Power Quality Improvement in a Standalone Microgrid System Using Coordinated PQ Theory in UPQC-SSO

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ABSTRACT

The standalone microgrid usage has increased because of its specific characteristics such as more flexible to supply energy consumer needs, reduced losses, less polluting, and more efficient. The power quality issues (PQ) increase in standalone microgrid due to integrating renewable energy resources (RES) with different load loads. In order to address power quality issues in standalone microgrid system, Unified Power Quality Conditioner (UPQC) with coordinated PQ theory controller-based Salp Swarm Optimization (SSO) is introduced in existing research. A standalone microgrid is planned with Wind Turbine (WT), Battery Energy Storage System (BESS) and Photovoltaic (PV). The Functional Order Proportional Integral Derivative (FOPID) and synchronized PQ theory controller are created in UPQC device in proposed method. To supply best pulses to converter, UPQC shunt and series controllers use combined PQ theory. Current and voltage's PQ issues are resolute through controller process that enhance independence microgrid system with reliable and stable operation. Optimal parameters of FOPID controller are commuted through SSO algorithm. Proposed method accomplished in MATLAB/Simulink platform as well as examined performance by various PQ issues such as disturbance, swell, interruption, and sag along with harmonics. As load is set 180 e3 V, 50 Hz for validate proposed model. Performance analysis is computed by fair analysis of current methods of FOPID controller namely, Grey Wolf Optimization (GWO), Particle Swarm Optimization (PSO) and Whale Optimization Algorithm (WOA).

1. INTRODUCTION

In recent years, energy demand is increasing and amassing greenhouse gases emission in the atmosphere. To reduce greenhouse emissions and increase energy generation, renewable energy resources are considered the best solution [1]. Renewable energy resources can generate power without omitting the toxic gases in the environment. There are numerous sorts of renewable energy sources widely accessible, such as Photovoltaic (PV), Wind Energy Conversion Systems (WECS), Biomass, Tidal energy, geothermal energy and Hydro energy [2]. Among them, PV and WECS are the most advanced renewable energy resource and widely used in any system. The PV and WECS have become comfortable and beneficial because of characteristics such as cost-effective attractiveness and significant [3, 4]. The WECS and PV generation closely depends on environmental conditions such as weather and climate changes. Maximum Power Point Tracking (MPPT) approaches are used to improve PV and WECS systems' performance as result of changes in environment [5].

A hybrid power system called standalone microgrid integrates all different kinds of DG units to fully utilise both their supportive and unique qualities [6]. The standalone microgrid system increases the energy efficiency, power supply reliability, and energy utilization rate of the system [7]. Besides that, standalone microgrid system is associated to renewable energy supplies to compensate load requirements. A standalone microgrid system may suffer power quality issues and instability issues because of interconnected renewable energy sources. Additionally, unstable conditions are increased in the load side because of intermittent environmental conditions of renewable energy resources [8]. In standalone microgrid system, due to intermittent environmental change of renewable energy resources and load changes like unbalanced load, non-linear load and critical load, PQ issues happen, viz disturbance, sag, harmonics, and swell [9]. This changes voltage levels in load side because of power quality issues, which will trip the load. The continuous tripping of standalone microgrid affects reliability of system. Tripping on system must be prevented

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in order for system to function properly [10].

Reliability and stability of the system are increased by preventing the system from power quality issues. Generally, these problems are alleviated with the help of filters and power custom devices of flexible alternating current transmission systems (FACT) devices. In a standalone microgrid, FACT devices are used to overcome problem based on power quality, which enable reliability and stability of the system [11]. Series and shunt types of FACT devices are linked in a microgrid for purpose of recompense PQ issues. The series FACT devices are Dynamic Voltage Restoration (DVR) [13] and Static Synchronous Series Compensator (SSSC) [12] which will be connected in series and compensated for the voltage issues in the microgrid. The shunt FACT device is Thyristor Controlled Reactor (TCR) [14] and Distribution Static Compensator (DSTATCOM) [15], which are connected in shunt and compensate and regulate voltage in the system. The DSTATCOM is used to compensate for voltage problems but fails to reduce the harmonics. DVR also performs compensation for voltage problems, but it required additional capacitors or storage elements. The paper is mainly focused on mitigating power quality issues in a standalone microgrid system and maintaining stability with reliability operation. The main objectives of the proposed design are listed below.

1.1 Organization and contribution of the paper

Due to interconnection of renewable energy sources with various types of loads, standalone microgrid system may have power quality concerns that are linear load, unbalanced and non-linear load condition. Key contribution of paper is listed as below,

- ❖ The design of standalone microgrid system is done using BESS, PV, and WT. Power was generated by WT and PV systems according to the irradiance and wind speed. While WT and PV struggle to load conditions due to environmental factors and partial shading, purpose of using BESS is to store excess energy as well as deliver the power needed to meet load requirements.
- ❖ Standard microgrid system is connected to linear load, critical load, non-linear load, and unbalanced load circumstance. An interrelated system can introduce PQ problems of interference, swelling, disturbance, sagging, and harmonics in current and voltage signals. PQ concerns affect the stability and reliability of the system, which can be solved through the use of UPQC device.
- ❖ On the UPQC device, SSO-based FOPID controller strategy is developed, which allows individual microgrid PQ failures to be minimized and load requirement to be met. To recompense for the load requirement as well as to absorb more energy as of standalone microgrid system, power is supplied to the controller continuously, which is used to deliver the essential power to compensate the load requirement with the alleviation of PQ problems. The UPQC device used to create this controller works with two separate controllers: the Shunts Active Power Filter Controller and the Series Active Power Filter Controller.
- ❖ To design a control strategy of proposed model and verified by combining the loads in demand side namely critical load, non-linear load, and unbalanced load levels. PQ problems are utilized to analyze four types, viz interference, swell, disturbances and sag, generated by use of non-linear loads. Furthermore, harmonics in system analyzed under two circumstances that are with and without UPQC connected in system. The presentation of proposed method contrast by way of techniques already designed such as GWO, WOA and PSO optimization.

The research manuscript is preset as follows; some kind of correlated work based on power quality enhancement in standalone microgrid system. Section 3 featuring a standalone microgrid system, provides a full description of proposed system architecture. Section 4 gives detailed clearance of proposed control structure using UPQC, such as shunt or series active power filter. Proposed FOPID controller approach is used to improve the performance of power system. The FOPID controller is enhanced with help of SSO algorithm. The background information and flowchart of SSO is described in section 5. An evaluation of proposed technique is described in this presentation in section 6. Section 7 concludes manuscript with future works.

2. LITERATURE REVIEW

The power quality enhancement is an essential factor in a standalone microgrid system to enable stability and reliability. In standalone microgrid system, variety of approaches were designed to address power quality concerns. This section examined few strategies.

The hierarchical control techniques were designed by Bishoy E. Sedhom *et al.* [16] to reduce problems with power quality in Smart Micro Grids (SMGs). Goal of technique was to decrease impact of power quality issues as well as Total Harmonic Distortion. This approach can save system costs by reducing power supply problems.

Bishoy E. Sedhom *et al.* [17] have presented multistage H-infinity (H-) controller to mitigate PQ problems and improve operation reliability. The Harmony Search Algorithm included as part of intended strategy to improve controller's display. Designed method was compared with four various methods such as voltage control loop, droop control loop, control loop for inductance capacitance inductance (LCL) filter and current control loop. An internal modeling system were available in H-Infinity Control which adjusts frequency while increasing reliability and stability of system.

Ahmed Hussain Elmetwaly *et al.* [18] have suggested Proportional Integral Derivative (PID) controller with an Adaptive Switched Filter Compensator (ASFC) for improving stability, dynamic performance and minimising power quality problems.

Mojtaba Yavari *et al.* [19] have presented UPQC uses sliding mode control, immediate proactive and reactive power theories to improve system performance. The designed method has special features such as good performance in the power system under disturbances, complete compensation of UPQC, fast dynamic response.

Santanu Kumar Dash *et al.* [20] have presented model reference-based integral plus sliding mode dc-link controller with enhanced system stability and dependability. The PV was tied with UPQC design, which improves the system performance by reducing power quality issues.

Brahim Berbaoui *et al.* [21] have presented an ideal control technique in UPQC system to improve power sharing and reliability among series and shunt active power filters.The UPQC design was designed to protect the source and load side voltage disturbances in non-linear load conditions. The power factor, sag, and THD problems were reduced by the UPQC system. The virus colony search was used to computing the PI controller coefficients of the system.

Prasanta K. Barik *et al.* [22] have presented to lessen PQ problems in microgrid, fuzzy controller with modified synchronous frame theory used in Shunt Active Power Filters (SAPF). Standalone microgrid system was designed with solar, wind, fuel cell and DG, which connected through SAPF to enhance system behaviour under PQ problems.

Jitender Kaushal *et al.* [23] have presented PV combined AC microgrid with an artificial neural network (ANN) to lessen issues with unbalancing, power factor, THD, sag, frequency and swell. With proposed approach to increase dependability of standalone microgrid system, this method, power energy management, as well as power quality enhancement, were accomplished.

In ref [16], novelist explain hierarchical control techniques for power quality mitigation. The outcome is more effective and automatically evaluate the weight to improve the controller performance. However, the breakdown of the master unit has an impact on the control system, lowering system reliability and slow transient time. In ref [17], the author describes the multistage H-infinity (H-∞) controller to mitigate power quality issues and improve the system reliability. It gives a good performance and best outcome. Yet, the method has a poor transient response and improper handling of large systems and trouble in complex and non-linear conditions. In ref [18], ASFC with PID controller is described by novelist as a way to improve system stability. The method provides best response time and fast action to eliminate PQ issues. However, approach fails in unbalanced load settings and when source-side parameters change, and it also lacks an adaptive controller to address overall power supply problems and dc-link voltage management. In ref [19], to increase system stability and reduce PQ concerns, author explains sliding mode control and instantaneous active with reactive power theory in UPQC. The outcome well and fast response, however, it was a well-organized controller that affects the steady-state performance and transient state variables but complex system problems not solved by these controllers. In ref [20], in order to increase system dependability and security, author explains using an integral plus sliding mode dc-link controller with model reference-based control. It provides good performance and simple to use. However, these methods only suitable for PV tied with systems, not with microgrid systems. In ref [21], the author explains an optimal control method in UPQC system to mitigate PQ issues and improve the power sharing capability. It had an excellent effect on mitigating problems quickly, however, this method had been used for enhance system's reliability and stability that can withstand high load and non-linear load conditions. In ref [22 illustrates the ambiguous controller with modified synchronous framework that contain mitigation of PQ issues done through use of Shunt Active Power Filter (SAPF) more effectively. However, this method performs a good job to reduce power quality issues, but it needs an extra circuit for synchronization. In ref [23], to decrease PQ issues during extremely fast operation, author describes an ANN in PV integrated AC microgrid. However, this method was used to regulate system reliability, but large oscillations in the source and load side cannot be compensated.

In the literature, the existing method is reviewed. It has limitations that must be solved and improved by the proper method. The proposed method with proper control technique is designed, which described in the following sections.

3. A PROPOSED SYSTEM MODEL OF STANDALONE MICROGRID

Nowadays, power safety, global warming, increasing demand, and environmental problems are arising worldwide. A standalone microgrid thought to be greatest solution to these issues because it connects renewable energy sources with energy storage systems. An appealing design for regulating load needs and renewable energy sources on load side freestanding microgrid. The standalone microgrid created using load-connected systems and renewable energy sources like WT, BESS and PV [24]. WT, PV is used to generate the power from sunlight energy and wind speed which more advantages such as low maintenance, no fuel, and free with noise and hazard gases. In standalone microgrid system, renewable energy resources and loads are connected, which creates PQ problems like swell, disturbances, oscillations, and sag. PQ problems are collapse reliability and stability of standalone microgrid system. The PQ problems mitigated by connecting UPQC to system. Sag conditions, swell and voltage and current disturbance mitigated with assistance of UPQC. Proper control is an essential part of UPQC to reduce PQ problems. The coordinated PQ theory is designed in UPQC, which reduces the oscillations in the standalone microgrid system. The FOPID controller with SSO is introduced to improve the coordinated PQ theory controller of UPQC in the standalone microgrid system.

