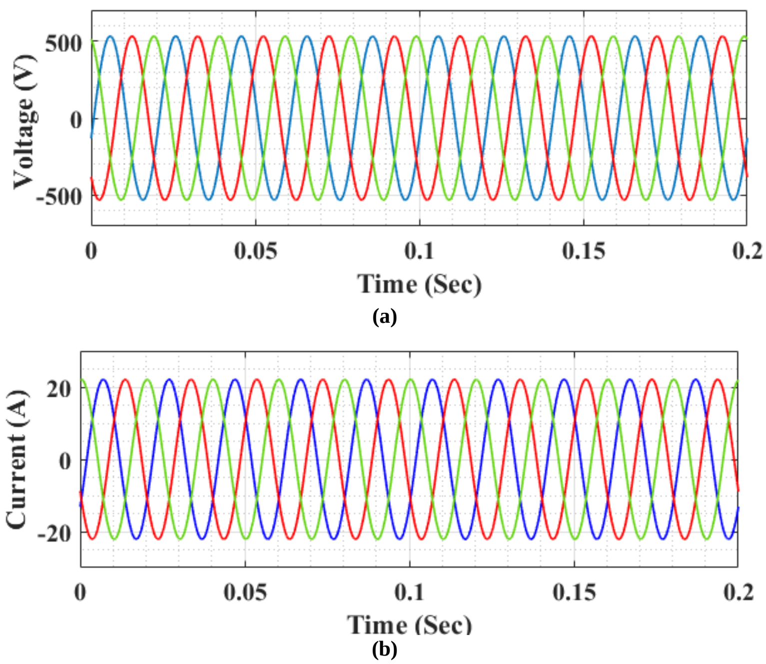


Fig. 10 Simulation result for voltage and current with PRc-PID controller and GWO

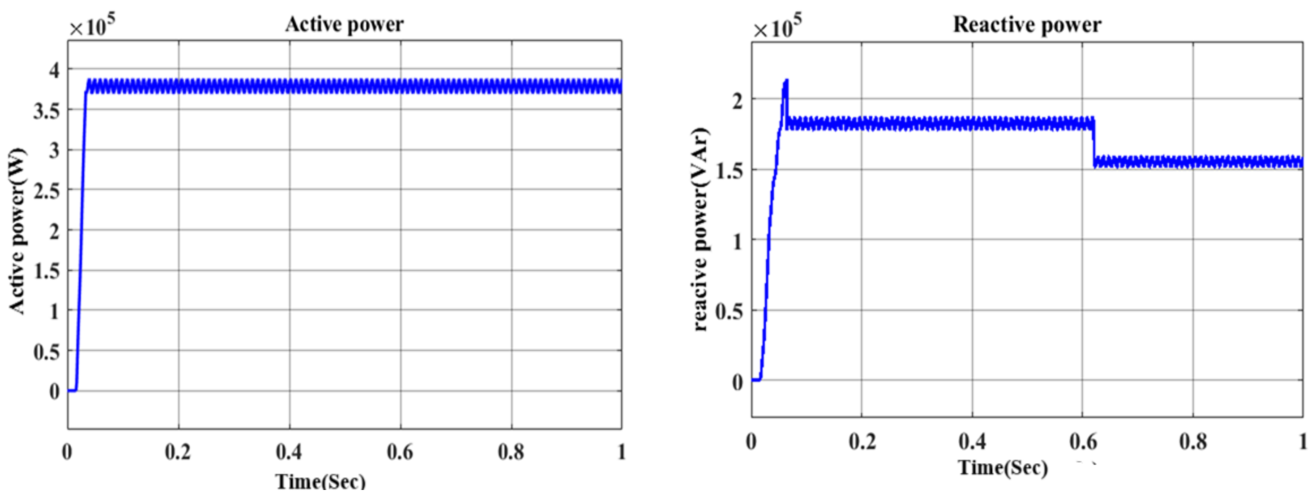


Fig. 11 Active and reactive power with PRc-PID controller and GWO

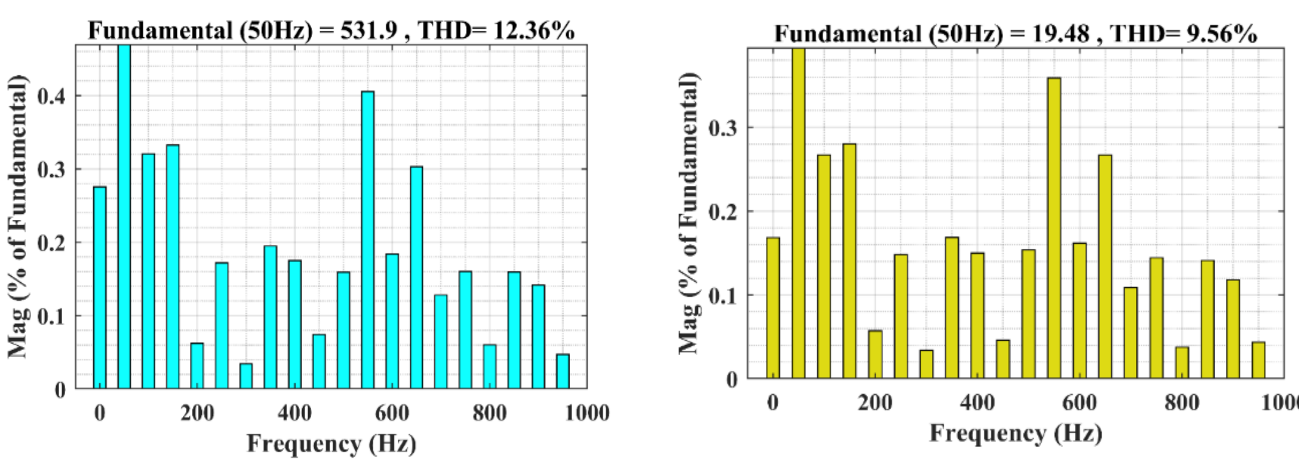


Fig. 12 THD for current in case 2

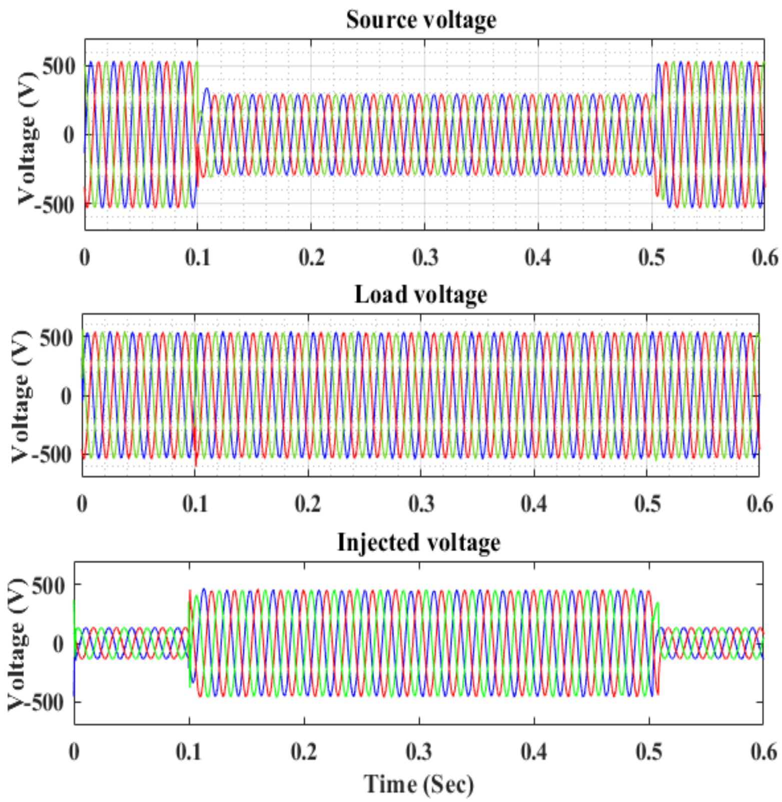


Fig. 13 Analysis of voltage sag condition in a standalone MG system

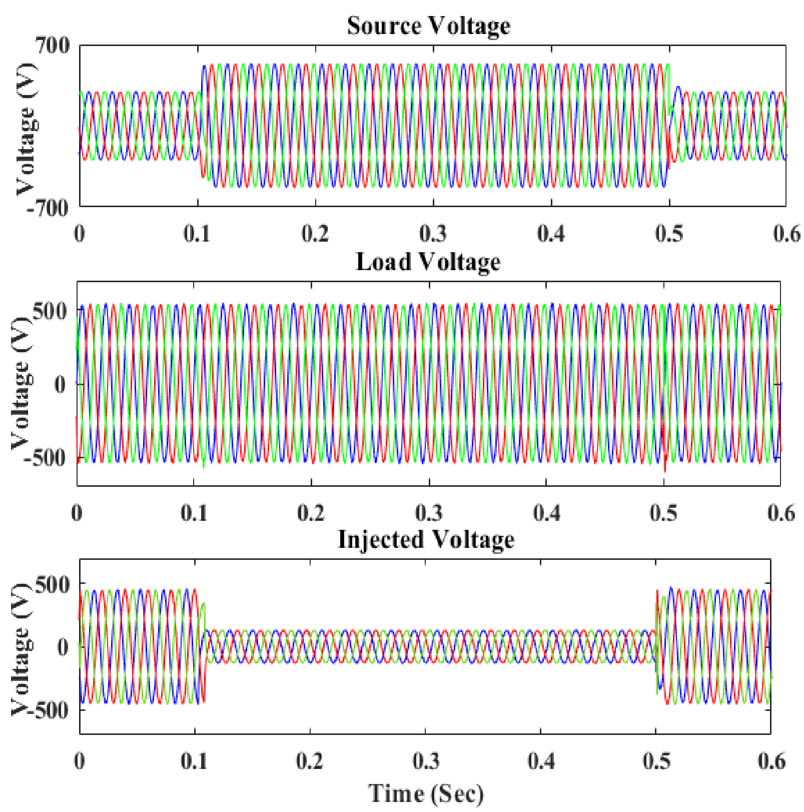


Fig. 14 Results of voltage swell in standalone MG

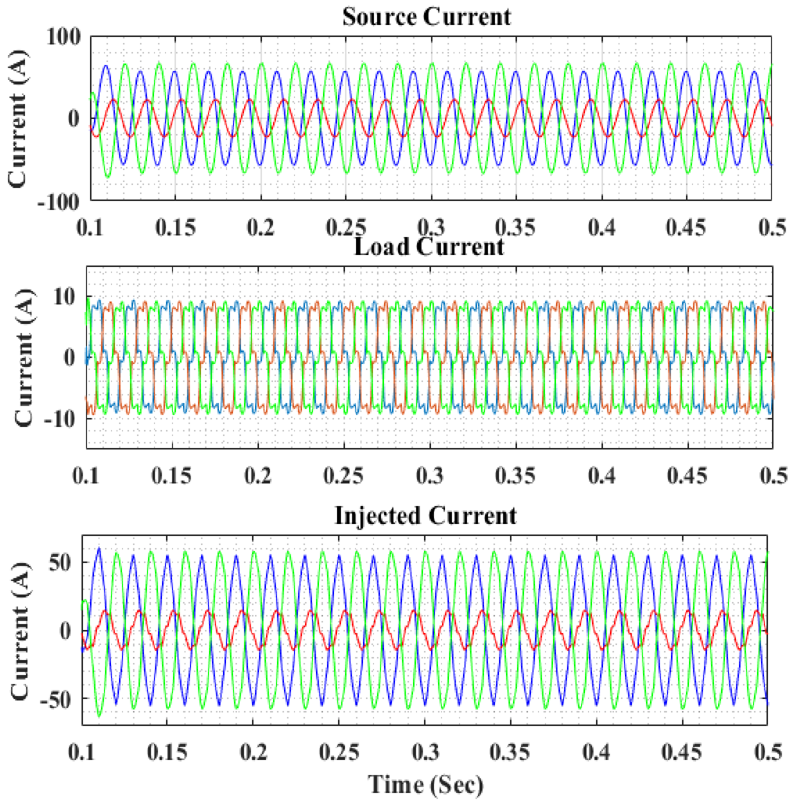


Fig. 15 Simulation result for current while applying the fault

7.3. Case 3: PRc-PID Controller and GWO Algorithm with Fault

The validation for voltage and current sag is done by applying the fault in the load. Case 3 represents the enhancement of the PQ in this proposed method by applying a fault. For the system to run reliably and consistently, the voltage drop must be corrected. PQ issues are sustained by using UPQC, and it provides the power required to meet the load.

Figure 13 shows the sag generation in the voltage signals. The UPQC and the proposed controller with optimization manage this sag. The proposed method shows the voltage drop in standalone MGs. Voltage swell should be solved to run the system steadily and linearly.