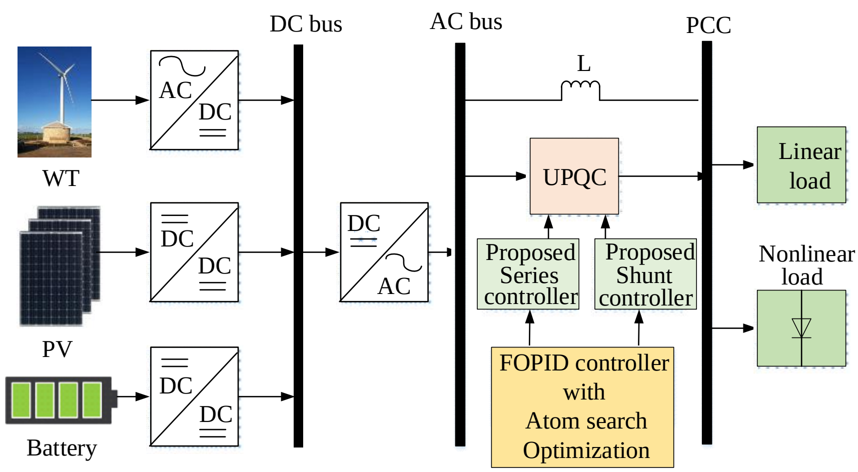

Fig. 1. System Architecture of the proposed method in standalone microgrid

Figure 1 shows anticipated technique's system architecture. The generation and storage systems integrated within standalone microgrid. Generally standalone microgrid system contain generation sources that produces power to meet load requirement. Ecological surroundings may cause PV and WT systems to increase or decrease their productivity. The batteries discharged to produce energy when PV and WT generation insufficient to meet load requirement. Similar to this, battery's charging process also stores extra power generated by WT and PV. Primary goal of effort to use UPQC to alleviate PQ issues in standalone microgrid system. The UPQC with coordinated PQ theory introduced in series active power filters and shunt active power filters. FOIPD controller with SSO designed in coordinated PQ theory, which improves control structure of proposed methodology towards compensating power quality problems like interruption, disturbance, swell, sag, and oscillations. The mathematical modelling of standalone microgrid generation and storage components are presented in the next unit.

3.1. Mathematical modelling of PV

Depending on irradiation levels, PV system converts solar energy into electricity. The authorized power of PV is used to determine its output generated power at typical light intensity levels [25]. Circuit design of PV model is illustrated in Figure 2.

Apply KCL in circuit 2, and the output current is formulated as follows,

$$I = I^{ph} - I^{d} - I^{sh} \tag{1}$$

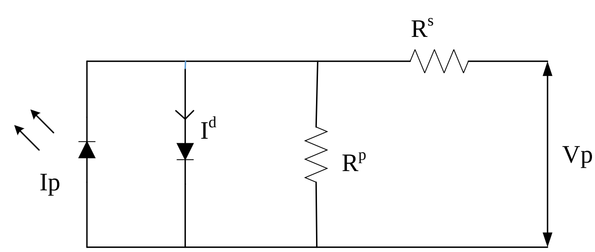

Fig. 2. PV system model.

The PV panel current is varied based on irradiance and temperature, which can be formulated as follows,

$$I^{PV} = N^P I^{ph} - N^P I^s \left[exp\left[\left(\frac{Q}{Nkt}\right)\left(\frac{V^{PV}}{N^s} + \frac{I^{PV}R^s}{N^P}\right)\right] - 1\right] - \frac{N^P}{R^P}\left(\frac{V^{PV}}{N^s} + \frac{I^{PV}R^s}{N^P}\right) \tag{2}$$

where, R^s is described series resistance, t is described as temperature $(25^0 c)$, k is described as Boltzmann constant $(1.38 * 10^{-19} J/K)$, Q is described as electron charge of$(1.607 * 10^{-19} C)$, N^P is described as several in parallel connected cells, N^s is described as several in series-connected cells and $I^{PV}$is described as the PV cell current, which also called immersion current. Provided in section below is WT modelling.

3.2. Mathematical modelling of WT

The power of wind has absorbed by wind turbine device. Wind kinetic energy collected by blades of wind turbine and transformed into mechanical energy. The mathematical formulation of wind turbine essential for determining operating zone of wind and comprehending wind turbine reaction [26]. Figure 3 depicts fundamental outline of wind turbine. The mathematical formulation for wind turbine's kinetic energy and power it produces as follows:

$$Kinetic\ energy\ (E) = \frac{1}{2}mv^2 \tag{3}$$

$$P^a = \frac{1}{2}\rho A V^3 \tag{4}$$

where ρ is described as air density, V is described as wind velocity, A is described as an area of windswept, m is described as wind turbine's mass flow rate.

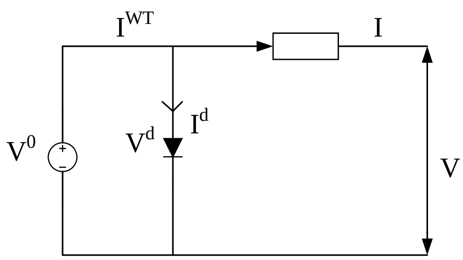

Fig. 3. Circuit model of a wind turbine system.

Motor blades produce wind power, which is total of down and upstream power variations. The wind power is formulated as follows,

$$P^w = \frac{1}{2}K^m\left(V^2 - V^{0^2}\right) \tag{5}$$

where, $K^m = \rho . A . \frac{V^2 - V^0}{2}$, V, V^0 is described as top and bottom speeds at start of rotor blades. The wind turbine's power coefficient is expressed mathematically as,

$$C^P = \frac{1}{2}\left(1 - \frac{V^0}{V}\right)\left[1 - \left(1 - \frac{V^0}{V}\right)^2\right] \tag{6}$$

where C^Preferred as wind system's power coefficient. The pitch angle (β) and tip speed ratio (α) have most effects on power coefficient. Wind's output power in watts is computed as below formula,

$$P(W) = \eta^W * 0.5 * \rho * C^P(\beta, \alpha) * V^2 \tag{7}$$

where, η^W is described as the efficiency of wind. The pitch angle$(\beta = 0^0)$, that condition extreme power is achieved as of the wind turbine. The power coefficient value also fixed as the maximum value.

3.3. Mathematical modelling of BESS

In standalone microgrid system, battery is used to supplying/storing electrical energy by charging as well as discharging processes. The battery is an essential device in standalone microgrid system to compensate load demand under environmental conditions of PV and WT connected system [27]. The charging and discharging behaviour of battery at hour t is mathematically formulated and presented follows,

$$C^{bat} = C^{bat}(t-1)(1-\sigma) \pm \left[\frac{E^{load}(t)}{\eta^{inv}} - E^{Pv}(t)E^w(t)\right]\eta^{bat} \tag{8}$$

where σ describes self-discharge rate of battery, η^{bat} describes battery efficiency, $C^{bat}(t-1)$ defined battery bank capacity in (Wh) at hour $t-1$ and $C^{bat}(t)$ describes battery bank capacity in (Wh) at hour t. E^{load} defined as load power usage of MG at an hour (t), $E^w(t)$ defined as wind energy, η^{inv} mentioned as inverter performance and $E^{Pv}(t)$ stated as PV energy,

The negative or positive signs refer to discharging and charging rate. The main battery objective in standalone microgrid system, regulation of also charging to battery discharge associated with renewable energy, load demand available and state of charge (SoC). And battery SOC is presented by follows,

$$SoC = SoC_0 - \frac{1}{C^{nom}}\int_{to}^{t} I^{batt}(t)\,dt \tag{9}$$

In equation (9), battery current is denoted by I^{batt} and nominal capacity of battery is denoted byC^{nom}. The battery is used in a standalone microgrid system to compensate for load demand and solve environmental issues of PV and WT power unbalance scenarios.

3.4. Mathematical modelling of UPQC

In a stand-alone microgrid system, power quality issues are considered to be a major problem due to interconnected renewable energy sources such as unbalanced load, main load and non-linear load. A single microgrid can have its voltage, current PQ and other issues adjusted using UPQC technology. Two active power filters are included in UPQC design: series active power filter and shunt active power filter [28]. The dc-link connects to capacitor series and shunt active power filters are reconnected backwards. Design of UPQC is shown in Figure 4.

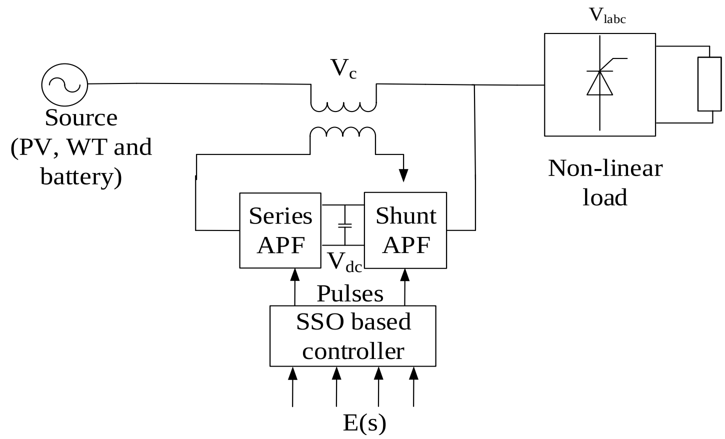

Fig. 4. Design of UPQC in standalone microgrid system.

From Figure 4, series converter through transformers among load and source. The Point of Common Coupling (PCC) similarly connects shunt converter in parallel. In UPQC arranged design, series active power filter serves as voltage source and shunt active power filter serves as current source. In standalone microgrid system, UPQC can be used to adjust for power quality issues with current and voltage signals. The UPQC design consists of shunt coupling inductor which is utilized to connecting the converter through the power line. By using this design, power quality issues can be made up for by increasing dc-link voltage to necessary parameter. A shunt converter's primary goals are to reduce load current harmonics and control dc-link voltage. Without doubt, shunt converter used to correct voltage swell and sag in renewable energy sources' supply side. To alleviate high frequency switching ripple, low pass filter is preferred. A transformer connected at output of converter provides section between converter and electrical connections. Shunt and series converters employ Insulated Gate Bipolar Transistors (IGBTs) with anti-parallel diodes to adjust switching impulses and solve PQ issues. The UPQC design is attempting to reduce the voltage power quality and voltage issues that have been identified through surveys.

- ❖ The PCC voltage inside shunt converter serves as current source if shunt active power filter is turned on while series converter is off. Voltage harmonics and power quality problems are lessened in this style of operation.
- ❖ The DC-link capacitor voltage is controlled by the shunt filter, which also mutes the current harmonics. The series filter, on the other hand, activates the voltage sock and swell harmonics.

In standalone microgrid system, performance of UPQC device should be increased by implementing an appropriate control structure to minimise PQ issues with current and voltage signals. Proposed coordinated PQ theory is introduced in a standalone microgrid system which completely reduces the power quality issues and regulating dc-link voltage. With aid of FOPID controller and SSO optimization, coordinated PQ theory also effectively manages signals. The following part introduces proposed synchronized PQ theory, FOPID controller with SSO description.

4. PROPOSED COORDINATED PQ THEORY DESCRIPTION

The standalone microgrid system usage has been increased to meet required load requests from consumers because of industrialization. The standalone microgrid system is designed with renewable energy resources and a battery which connected through the load conditions as per consumer usage. With interconnected loads with renewable energy resources, power quality issues may have happened, which collapse system stability and reliability. Problems related to PQ essential to be reduced for achieving better stability as well as reliability in standalone microgrid system. So, to solve problem of power quality and harmonic UPQC is linked with standalone microgrid system. To reduce voltage and current swell, sag, harmonics, and system disturbance, UPQC incorporates shunt and series active power filter. The series active power filter used in standalone microgrid system to lessen voltage swelling, sagging, harmonics and disturbances. A shunt active power filter used in standalone microgrid system to reduce current swell, sag, harmonics and disturbances. Furthermore, PQ principle integrated with FOPID controller used to improve optimal regulation of series and shunt active power filters of UPQC system in proposed model. In order to alleviate current and voltage PQ in signals, UPQC has two types of controllers. The reason for this problem unbalanced load on critical load, non-linear load and unbalanced load in load side. Overall control system with UPQC in complete microgrid system illustrated in Figure 5.

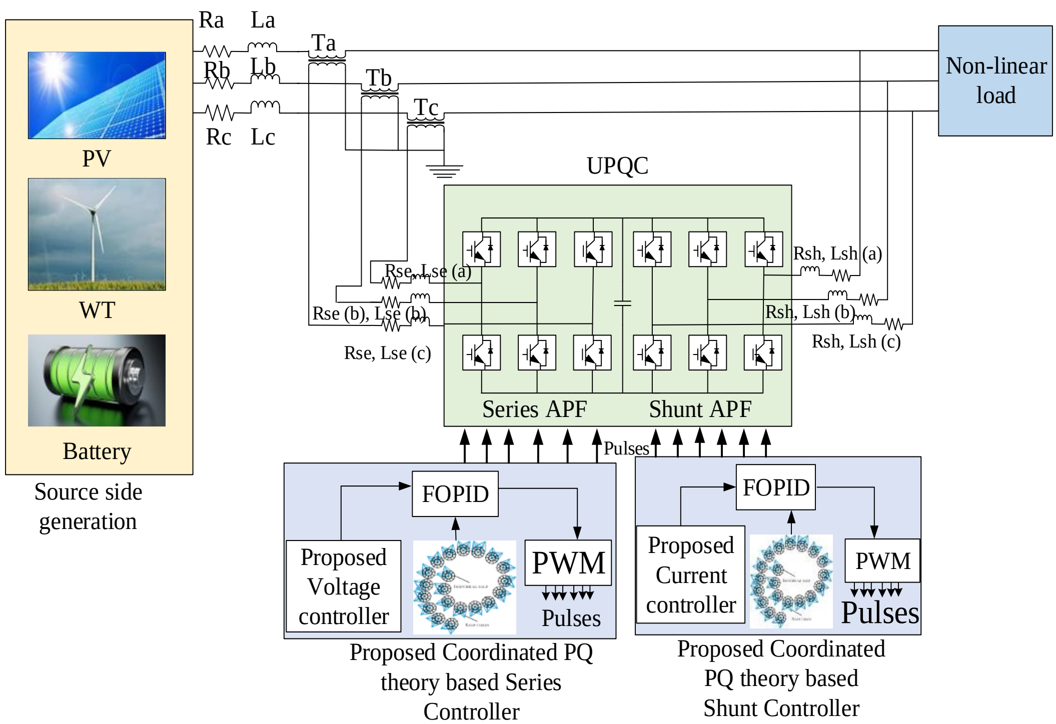

Fig. 5. Proposed Control structure design in standalone microgrid system.