Figure 14 illustrates the evolution of the voltage swell. By combining the suggested controller with an optimization technique, the mitigation is accomplished. The threshold conditions are uncontrollable due to power grid damage. When the reported voltage goes up or down by a specific criterion, the program isolates the system. The active power filters receive the necessary power, and the suggested way decreases the swell. This method's output is unaffected by this swell and sag situation. Therefore, PQ problems, such as voltage and current sags and bulges, are addressed using this technology.

Figure 15 indicates the current after applying a fault in the proposed method. But the current will not be affected by these faults because of the proposed method with GWO. Thus, the PQ enhancement is achieved by using this method.

The THD of the proposed method is reduced to 8.54%, while without the optimization method, it achieved 22.11% and 18.56% UPQC, and the system is reliable and dependable thanks to the PRc-PID controller and optimization theory. Using a controller and technique, PQ issues are totally eliminated in a standalone microgrid system with the correct controlling signals of shunt and series APF.

This method is used to reduce PQ issues, including disruption, interruption, swell, harmonics, and sag. The suggested controller with optimization method can help by creating the right control pulses for series and shunt APF. It is used to reduce current and voltage oscillations in linked standalone microgrid systems. The PQ is measured using a UPQC device with a controller and optimization method.

Output power with less harmonics represents the enhanced PQ. PQ is also measured by applying a fault in the input side, by which fault sag and swell may occur. The proposed controller and optimization method connected with UPQC will prevent these flickering and generate the output voltage with no distortions.

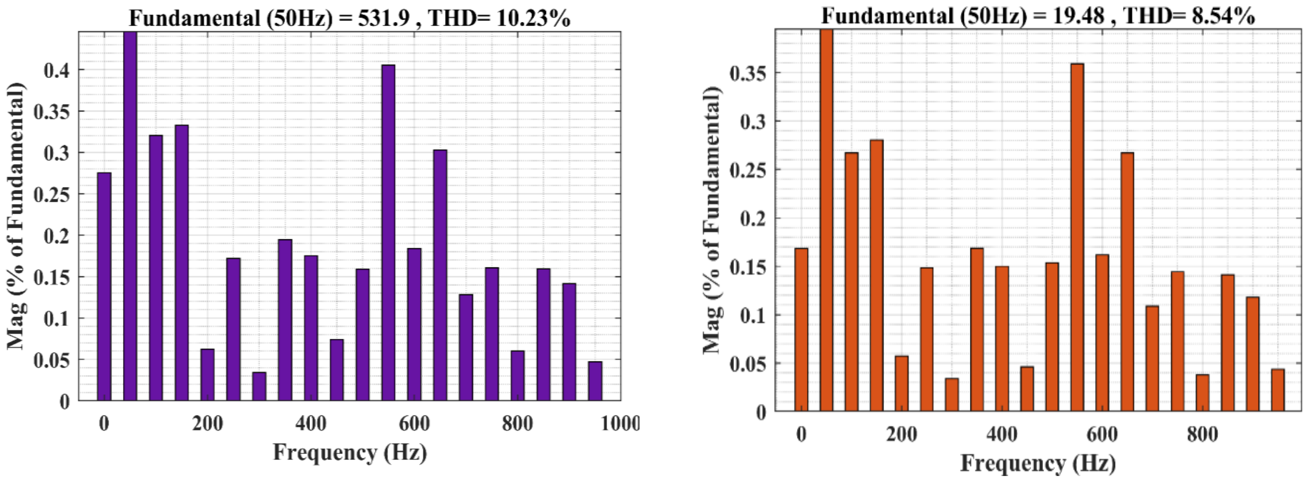


Fig. 16 THD for current in case 3

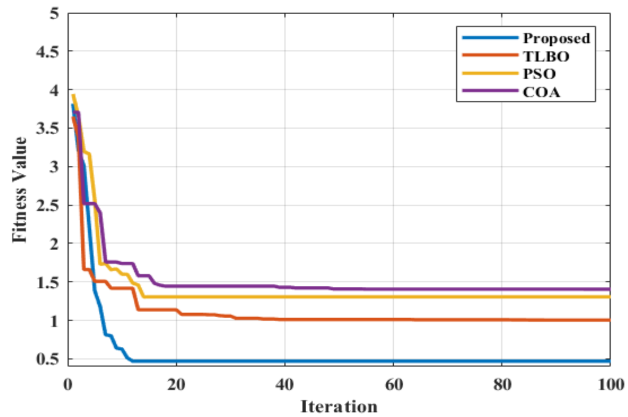


Fig. 17 Convergence curve

Table 1. Comparison of THDs with proposed controllers

Controllers	THD for Voltage (%)	THD for Current (%)
PRc-PID Controller	22.11	18.56
PRc-PID with TLBO	18.21	13.56
Prc-PID with TLBO(Fault)	14.21	10.56
Prc-PIC with GWO	12.36	9.56
Prc-PID with GWO(Fault)	10.23	8.54

Table 2 shows the parameters utilized for standalone MG and GWO implementation

Table 2. Implementation parameters

S. No	Description	Parameters	Values
1	PV	Irradiance	1000
2		Temperature	25 C
3	WT	Generated power	50 KW
4		Base Torque	200/0.9 N/m
5		Base rotational speed	1.2 m/s
6		Nominal mechanical output power	20 KW
7		Armature inductance	0.000835
8		Base wind speed	12 m/s
9	GWO	Number of iterations	100
10		Number of Search Agents	100
11		Dimension	30

8. Conclusion

This paper reveals the effectiveness of Grey Wolf Optimization for tuning UPQC control parameters in standalone microgrids. The proposed approach results in enhanced power quality, reduced harmonic content, and improved voltage regulation. Future work may involve hardware-in-the-loop implementation and comparison with TLBO. The use of a PRc-PID with Grey Wolf Optimization-based UPQC is a promising approach for enhancing power quality in standalone microgrids. This method offers the potential for improved performance, greater stability, and better overall management of power quality issues in such systems. To lessen power quality problems, this study suggests a standalone microgrid system that uses UPQC based on coordinated PQ theory controllers. The design of a standalone microgrid incorporates the WT, PV, and BESS systems. Power from PV and WT is used to compensate for the load side's required demand power. Connected load systems that rely on renewable energy sources may face challenges due to power quality issues. To compensate for power quality issues in a standalone microgrid, the UPQC with coordinated PQ theory is employed.

The PRc-PID controller controls the active power filters in both series and shunt configurations. By selecting optimal pulses, GWO enhances the PRc-PID controller's performance according to coordinated PQ theory. Although the power quality of the standalone microgrid system is low, the suggested techniques can rectify this. Four distinct PQ problems, sag, Swell Current Distortions, and THD, are examined in order to assess the suggested controller. In standalone microgrid systems, THD analysis of these signals is performed both prior to and after the installation of UPQC. The study found that the most effective method for reducing power quality issues was a synchronized PQ theory controller that used PRc-PID and GWO algorithms.

References

[1] Waqas Ahamd, and Irfan Ullah, "Unified Power Quality Conditioner-Based Power Quality Improvement in Micro-Grid," *2025 IEEE Texas Power and Energy Conference (TPEC)*, College Station, TX, USA, pp. 1-6, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[2] Sebastian Lobos-Cornejo et al., "Smart Energy Strategy for AC Microgrids to Enhance Economic Performance in Grid-Connected and Standalone Operations: A Gray Wolf Optimizer Approach," *Sci*, vol. 7, no. 2, pp. 1-43, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[3] Devesh Raj Mani, Sivasubramanian Muthu, and Kumarasamy Kasilingam, "Enhanced Power Quality and Efficient Photovoltaic Integration with a PV-Based Unified Power Quality Conditioner Using Optimized MPPT Technique," *Electrical Engineering*, vol. 107, no. 2, pp. 2015-2036, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[4] Mehdi Sanaei et al., "New PSO-GWO-Based Model for Enhancing Power Quality in Electrical Networks Interconnected with Photovoltaic Sources," *Frontiers in Energy Research*, vol. 12, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[5] P.A. Mohanarao, Sarat Kumar Sahu, and G. Saraswathi, "Power Quality Improvement in a Standalone Microgrid System Using Coordinated PQ Theory in UPQC-SSO," *GMSARN International Journal*, vol. 17, pp. 118-140, 2023. [Google Scholar] [Publisher Link]