The standalone microgrid system, renewable energy sources of PV, WT is considered as source voltage to supply the load. The PV and WT system may be affected by environmental conditions that must be solved; otherwise, a supply drop in the load side has occurred. To solve environmental conditions, the battery is additionally connected to a standalone microgrid system. The load requirements are changed due to consumer consumption of power from the generation power of PV and WT. Excessive, imbalanced and critical loads which can result in harmonics, sag, interruption, swell and PQ disturbances are frequently utilised. Through use of UPQC device, proposed control technique in both shunt and series active power filters makes up for PQ problems. The challenges in standalone microgrid system are completely removed by proposed coordinated PQ theory, FOPID controller and SSO. The series and shunt APF's suggested control scheme is depicted in following unit.

4.1. Control procedure of series APF

To lessen voltage variance in standalone microgrid system, UPQC design can use series active power filter. Utilizing third harmonic frequency component, system's dc voltage kept constant in series converter. A dc-link capacitor voltage gives right amount of series voltage in UPQC. If there are any power quality issues, series filter utilized to reduce voltage disturbance in standalone microgrid system [29]. A series of APFs protect power system from variety of PQ concerns, including interruption, swell, harmonics, sag and other disturbances. A series active power filter with proposed control topology is shown in Figure 6. The error voltage is determined and signals are produced by comparing source and line voltages. The proposed controller uses series active power filter to provide necessary voltage in order to handle power quality concern.

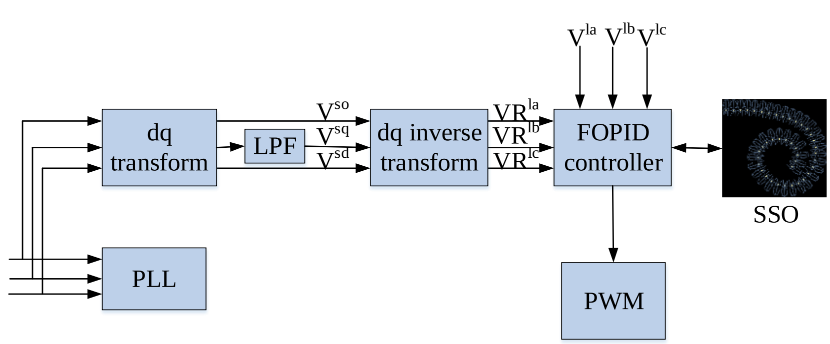

Fig. 6. Proposed control structure of series active power filter.

In order to create d-q coordinates in this controller, three-phase voltage ($V^{s(abc)}$) was first changed.

$$\begin{pmatrix} V^{s0} \\ V^{sd} \\ V^{sq} \end{pmatrix} = \frac{2}{3}\begin{pmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \sin(\omega t) & sin\left(\omega t - \frac{2\pi}{3}\right) & sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos(\omega t) & cos\left(\omega t - \frac{2\pi}{3}\right) & cos\left(\omega t + \frac{2\pi}{3}\right) \end{pmatrix} \times \begin{pmatrix} V^{sa} \\ V^{sb} \\ V^{sc} \end{pmatrix} \quad (10)$$

where, V^{sd}, V^{sq} is described as direct and quadrature axis voltage and V^{sa}, V^{sc}, V^{sc} is described as a source voltage of three phases such as phase a, phase b, and phase c, respectively. The direct axis voltage can be computed by the below equation,

$$V^{sd} = \widehat{V^{sd}} + \overline{\overline{V^{sd}}} \quad (11)$$

where, $\overline{\overline{V^{sd}}}$ is described as an oscillatory component and $\widehat{V^{sd}}$ is described as mean components. The mean component voltage is computed with the utilization of a 2nd order filter. The load voltage$V^{l(abc)}$ is computed based on the below equation,

$$\begin{pmatrix} VR^{la} \\ VR^{lb} \\ VR^{lc} \end{pmatrix} = \frac{2}{3}\begin{pmatrix} \sin(\omega t) & \cos(\omega t) & 1 \\ sin\left(\omega t - \frac{2\pi}{3}\right) & cos\left(\omega t - \frac{2\pi}{3}\right) & 1 \\ sin\left(\omega t + \frac{2\pi}{3}\right) & cos\left(\omega t - \frac{2\pi}{3}\right) & 1 \end{pmatrix} \times \begin{pmatrix} \overline{\overline{V^{sd}}} \\ 0 \\ 0 \end{pmatrix} \quad (12)$$

where reference load voltage is shown by symbols $VR^{la}, VR^{lb}\ and\ VR^{lc}$. The intended system's actual voltage output is compared to value of reference voltage and obtained error voltage then determined using FOPID controller. Equation (13), which shown below, is used to compute error voltage.

$$E(V) = VR^{labc} - V^{sabc} \quad (13)$$

where an erroneous voltage referred to as $E(V)$. Gain values are chosen using SSO optimization and error components are given to FOPID controller. The error voltage was decreased by ideal gain parameters sending best pulses to series-connected active power filters. IGBT switches in series active power filter provide chosen pulses. Similar to that, section below describes shunt active power filter control structure.

4.2. Control procedure of shunt active power filter

To lessen current disturbances in standalone microgrid system, shunt active power filter with controller is used. The shunt controller injects the required current to compensate for disturbance currents in the system. In this shunt controller design, the current swell, sag, harmonics, and disturbances are compensated. The shunt proposed controller is illustrated in Figure 7.

The system's current harmonics are managed using instantaneous reactive power theory. Three-phase voltages and currents are translated into α and β coefficients, which are represented as follows:

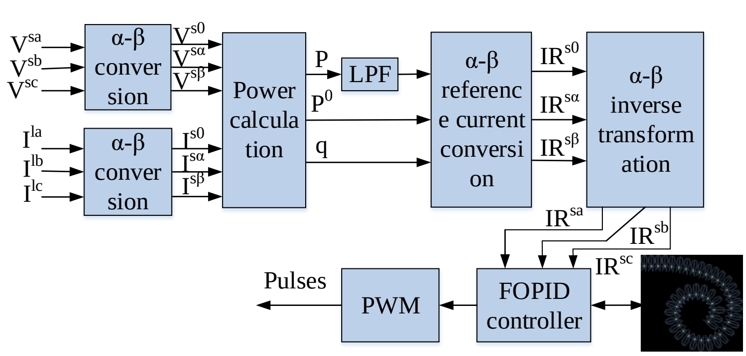

Fig. 7. Proposed control structure of shunt active power filter.

$$\begin{pmatrix} V^0 \\ V^\alpha \\ V^\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{pmatrix} \begin{pmatrix} V^{sa} \\ V^{sb} \\ V^{sc} \end{pmatrix} \quad (14)$$

$$\begin{pmatrix} I^0 \\ I^\alpha \\ I^\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{pmatrix} \begin{pmatrix} I^{sa} \\ I^{sb} \\ I^{sc} \end{pmatrix} \quad (15)$$

where I^{sa}, I^{sb}, I^{sc} are designated as input currents for phases a, b and c, accordingly. The oscillatory component contains a negative sequence component, and the mean component contains a positive component of source currents. From that, active and reactive power is computed based on the below equation,

$$\begin{pmatrix} P \\ Q \end{pmatrix} = \begin{pmatrix} V^\alpha & V^\beta \\ -V^\beta & V^\alpha \end{pmatrix} \begin{pmatrix} I^\alpha \\ I^\beta \end{pmatrix} \quad (16)$$

The system needs correction to account for present harmonics. Equations below are used to determine reference currents for shunt active power filter.

$$\begin{pmatrix} IR^\alpha \\ IR^\beta \end{pmatrix} = \frac{1}{(V^\alpha)^2} + \left(V^\beta\right)^2 \begin{pmatrix} V^\alpha & V^\beta \\ V^\beta & V^\alpha \end{pmatrix} (P + P^0 + P^{loss}) \quad (17)$$

$$P^0 = V^0 * I^0 \quad (18)$$

The reference currents are computed, which used to calculate error currents. The reference current computation is presented as follows,

$$\begin{pmatrix} IR^{sa} \\ IR^{sb} \\ IR^{sc} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & \sqrt{\frac{3}{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & -\sqrt{\frac{3}{2}} \end{pmatrix} \begin{pmatrix} I^0 \\ IR^\alpha \\ IR^\beta \end{pmatrix} \quad (19)$$

$$I^0 = \frac{1}{\sqrt{3}} (I^{sa} + I^{sb} + I^{sc}) \quad (20)$$

$$E(I) = IR^{sabc} - I^{labc} \quad (21)$$

where, $E(I)$ is described as error currents. The variation current is fed to the FOPID controller. SSO optimization chooses gain values. SAPF receives best pulses from best gain settings, which lowers error current. Shunt active power filter's IGBT switches deliver required pulses. The section below provides description of FOPID controller.

4.3. Control procedure of FOPID controller design

FOPID controller used to reduce voltage and current in case of both shunt and series active power filters. FOPID controllers are typically considered to be an all-inclusive version of conventional PID controllers [30]. The shunt and series active power filter controller components of fractional controller vary slightly. By using fractional controller can actually accomplish iso-damping properties, which are controller actions that have same phase margin over given frequency range. The FOPID controller transfer function is mathematically formulated as,

$$FOPID\big(u(t)\big) = K^P E(S) + K^I S^{-\lambda} E(S) + K^I S^\mu E(S), (\lambda, \mu > 0) \quad (22)$$

where, $u(t)$ is described as control outputs, $E(S)$ is described as error voltage and current, K^P is described as proportional gain constants, K^I is described as integral gain constants, both $S^{-\lambda}$ and S^μ can be thought of as fractional orders of integral and derivative terms, respectively. The fractional orders of integral term and derivative term often fall between 0 and 2. The two FOPID controllers are designed in series both SAPF for current and voltage error minimization which mathematically presented as follows,

$$FOPID\big(u(t)\big) = K^P E(V) + K^I S^{-\lambda} E(V) + K^I S^\mu E(V), (\lambda, \mu > 0) \quad (23)$$

$$FOPID\big(u(t)\big) = K^P E(I) + K^I S^{-\lambda} E(I) + K^I S^\mu E(I), (\lambda, \mu > 0) \quad (24)$$

where $E(I)$ denotes erroneous shunt APF's current and $E(V)$ denotes error voltage of series APF. The optimal filter switch pulses are chosen in addition to lowering error levels. To reduce accuracy of filter, pulses are tweaked using proper gain settings. FOPID controller is tuned using the SSO algorithm. The standalone microgrid system's oscillations have been reduced to minimum by FOPID controller and SSO with appropriate recommended controller, enabling system's stability and dependability. As a result, suggested Shunt and Series APF control system makes up for power quality problems. Below is detailed explanation of SSO algorithm.

5. SALP SWARM OPTIMIZATION-BASED CONTROL STRUCTURE

Sulf Swarm optimization is employed in proposed method to lower current and voltage deflections in standalone microgrid systems with both shunt and series controllers. Solar and wind energy are employed as primary sources of supply to alter load requirement, while battery systems are coupled in standalone microgrid for energy storage. The entire microgrid system experiences power quality issues like disruptions, sag, interruptions, swell and harmonics because renewable energy supplies are connected to linear, non-linear, unbalanced and critical load circumstances. When different load conditions are enforced on load side, PQ difficulties occur. These power quality problems are detrimental to system's performance, including stability, dependability and support for power management. Power quality problems must be fixed in order to guarantee stability and dependability of system. UPQC could be developed, and integrated PQ theory was established in order to address PQ problems in standalone microgrid.

For UPQC, shunt and series APF controllers are offered. These controllers can identify changes in current and voltage on load side when applied to unbalanced loads, non-linear loads and critical load circumstances. When UPQC device is taken into consideration, dc-link capacitor can adjust for current and voltage variations. The autonomous microgrid system's reliable operation depends on UPQC device's dc-link voltage maintenance task. The voltage and current variations are sent to FOPID controller. To lessen defective current and voltage, FOPID controller modifies series and shunt APF pulses. The best tuning setting for FOPID controller is discovered using SSO method. SSO is new optimization technique that provides best results for fitness function of voltage and current error minimization. This section covers SSO general protocol as well as recommended procedure.

Background information on SSO

Salps' natural behavior served as an inspiration for SSO. The salps have transparent barrel-shaped body and are members of Salpidae family. The tissues of salps are incredibly delicate, similar to jellyfish tissues. Salps use propulsion properties, which are comparable to jellyfish features, to move ahead in the water. The SSO was created to mimic their swarming behavior. The salps linked together to form chain known as a salp chain. Although purpose of salp chain development is unclear, some experts think it is done to achieve best possible mobility through synchronized modifications and foraging. Salp chain formation is often divided into two clusters: leaders and followers [31]. In chain of slaps, head slap is referred to as leader slap, and last smack referred to as follower slap. Thus, the head salp guides the remaining swarm, and followers are following the head in a chain. The formation of salp chain behavior assists salp to attain more kinetic energy searching and attacking the food source. The salp chain formation of SSO is illustrated in Figure 8.

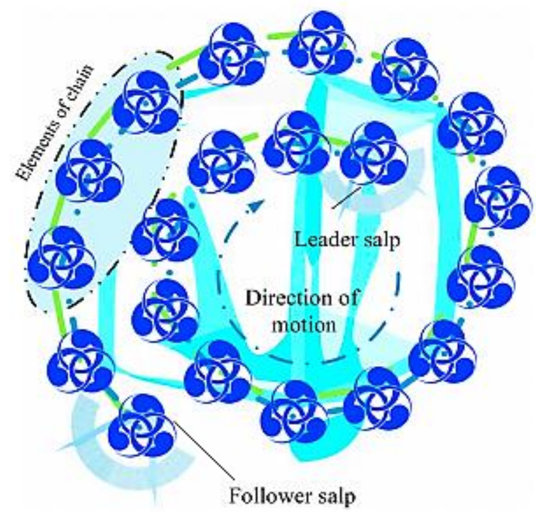

Fig. 8. Formation of salp chain in SSO.

The position vector of each salp presented in the salp chain is described for searching in n-dimensional space. The population's initialization is an initial setup of the SSO algorithm. The population position vector of salps with dimension is mathematically formulated as follows,

$$Y_A = \begin{bmatrix} Y_1^1 & Y_2^1 & \dots & Y_D^1 \\ Y_1^2 & Y_2^2 & \dots & Y_D^2 \\ : & : & \dots & : \\ Y_1^N & Y_2^N & \dots & Y_D^N \end{bmatrix} \quad (25)$$

where $N \times D$ is described as a dimensioned matrix, N is described as several decision variables. The population position vector is consist of N salps with D dimensions. Based on equation (11), the initial population is created with a random position. After that, the fitness of each salp is determined and the best position of salps taken as the best solution. The remaining salps follow salp chain to food source and are deemed to be in best positions as food sources. Then, movement of salps considered as updating function, which updated by two classes such as leader phase and follower phase. The leader and follower position is updated with the following equations,

$$Y_B^1 = \begin{cases} F_B + C_1\left((UB_B - LB_B)C_2 + LB_B\right), C_3 \geq 0 \\ F_B + C_1\left((UB_B - LB_B)C_2 + LB_B\right), C_3 < 0 \end{cases} \quad (26)$$

where, C_1, C_2 *and* C_3 are considered as random numbers of coefficient, LB_B is considered as a lower bound of B^{th} dimension, UB_B is considered as an upper bound of B^{th} dimension, F_B is considered as position of food source in B^{th} dimension and Y_B^1 is described as position of leader B^{th} dimension. The SSO has advantages; it effectively manages to avoid trapping into local minimum due to its updating functions. The SSA updates the position towards the leading position, which prevents the algorithm from struggling in the local optima problem. However, the SSO algorithm has provided the best optimal solution by avoiding the local optima problem. Additionally, the SSO algorithm has the best exploitation and exploration balancing capacity that is a general requirement of an optimization algorithm to achieve the best results. Based on equation 12, the leader salp position is updated with their location towards the food source. In equation 12, the coefficient values are very important, which is used to balance the SSO under exploitation and exploration. The coefficient parameters are mathematically computed based on the below equation,

$$C_1 = 2e^{-\left(\frac{4L}{nl}\right)^2} \qquad (27)$$

where nl represents current iteration count and L represents total number of iterations. Similarly, remainder coefficients in equation 12 are assumed to have constant values between 0 and 1. The position of follower's salp updated based on below equations, which is similar to newton's law of motion is used,

$$P_B^A = \frac{1}{2}AT^2 + V_oT \qquad (28)$$

where, V_o can be described as a velocity of the optimization process, which is fixed as 0. In the velocity values is changed in the optimization process due to iteration and changes among two continuous iterations did not in fractional number so, initial stage it fixed as 0, which formulated as below equation,

$$P_B^A = \frac{P_B^A + P_B^{A-1}}{2} \qquad (29)$$

where, P_B^A can be described as the position of A^{th} follower salp in the B^{th} dimension ($A \geq 2$). The salp chain moves towards obtaining the best solution considered a food source by exploiting and exploring search space.

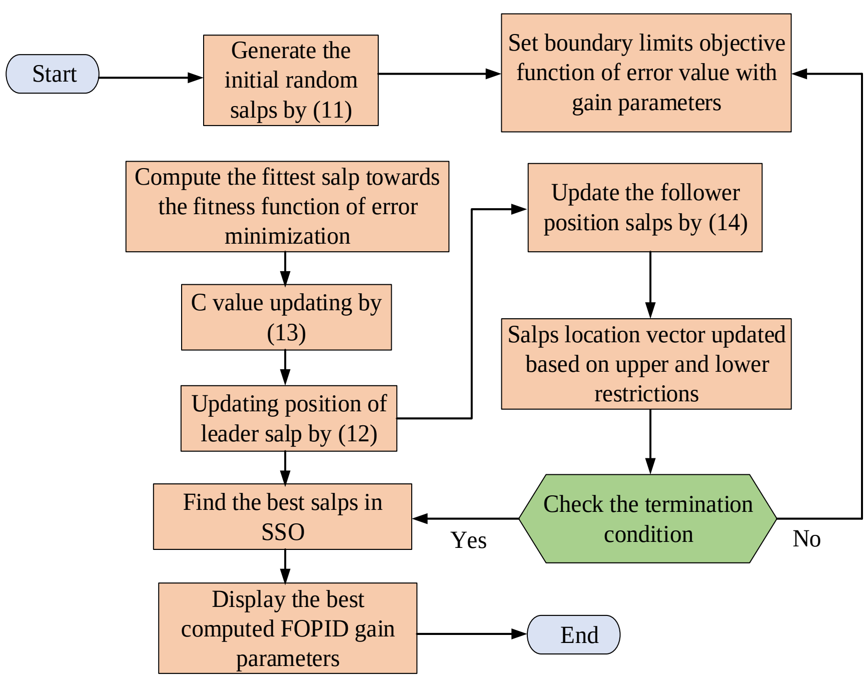

Fig. 9. Flowchart of SSO for tuning of FOPID controller.

The various features are available in SSO algorithm to meet objective function more than conventional methods, which are outlined below:

- After each iteration, SSA offers best answer and allocates ideal global variable. However, this algorithm never wiped out at complete population depreciates.
- The SSO updates the position of header salp, which is updated the position related to a food source. Hence, it is achieved the best solution, and the leader salp exploits and explores the search space.
- The leader salp position is followed by follower salp, which considered the best solution in the algorithm.
- The follower salps move towards the header salp gradually, which avoids the problem of local optima.
- In the SSO algorithm, the $c1$ values are decreased related to iterations that improve the algorithm to explore search space in the staring and exploits in the ending phase.

- The SSA has the advantages of $c1$ parameter, which reduces the implementation complexity and easy implementation.

The optimal gain values for FOPID controller are chosen using SSO algorithm. Initially, random population of salps is populated using error values depending on reference and real voltage and current levels. The current and voltage error minimization determines salps' fitness. SSO algorithm is used to select control gain values for FOPID controller. The fitness function-based leader salp position is updated. The remaining follower salps are moving towards leader position. The coefficient of c1 is updated and position of leader salp also updated based on above equations. Related to leader salp positions, follower salps are updated. The FOPID controller gain parameter limits are checked and salps inferior with superior limits are checked. After that, maximum iteration is achieved, best solution of FOPID controller five parameters are saved and stops algorithm process. The proposed combined PQ concept of shunt and series APF controller has reduced PQ in standalone microgrid system. For range of loads, includes linear, non-linear, unbalanced and critical loads, PV WT used to adjust load demand. PQ difficulties are reduced with help of FOPID controller and SSO algorithm. The performance of proposed controller on standalone microgrid system examined in section that follows.

6. PERFORMANCE EVALUATION

In this section, suggested controller's assessment in standalone microgrid system is shown. The MATLAB/Simulink platform, which is shown in Figure 11, is where projected controller is implemented. In current study, a FOFID controller is created to solve power quality issue in standalone microgrid. The performance is evaluated by verifying voltage and current with problem creation, injected and compensated waveforms. Table 1 lists implementation specifications for standalone microgrid system. The proposed controller is validated through the comparison analysis. The projected controller is compared with already designed techniques of PSO, GWO also WOA, respectively. The proposed controller is validated by the use of different power quality problems like swell, sag, disturbance, interruption, and harmonics. Three instances with four different power quality concerns are examined to show controller stability and reliability performance characteristics that are listed below.

- **Case 1:** Sag condition with sources constant
- **Case 2:** Swell condition with sources variation
- **Case 3:** Interruption condition and Disturbance condition.

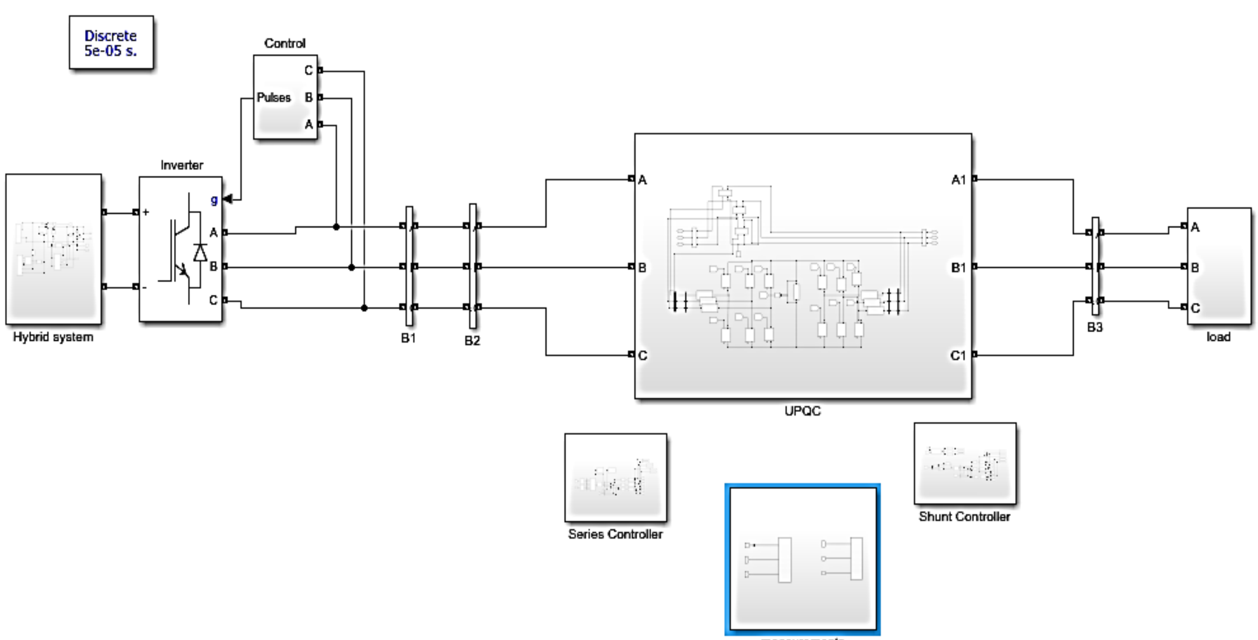

Fig. 10. Simulink diagram of the proposed design with standalone microgrid.

The proposed model approach tested with PQ concerns as interruption, harmonics, sag, swell and disturbance. Concerns about power quality are addressed with UPQC device, as well as proposed series and shunt active power filter controllers. The recommended controller provides right pulses of series and shunt active power filters to optimally regulate power quality concerns with aid of FOPID controller with SSO. In order to handle power quality problems and adapt for system load needs, UPQC can supply required power. A DC connected capacitor is used in proposed standalone microgrid system to power UPQC configuration and to resolve PQ issues. The principal source of power in system, WT and PV systems generate the necessary electricity to support fundamental load requirement. WT and PV can be affected by environmental factors, although this can be reduced by applying MPPT methods in system. The load need satisfied and PQ issues in system are removed using power produced by UPQC system. The UPQC system connected to load system that takes care of power quality problems in freestanding microgrid. Three fault conditions swell, sag, voltage disturbance, interruption, as well as harmonic levels of signal are focal points of planned design presentation.