[6] Emmanuel Hernández-Mayoral et al., "A Comprehensive Review on Power-Quality Issues, Optimization Techniques, and Control Strategies of Microgrid Based on Renewable Energy Sources," *Sustainability*, vol. 15, no. 12, pp. 1-53, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] N. Bharat Mohan, B. Rajagopal, and D. Hari Krishna, "Power Quality Enhancement of Hybrid Renewable Energy Source-Based Distribution System Using Optimised uPQC," *Journal of Control and Decision*, vol. 12, no. 3, pp. 449-470, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[8] G. Dinesh et al., *Multi-Objective Optimization Process to Analyze the Renewable Energy Storage and Distribution System from the Grid*, Sustainable Smart Homes and Buildings with Internet of Things, Wiley, pp. 187-202, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[9] Anca Miron, Andrei C. Cziker, and Horia G. Beleiu, "Fuzzy Control Systems for Power Quality Improvement-A Systematic Review Exploring their Efficacy and Efficiency," *Applied Science*, vol. 14, no. 11, pp. 1-28, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[10] Abdelrahman M. Nasser et al., "A Grey Wolf Optimization-Based Modified SPWM Control Scheme for a Three-Phase Half Bridge Cascaded Multilevel Inverter," *Scientific Reports*, vol. 14, no. 1, pp. 1-33, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[11] C. Udhaya Shankar, and N. Nithya devi, "UPQC-Based Hybrid Technique to Reduce Power Quality Problems in the Photovoltaic Grid System," *Journal of Circuits, Systems and Computers*, vol. 33, no. 13, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[12] Seetha Ramanjaneyulu Korada, Rajamony Brinda, and Irissappane Dhanusu Soubache, "Innovative Power Quality Control for Integrated Photovoltaic and Electric Vehicle Systems in Smart Grid," *Journal of Renewable Sustainable Energy*, vol. 17, no. 4, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[13] D. Krishna, M. Sasikala, and R. Kiranmayi, "FOPI and FOFL Controller Based UPQC for Mitigation of Power Quality Problems in Distribution Power System," *Journal of Electrical Engineering and Technology*, vol. 17, no. 3, pp. 1543-1554, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] D. Krishna, M. Sasikala, and V. Ganesh, "Adaptive FLC-Based UPQC in Distribution Power Systems for Power Quality Problems," *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 1719-1729, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] E. Himabindu, Radhika Dora, and D. Krishna, "Fuzzy Type-II Controller Based UPQC for Power Quality Enhancement in Grid Connected Micro Grid System," *2022 3rd International Conference for Emerging Technology (INCET)*, Belgaum, India, pp. 1-6, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[16] Himabindu Eluri, and M. Gopich Naik, "Energy Management System and Enhancement of Power Quality with Grid Integrated Micro-Grid Using Fuzzy Logic Controller," *International Journal of Electrical and Electronics Research (IJEER)*, vol. 10, no. 2, pp. 256-263, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[17] Himabindu Eluri, and M. Gopich Naik, "Energy Management System for Grid Integrated Microgrid Using Fuzzy Logic Controller," *2020 IEEE 7th Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, Prayagraj, India, pp. 1-6, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[18] M. Osama abed el-Raouf et al., "Performance Enhancement of Grid-Connected Renewable Energy Systems Using UPFC," *Energies*, vol. 16, no. 11, pp. 1-22, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[19] C. Vennila et al., "ALSO-DCGNN: Enhancing Power Quality and Voltage Regulation of Energy Storage Systems in DC Micro Grid," *Environment, Development and Sustainability*, pp. 1-25, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[20] Jatoth Rajender, Manisha Dubey, and Yogendra Kumar, "Cascaded Controller Tuned UPQC for PQ Enhancement in EV Connected Charging Station," *International Journal of Robust and Nonlinear Control*, vol. 35, no. 15, pp. 6589-6603, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[21] Addala Satyanarayana, and I.E.S. Naidu, "Grasshopper's Optimization Algorithm Based ASFC for Enhancing the Performance of Micro Grids," *SSRN Electronic Journal*, pp. 1-11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[22] Khwairakpam Chaoba Singh, Shakila Baskaran, and Prakash Marimuthu, "Renewable Based Micro-Grid System Energy: A Review," *Clean Technologies and Environmental Policy*, pp. 1-26, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[23] Ganesh Selvaraj et al., "Optimal Power Scheduling in Real-Time Distribution Systems Using Crow Search Algorithm for Enhanced Microgrid Performance," *Scientific Reports*, vol. 14, no. 1, pp. 1-20, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[24] Balakumar Subramanian et al., "Mitigating Voltage Quality Issues in Sawla Substation, Ethiopia: A Dynamic Voltage Restorer Controlled by Neural Networks and Fuzzy Logic," *Results in Engineering*, vol. 26, pp. 1-13, 2025. [CrossRef] [Google Scholar] [Publisher Link]