Case 1: Sag condition with sources constant

The validation of the projected controller in the standalone microgrid system is analyzed with a sag condition. Coupled non-linear loads, unbalanced loads and critical loads are most frequent causes of issues with power quality. These load situations cause sag in source side, which must be addressed in order to improve the standalone microgrid's stability and reliability. In this condition, the sag is created by fault in the source side, which solved by the proposed controller with UPQC. In this situation, source's constant condition used to analyses system performance. When standalone microgrid system, PV and WT systems are considered as a source. The PV and WT may be affected due to changes in environmental conditions because it strongly depends on the natural resources to generate the required power to meet the load. The source's constant wind speed and irradiance with generated power are presented in Figure 11. In this case of analysis, irradiance and wind speed is fixed as constant such as $1000W/m^2$ and $12\ m/s$. Associated with irradiance and wind speed conditions, the PV is generated $6KW$ power, and WT is generated $30\ KW$ power. On load side, power generated by PV and WT can be used to offset load demands. When PV and WT fail to meet demand, the battery is coming to provide essential power in the load. Similarly, PV and WT generate excess power means, and the battery is charging the power. To analyze the performance of the proposed method, the sag is created by applying fault. Sag issue in standalone microgrid system is then addressed using UPQC with coordinated PQ theory. The required voltage, as well as the current, is injected by UPQC to compensate for sag problems in the standalone microgrid system.

Table 1: Implementation parameters

S. No	Description	Parameters	values
1	Wind	The base power of an electrical generator	80KW/0.9
2		Base torque	8500 N/m
3		Nominal mechanical output power	80KW
4		Base rotational speed	0.4 m/s
5		Base wind speed	12m/s
6		Armature inductance	8.5e-3H
7		stator phase resistance	1.5 Ω
8	PV	Diode resistance	595.5 Ω
9		Irradiance	1000
10		Generated power	10KW
11		Forward voltage	0.8V
12	Battery	Initial state of charge	100
13		Type	nickel-metal-hydride
14	SSO	Maximum iteration	500
15		Number of Populations	50
16		Upper bound	100
17		Lower bound	-100
18		Dimension	5

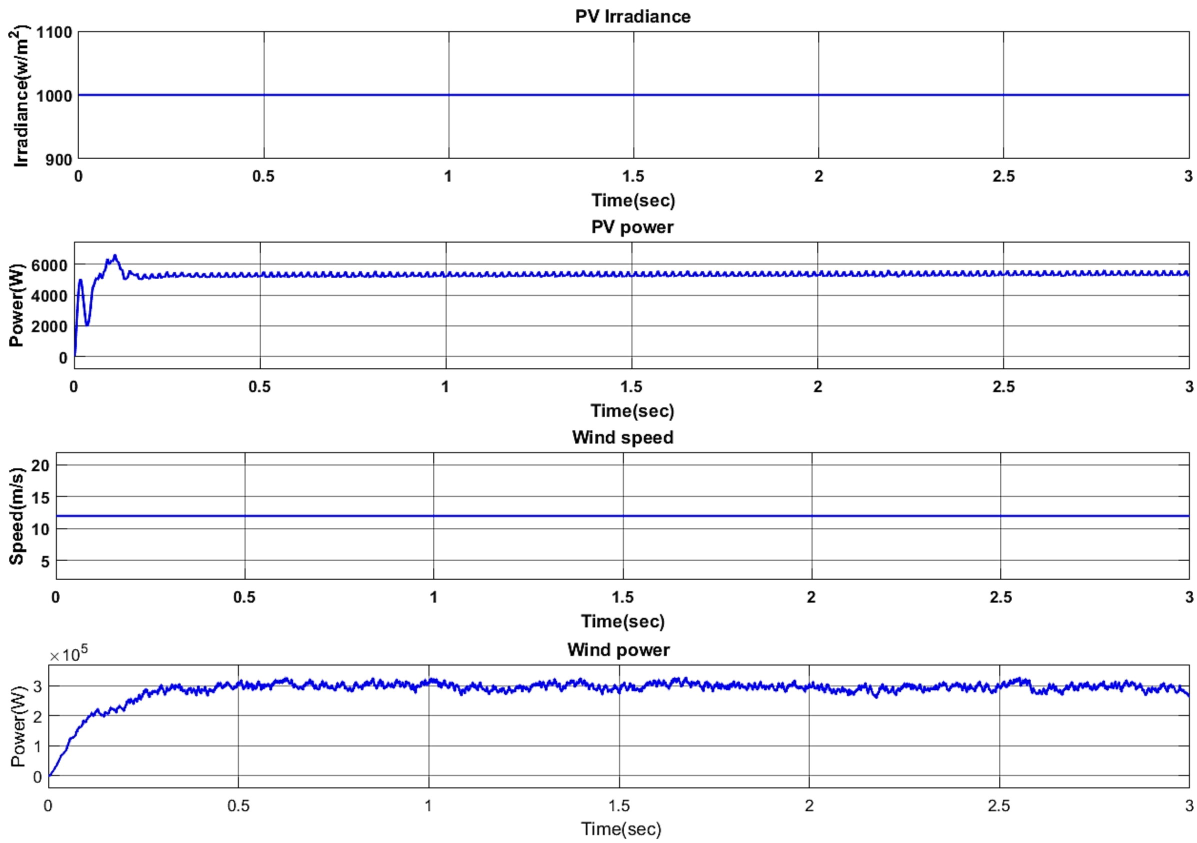

Fig. 11. Analysis of PV and WT generated power in sources constant.

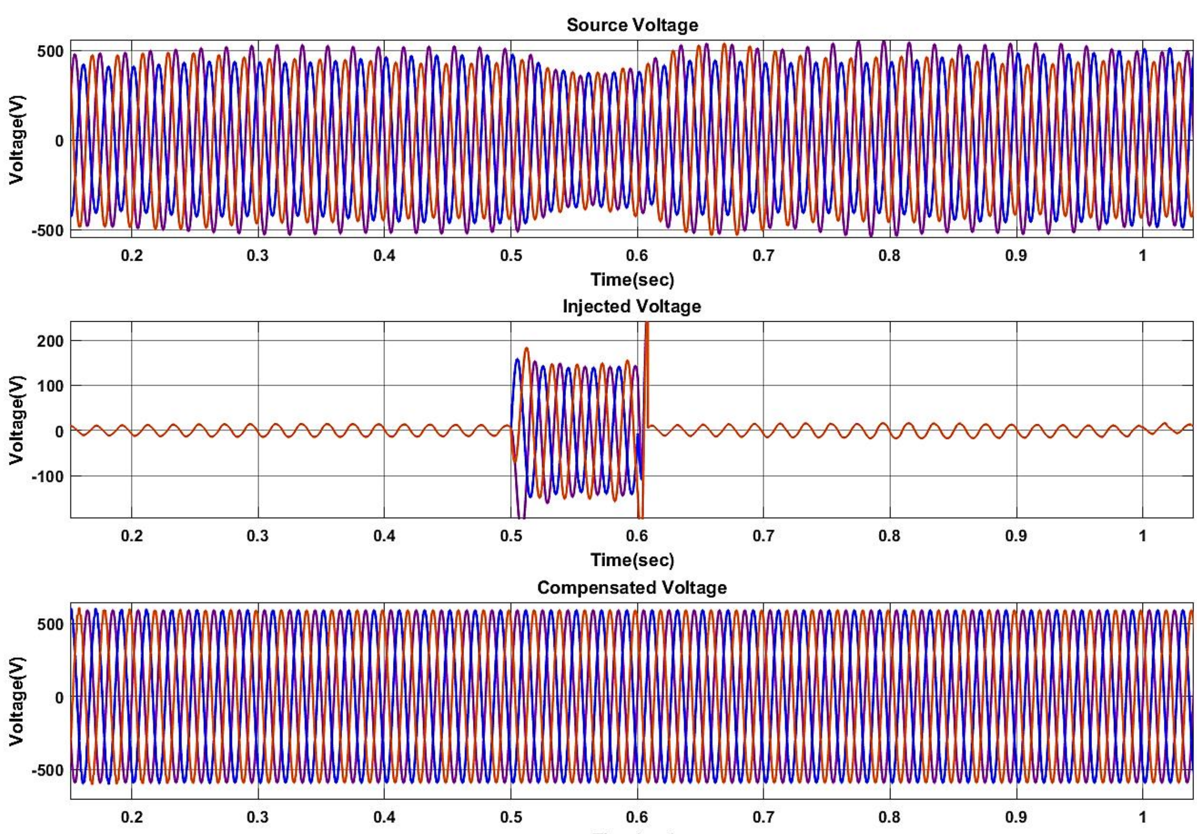

Fig. 12. Analysis of voltage sag condition in standalone microgrid system.

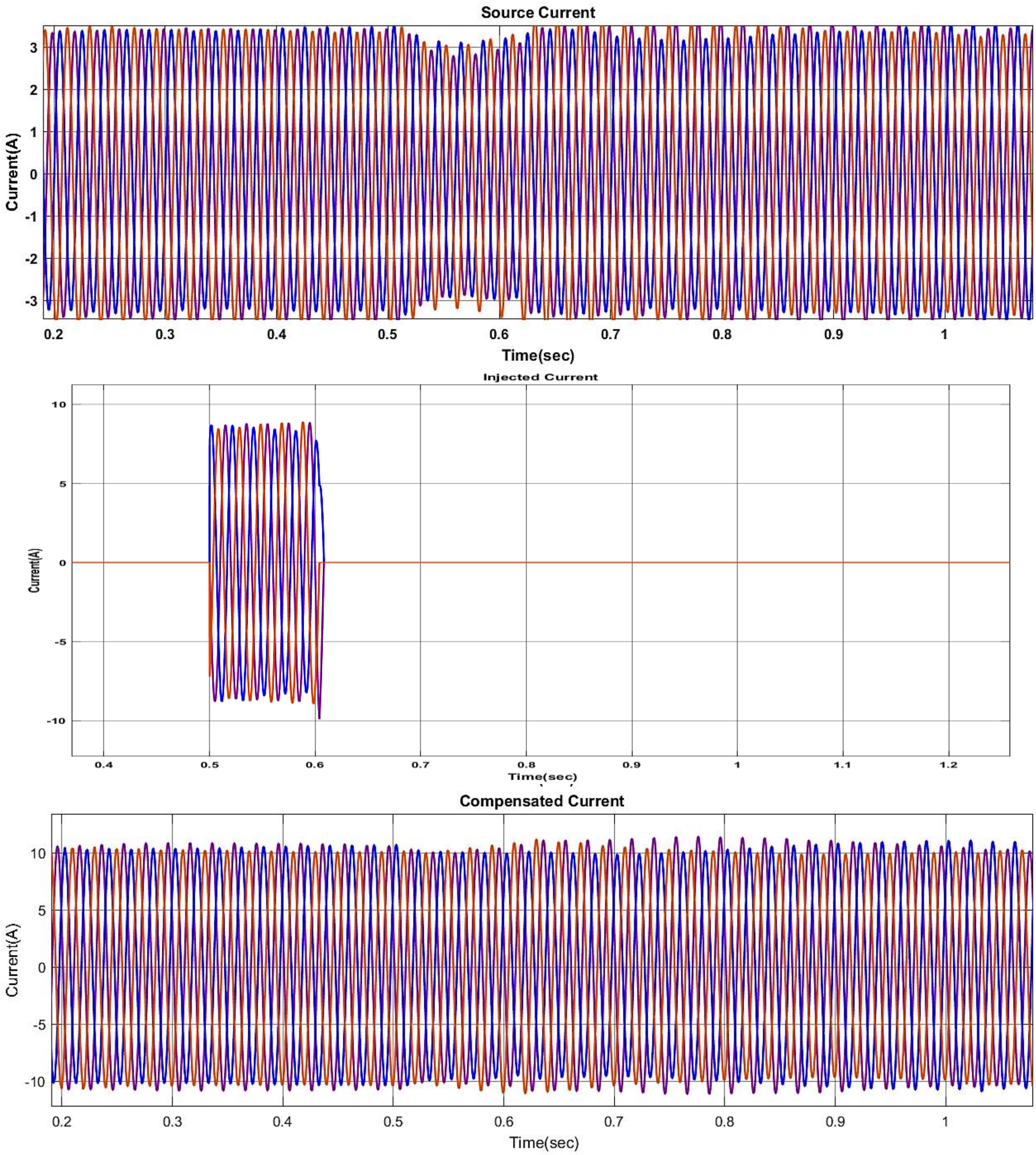

Fig. 13. Analysis of current sag condition in standalone microgrid system.

Voltage and current sags develop in standalone microgrid system when non-linear load is applied. In freestanding microgrid system, voltage sag results from application of non-linear demand. For system to run consistently and dependably, voltage sag must be fixed. A UPQC used to provide sufficient power to satisfy load demand while minimising PQ issues. The sag generation of voltage and current signals is shown in Figure 13. Through UPQC and coordinated PQ theory controller, current and voltage sags are managed. The required current and voltage are injected by shunt APF and UPQC series APF. The proposed controller helps to solve standalone microgrid system's voltage and current sag issues. Figure 13 displays corrected current and voltage. In end, UPQC and intended controller help to mitigate PQ problems like sag.

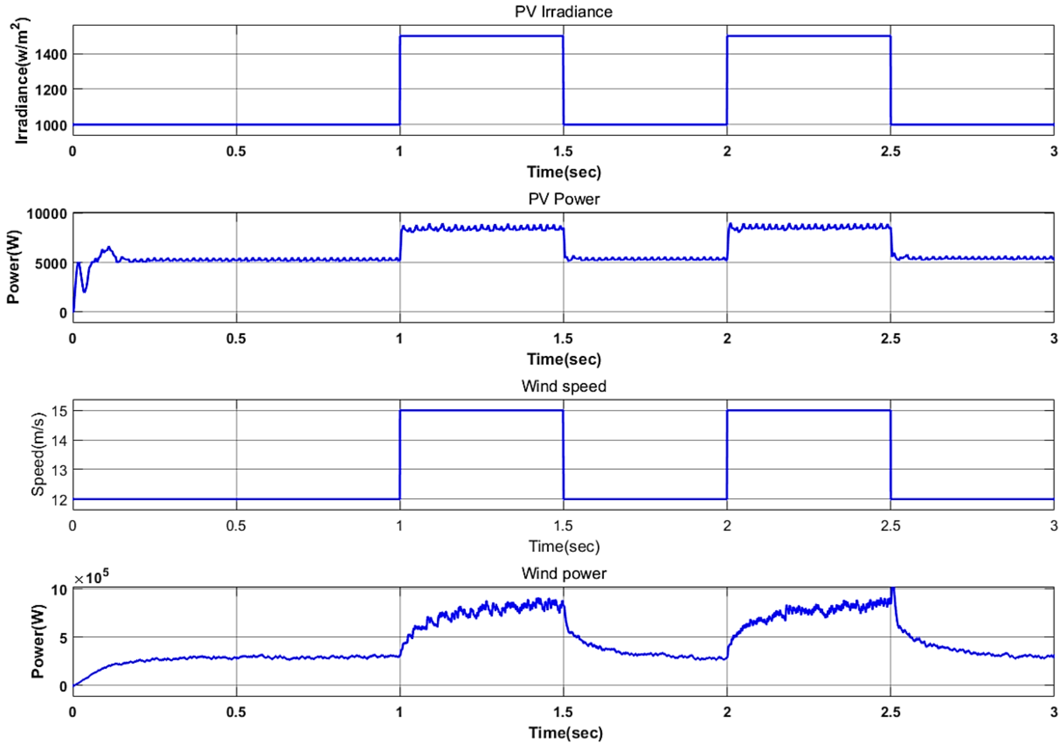

Fig. 14. Analysis of PV and WT generated power in sources variation.

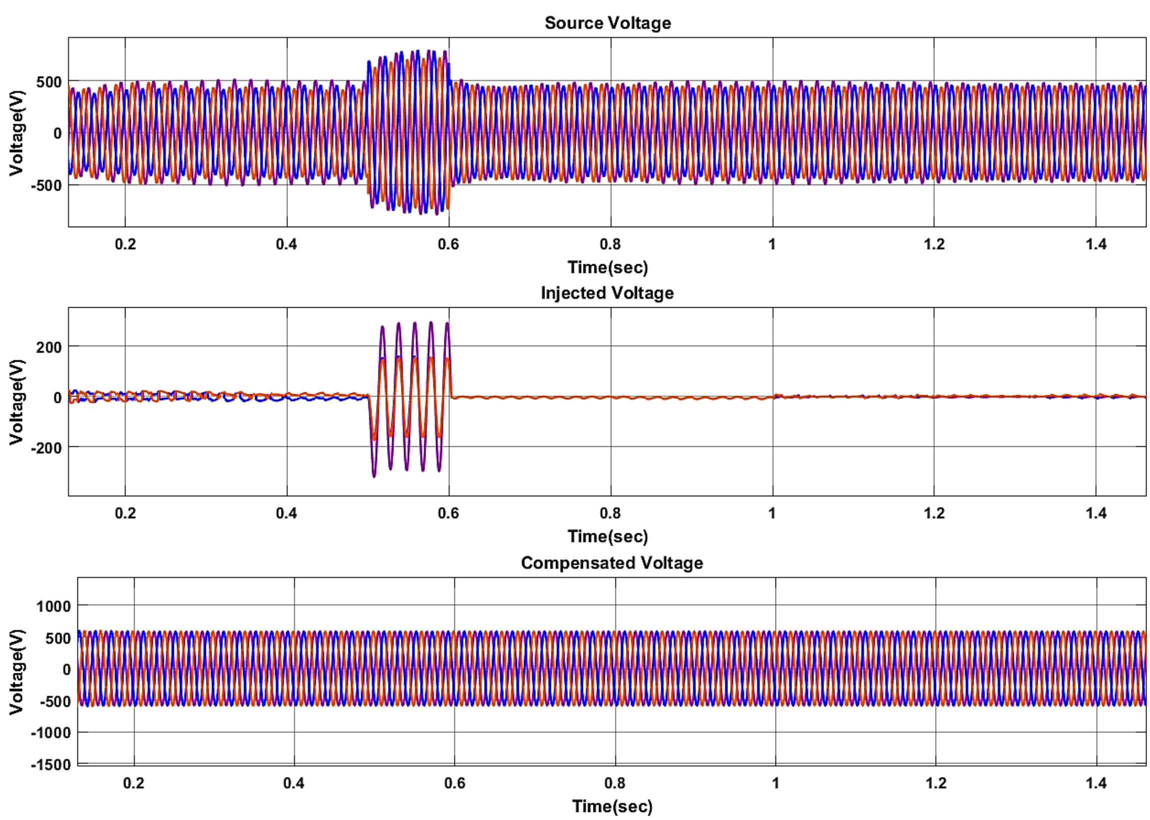

Fig. 15. Analysis of voltage swell condition in standalone microgrid system.

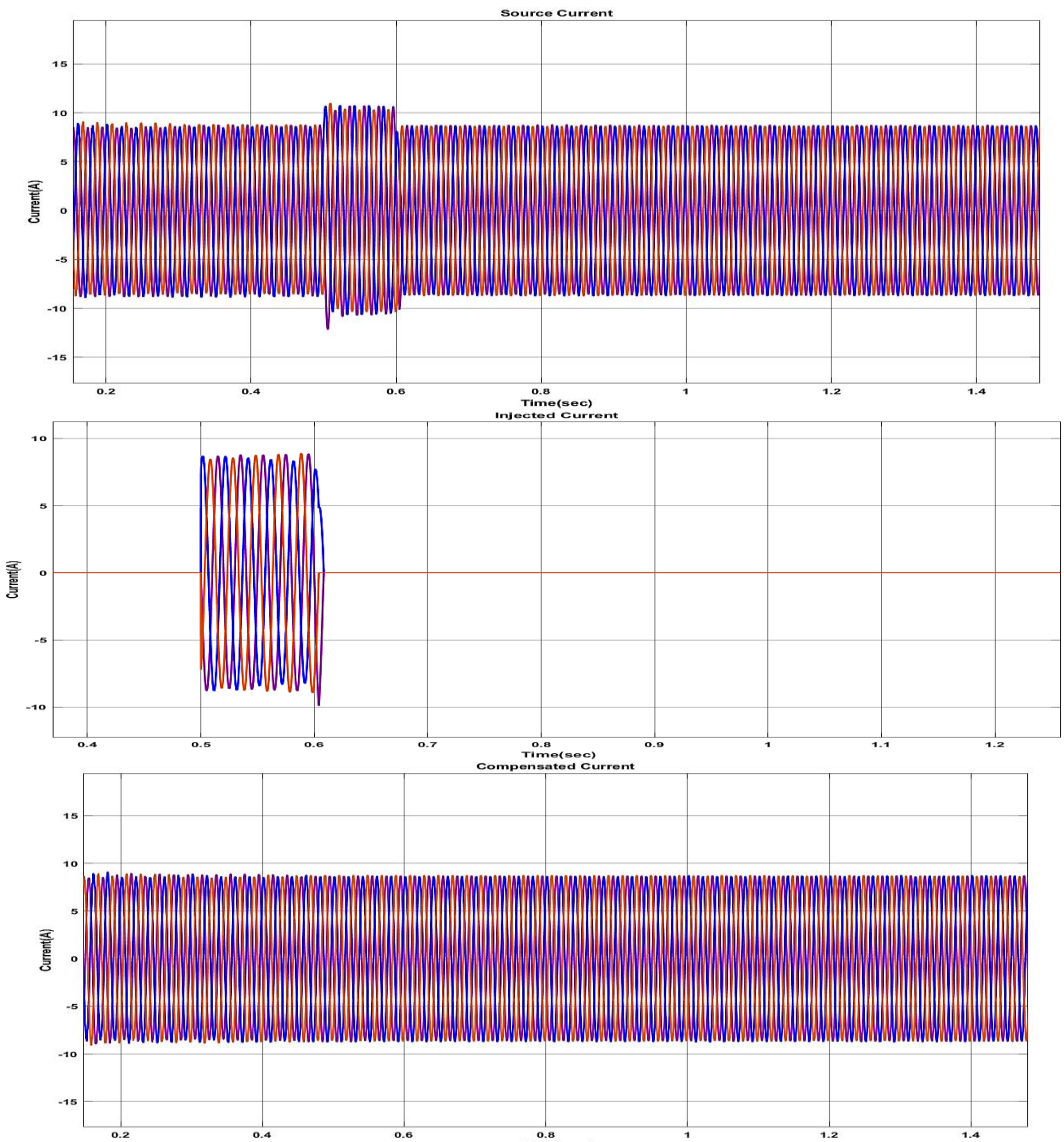

Fig. 16. Analysis of current swell condition in standalone microgrid system.

Case 2: Swell condition with sources variation

Swell condition and source variation are used to assess performance of suggested controller. The PV and WT generating sources are fixed as a variable condition, which is also used in the standalone microgrid, and the results are assessed. The power quality issues of swell are introducing applying fault in the source side, which must be solved by UPQC and proposed coordinated PQ theory. The source variation with generated power is illustrated in Figure 14.

PV irradiance raised from 1000 W/m2 to 2400 W/m2 and settings are as follows: 0-1 time seconds, 1000 W/m2; 1-1.5 time seconds, 1500 W/m2; 1.5-2 time seconds, 1000 W/m2; 2-2.5 time seconds, 1500 W/m2; 2.5-3 time seconds, 1000 W/m2. Due to fact that PV's generated power related to radiation's intensity, it fluctuates as radiation level changes. As amount of radiation rises, so does power produced by PV. Increased WT speed results in increased WT generated power. The outputs of PV system are 5 KW at 0-1 s, 8 KW at 1-1.5 s, 5 KW at 1.5-2 s, 8 KW at 2-2.5 s and 5 KW at 2.5-3 s. For first 0–1 sec, WT speed is altered to 12–15 m/s; for next 1–1.5 sec, wind speed is fixed at 15 m/s; for following 1.5–2 sec, wind speed is fixed at 12–15 m/s; for following 2.5–3 sec, wind speed is fixed. WT produces 200KW for 0-1 seconds, 80KW for

1.5-2 seconds, 200KW for 2-2.5 seconds and 80KW for 2.5-3 seconds.

A standalone microgrid system creates current and voltage waves by adding non-linear load and fault. Voltage swell happens in standalone microgrid system when a non-linear load and disturbance are supplied. To run linearly and steadily, voltage swell needs to be solved. UPQC used to produce enough power to meet needs for load while also lowering PQ concerns. Current and voltage waveform swell development is depicted in Figures 15 and 16. The current and voltage swell decreased by using UPQC and coordinated PQ theory controller. Required current and voltage are injected via UPQC shunt and series APF. Standalone microgrid system's current and voltage swell issues are mitigated by proposed controller. The corrected current and voltage are shown in Figures 15 and 16. Finally, use of UPQC and recommended controller minimises PQ problems like voltage and current swell.

Case 3: Interruption condition and Disturbance condition

In this case of analysis, the interruption and disturbance are analyzed with the proposed controller. The interruption and disturbances are created on the source side by applying fault and non-linear load on the load side. Interruption and disturbances are analyzed and illustrated in Figures 17 and 18. The standalone microgrid system is affected due to changes in renewable energy resources and load variations on the load side. System's interconnectedness may contribute to problems with system's power quality. Predicted coordinated PQ theory and UPQC should be used to resolve PQ problems. The proposed controller can mitigate power quality issues in a standalone microgrid system.

With assistance of projected technique, PQ issues of interruption and voltage disturbances are mitigated. UPQC and coordinated PQ theory controller provide reliability and dependability of system. The proper control pulses of shunt and series APF completely eliminate PQ concerns in standalone microgrid system. To make up for problems with current and voltage signal power quality, UPQC has shunt and series APF. The proposed coordinated PQ theory used in standalone microgrid system to account for interruptions and disturbances. Proposed method can address concerns with power quality that arose in standalone microgrid system as result of critical load, non-linear load and unbalance load. A comparative analysis a crucial component of paper described in section beneath and serves to evaluate proposed technique.

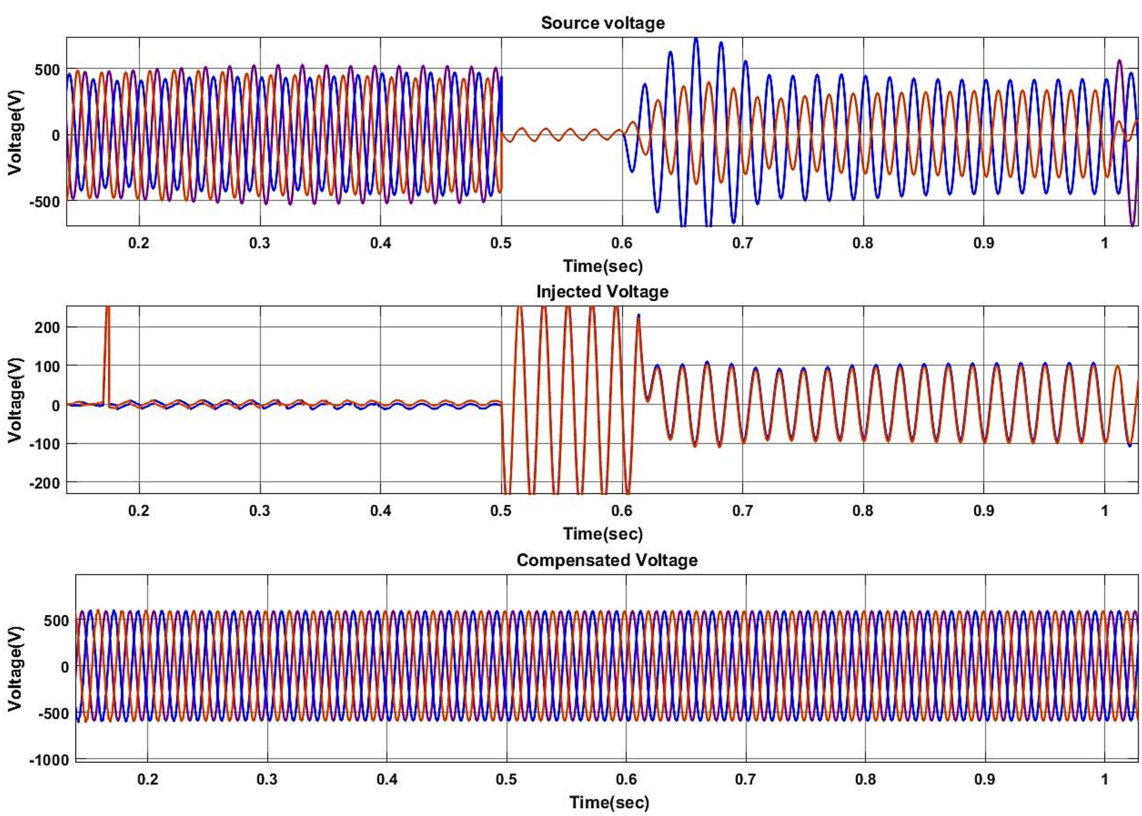

Fig. 17. Analysis of interruption condition in standalone microgrid system.

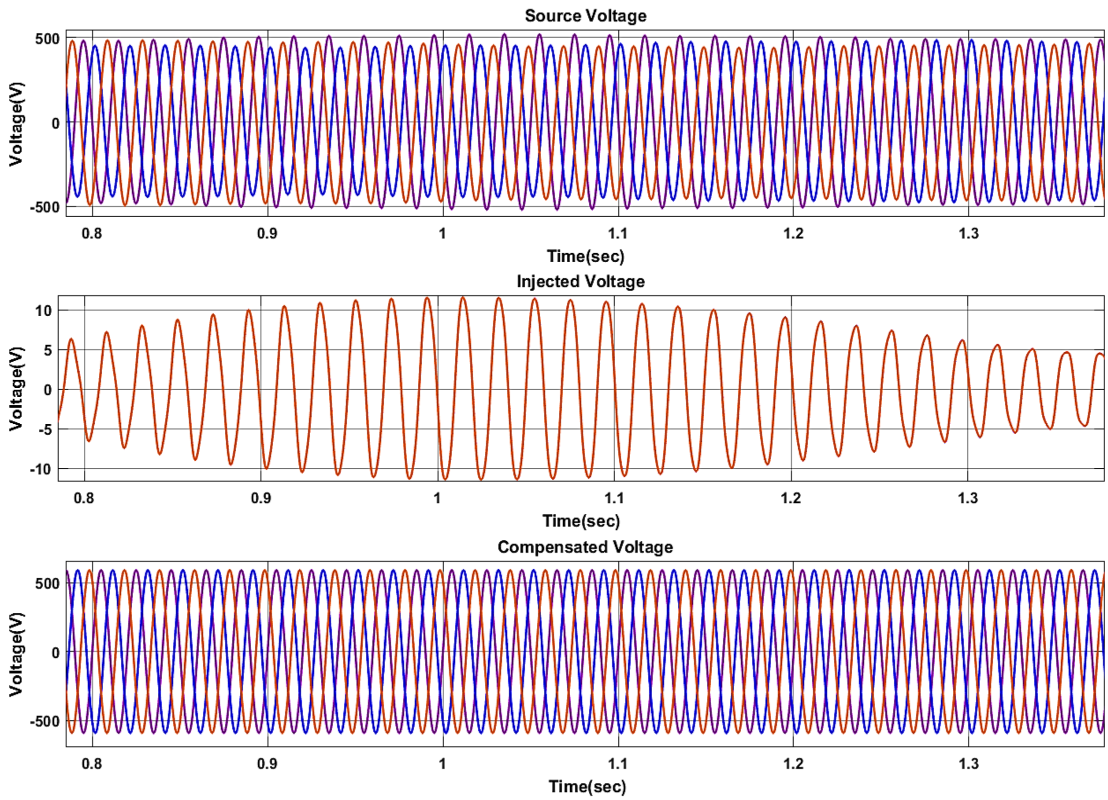

Fig. 18. Analysis of disturbance condition in standalone microgrid system.

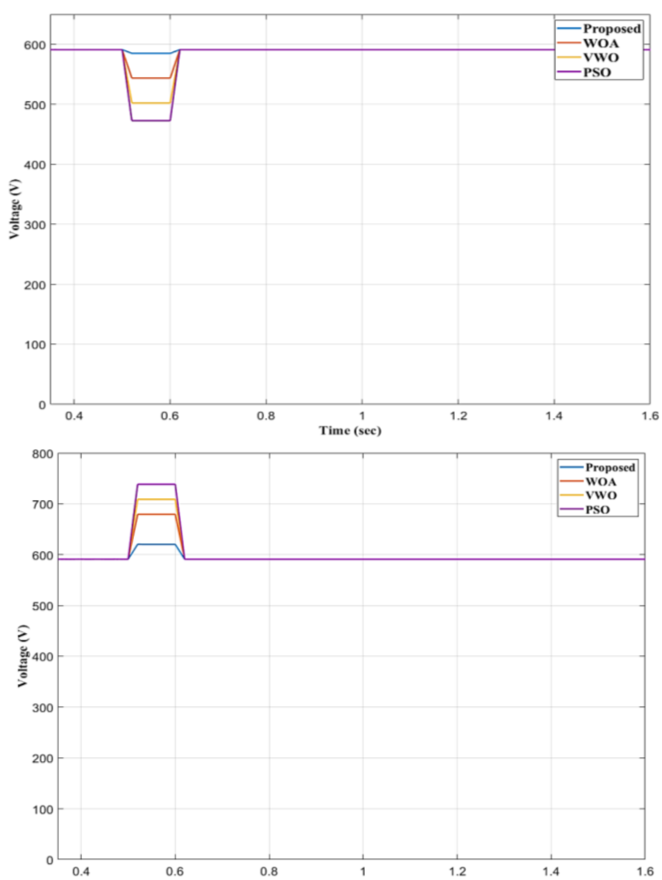

Fig. 19. Comparison of analysis of voltage at sag and swell condition.

Comparison of Validation of the proposed method

The comparison study validates proposed method. Proposed approach is contrasted with tried-and-true methods like GWO, PSO and WOA. To compare predicted approach with existing methods, THD was also examined. The representation of proposed methodology is examined using comparison study under variety of swell, sag, interruption, harmonics circumstances and voltage disturbances. Full strength of standalone microgrid system of PSO, GWO and WOA is disclosed when contrasted to previously developed approaches. Additionally, harmonics of signals were examined and verified using tried-and-true techniques. A planned technique's comparative study based on real power is shown in Figure 19. Additionally, the THD of the signals is analyzed before and after UPQC connected to the standalone microgrid system. The THD signal analysis is presented in Figure 20, and the THD comparison analysis is presented in Figure 21.

The research results show that proposed controller has best real-power performance. Similar to this, proposed controller helped keep load demand power steady. Furthermore, standalone microgrid system with storage device balances load's critical power under variety of environmental situations. From Figure 19, under sag and swell conditions, proposed approach compensating voltage variation in standalone microgrid system. An existing method of WOA, GWO and PSO are not able to compensate for sag and swell problems in standalone microgrid system. The proposed controller for SSO intended to maintain constant load needed power.

Harmonics, which result in unneeded heat and inefficiency, happen when essential or non-linear loads are connected in a system. To lower harmonics and improve system stability and dependability, UPQC is included. Both an instance before and one after UPQC connection is used to analyze suggested method. Prior to UPQC merger, recommended method's harmonic numbers were as follows: 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th and 29th levels, with harmonic levels of 11.00, 7.42, 6.31, 6.41, 6.08, 5.41, 5.12 and 4.10 levels. The harmonic value of proposed technique lower than that of present method. Performance testing is done when proposed methodology has been linked to system's UPQC. The proposed scheme examines harmonic values at fifth, seventh, eleventh, thirteenth, seventeenth, nineteenth, twenty-third and thirty-ninth levels, with harmonic quantities of 1.16, 0.14, 0.11, 0.09, 0.08, 0.07, 0.05, 0.03 and 0.02 in accordance.

From Figure 20 and 21, proposed method has lower harmonics near to 5 after UPQC installation in standalone microgrid system. The existing methods are getting higher harmonics level in microgrid system. Proposed methods resulted in lesser percentage of harmonics in signals. When compared to existing methods, proposed controller achieves best results while maintaining system's dependability and performance stability. Figure 22 shows comparison in convergence of optimization, it prove proposed method solve 500 iteration with low fitness function. But existing methods are cannot fully solve optimal problems. PSO reach 500 iteration at 11 fitness value, like GWO reach 500 iteration at 8 fitness value and WOA reach 500 iteration at 5 fitness value.

Table 2. Comparison of THD analysis

S.No	**Methods**	**Before UPQC**								
		5	**7**	**11**	**13**	**17**	**19**	**23**	**25**	**29**
1	Proposed	11.00	7.42	6.42	6.31	6.08	5.41	5.12	5.11	4.10
2	WOA	33.95	9.91	9.85	9.55	9.43	9.42	9.37	9.11	9.05
3	GWO	32.85	8.90	8.81	8.52	8.38	8.35	8.27	8.11	8.04
4	PSO	29.81	29.80	8.75	8.19	8.18	8.17	8.15	8.10	8.03
S.No	**Methods**	**After UPQC**								
		5	**7**	**11**	**13**	**17**	**19**	**23**	**25**	**29**
1	Proposed	1.16	0.14	0.11	0.09	0.08	0.07	0.05	0.03	0.02
2	WOA	4.75	0.33	0.31	0.28	0.23	0.20	0.17	0.14	0.11
3	GWO	4.62	0.32	0.27	0.26	0.21	0.19	0.16	0.12	0.10
4	PSO	4.15	0.28	0.25	0.22	0.18	0.15	0.13	0.09	0.06

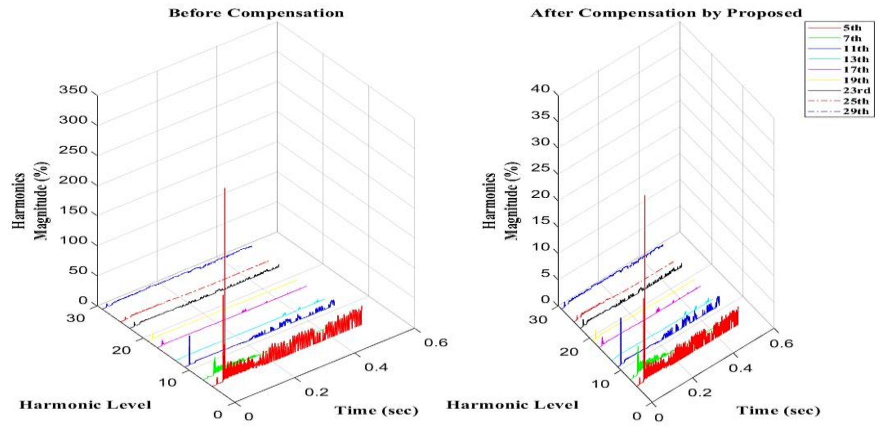

Fig. 20. Analysis of harmonics before and after UPQC.

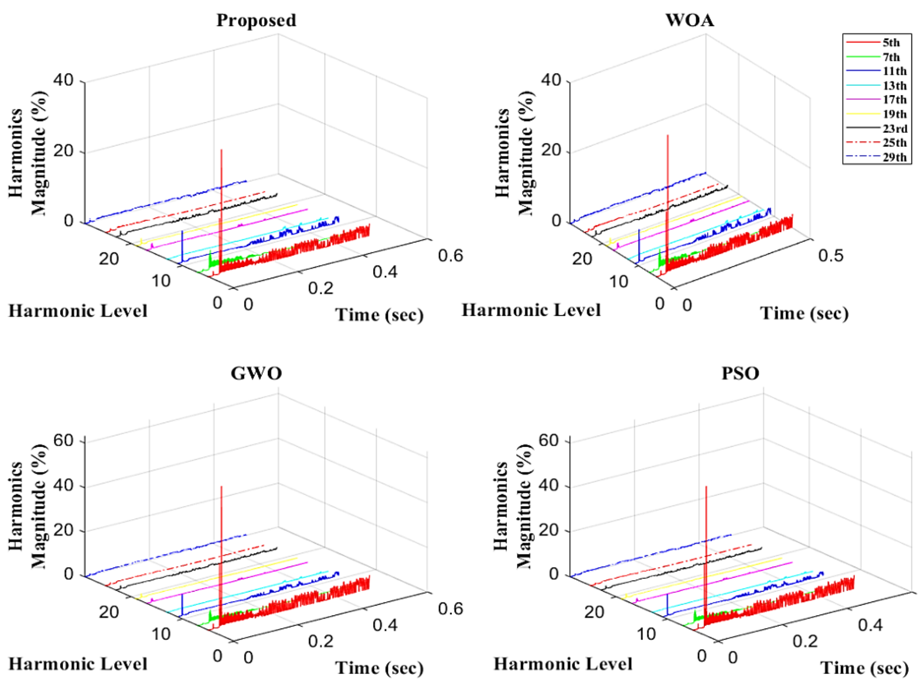

Fig. 21. Analysis of harmonics of proposed and existing methods.

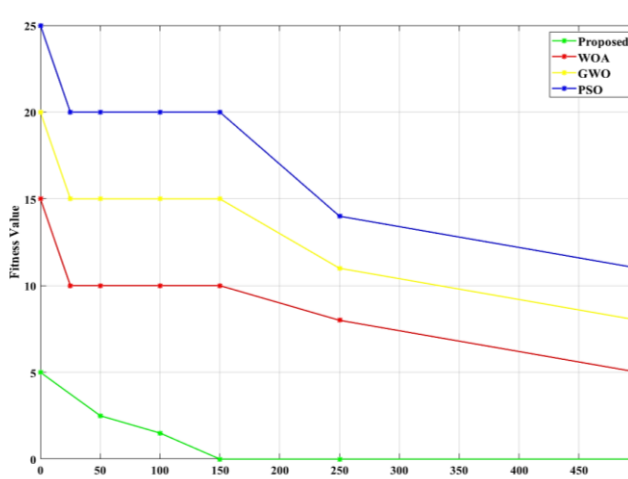

Fig. 22. Comparison of convergence of optimization.

Table 3. Parameter of FOPID controller

Mehods	Parameters				
	K^p	K^I	K^D	λ	μ
Proposed	69.127	65.6485	0.1553	1.0	0.82
WOA	0.0788	0.1304	0.9897	1.0	0.82
GWO	0.489	9.069	4.5 e-05	1.0	0.82
PSO	52.11	72.17	21.41	1.0	0.82

The proposed controller used in standalone microgrid to lessen PQ difficulties, such as disruption, interruption, swell, harmonics and sag to adjust for load requirements. Suggested technique can assist in reducing current and voltage oscillations in connected standalone microgrid system by producing proper control pulses for series and shunt APF. On load side, non-linear loads, faults, critical loads and unbalanced loads are connected to produce interruption, swell, disturbance, and sag conditions. The proposed controller then employed to address PQ issues.

7. CONCLUSION

This paper proposes coordinated PQ theory controller-based UPQC for standalone microgrid system to reduce power quality issues. The WT, PV and BESS systems are included in standalone microgrid's design. PV and WT are utilised to make up for necessary demand power on the load side. Power quality problems may have an impact on how renewable energy sources are linked to connected load system. The UPQC with coordinated PQ theory used to make up for power quality problems in solo microgrid. Both series and shunt active power filters are managed by FOPID controller. In coordinated PQ theory, SSO improves performance of FOPID controller by choosing best pulses. The standalone microgrid system's poor power quality can be made up for with proposed methods. To evaluate proposed controller, four different types of PQ issues interruption, sag, disturbance and swell are investigated. THD analysis of these signals is also carried out both before and after UPQC is installed in standalone microgrid system. The proposed controller contrasted with already-developed strategies like PSO, WOA and GWO. According to the investigation, proposed coordinated PQ theory controller with FOPID controller and SSO algorithms provides best results for power quality mitigation.

REFERENCES

[1] Lima, M.A.; Mendes, L.F.R.; Mothé, G.A.; Linhares, F.G.; Castro, M.P.P.D.; Silva, M.G.D. and Sthel, M.S. 2020. Renewable energy in reducing greenhouse gas emissions: Reaching the goals of the Paris agreement in Brazil. Environmental Development 33: 100504.

[2] Zhao, P.; Xu, W.; Zhang, S.; Wang, J. and Dai, Y. 2020. Technical feasibility assessment of a standalone photovoltaic/wind/adiabatic compressed air energy storage-based hybrid energy supply system for rural mobile base station. Energy Conversion and Management 206: 112486.

[3] Mbungu, N.T.; Naidoo, R.M.; Bansal, R.C.; Siti, M.W. and Tungadio, D.H. 2020. An overview of renewable energy resources and grid integration for commercial building applications. Journal of Energy Storage 29:101385.

[4] Yoshida, Y. and Farzaneh, H. 2020. Optimal Design of a Stand-Alone Residential Hybrid Microgrid System for Enhancing Renewable Energy Deployment in Japan. Energies 13(7): 1737.

[5] Sitharthan, R.; Karthikeyan, M.; Sundar, D.S. and Rajasekaran, S. 2020. Adaptive hybrid intelligent MPPT controller to approximate effectual wind speed and optimal rotor speed of variable speed wind turbine. ISA transactions 96: 479-489.

[6] Cecilia, A.; Carroquino, J.; Roda, V.; Costa-Castelló, R. and Barreras, F. 2020. Optimal energy management in a standalone microgrid, with photovoltaic generation, short-term storage, and hydrogen production. Energies 13(6): 1454.

[7] Jiao, P.H.; Chen, J.J.; Peng, K.; Zhao, Y.L. and Xin, K.F. 2020. Multi-objective mean-semi-entropy model for optimal standalone micro-grid planning with uncertain renewable energy resources. Energy 191: 116497.

[8] Adefarati, T. and Obikoya, G.D. 2020. Assessment of Renewable Energy Technologies in a Standalone Microgrid System. In International Journal of Engineering Research in Africa. Trans Tech Publications Ltd 46: 146-167.

[9] Sinha, S. and Bajpai, P. 2020. Power management of hybrid energy storage system in a standalone DC microgrid. Journal of Energy Storage 30: 101523.

[10] Batiyah, S.; Sharma, R.; Abdelwahed, S. and Zohrabi, N. 2020. An MPC-based power management of standalone DC microgrid with energy storage. International Journal of Electrical Power & Energy Systems 120: 105949.

[11] Elmetwaly, A.H.; Eldesouky, A.A. and Sallam, A.A. 2020. An Adaptive D-FACTS for Power Quality Enhancement in an Isolated Microgrid. IEEE Access 8: 57923-57942.

[12] Ain, Q.; Jamil, E.; Hameed S. and Naqvi K.H. 2020. Effects of SSSC and TCSC for enhancement of power system stability under different fault disturbances. Australian Journal of Electrical and Electronics Engineering 17(1): 56-64.

[13] Bajaj, M. 2020. Design and Simulation of Hybrid DG System Fed Single-Phase Dynamic Voltage Restorer for Smart Grid Application. Smart Science 8(1): 24-38.

[14] Çalgan, H.; Ilten, E. and Demirtas, M. 2020. Thyristor controlled reactor-based voltage and frequency regulation of a three-phase self-excited induction generator feeding unbalanced load. International Transactions on Electrical Energy Systems 30(6): e12387.

[15] Naz, M.N.; Imtiaz, S.; Kamran, M.; Bhatti, L.; Awan, W.Q.; Siddique, M. and Riaz, A. 2020. Dynamic Stability Improvement of Decentralized Wind Farms by Effective Distribution Static Compensator. Journal of Modern Power Systems and Clean Energy.

[16] Sedhom, B.E.; El-Saadawi, M.M.; Hatata, A.Y. and Alsayyari, A.S. 2020. Hierarchical control technique-based harmony search optimization algorithm versus model predictive control for autonomous smart microgrids.

International Journal of Electrical Power & Energy Systems 115: 105511.

[17] Sedhom, B.E.; El-Saadawi, M.M.; Hatata, A.Y.; Elhosseini, M.A. and Abd-Raboh, E.E. 2020. Robust Control Technique in an Autonomous Microgrid: A Multi-stage $$ H\infty $$ H∞ Controller Based on Harmony Search Algorithm. Iranian Journal of Science and Technology, Transactions of Electrical Engineering, 2018(1): 377-402.

[18] Elmetwaly, A.H.; Eldesouky, A.A. and Sallam, A.A. 2020. An Adaptive D-FACTS for Power Quality Enhancement in an Isolated Microgrid. IEEE Access 8: 57923-57942.

[19] Yavari, M.; Edjtahed S.H. and Taher. S.A. 2018. A non-linear controller design for UPQC in distribution systems. Alexandria engineering journal 57(4): 3387-3404.

[20] Dash, S.K. and Ray, P. K. 2018. Novel PV-tied UPQC topology based on a new model reference control scheme and integral plus sliding mode dc-link controller. International Transactions on Electrical Energy Systems 28(7): e2564.

[21] Berbaoui, B. 2018. Fuzzy multi-objective technique combined with VCS algorithm for unified power quality conditioner based on hybrid power source PEMFC/SC. International Journal of Hydrogen Energy 43(12): 6275-6293.

[22] Barik, P.K.; Shankar, G. and Sahoo, P.K. 2020. Power quality assessment of microgrid using fuzzy controller aided modified SRF based designed SAPF. International Transactions on Electrical Energy Systems 30(4): e12289.

[23] Kaushal, J. and Basak, P. 2020. Power quality control based on voltage sag/swell, unbalancing, frequency, THD and power factor using artificial neural network in PV integrated AC microgrid. Sustainable Energy, Grids and Networks, 100365.

[24] Zhao, B.; Zhang, X.; Chen, J.; Wang, C. and Guo, L. 2013. Operation optimization of standalone microgrids considering lifetime characteristics of battery energy storage system. IEEE transactions on sustainable energy 4(4): 934-943.

[25] Hossein, M.; Amrollahi and Bathaee, S.M.T. 2017. Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response. Applied energy 202: 66-77.

[26] Rathore, A. and Patidar, N.P. 2019. Reliability assessment using probabilistic modelling of pumped storage hydro plant with PV-Wind based standalone microgrid. International Journal of Electrical Power & Energy Systems 106: 17-32.

[27] Marzebali, M.H.; Mazidi, M. and Mohiti, M. 2020. An adaptive droop-based control strategy for fuel cell-battery hybrid energy storage system to support primary frequency in stand-alone microgrids. Journal of Energy Storage 27: 101127.

[28] Kumarasabapathy N. and Manoharan, P.S. 2015. MATLAB simulation of UPQC for power quality mitigation using an ant colony based fuzzy control technique. The Scientific World Journal.

[29] Naidu, R.P.K. and Meikandasivam, S. 2020. Power quality enhancement in a grid-connected hybrid system with coordinated PQ theory & fractional order PID controller in DPFC. Sustainable Energy, Grids and Networks 100317.

[30] Verma, S.K.; Yadav, S. and Nagar, S.K. 2017. Optimization of fractional order PID controller using grey wolf optimizer. Journal of Control. Automation and Electrical Systems 28(3): 314-322.

[31] Mirjalili, S.; Gandomi, A.H.; Mirjalili, S.Z.; Saremi, S.; Faris, H. and Mirjalili, S.M. 2017. Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems. Advances in Engineering Software 114: 163-191.