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A Novel Control Scheme for Renewable Energy Sources to Power Quality Enhancement in Micro Grid System: An IBSMFO Technique

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Abstract - In this paper, a novel control scheme is proposed for power quality enhancement of renewable energy sources (RESs) with energy storage. The proposed control plan is the combined execution of Improved Bat Search Algorithm (IBSA) with Moth Flame Optimization Algorithm (MFOA) named as IBSMFO. Here, the searching behavior of the bats is modified by using the efficient neighborhood search functions like crossover and mutation. In the proposed approach, the MFOA has handled the searching behavior of the IBSA in perspective of the minimum error objective function. The objective of the proposed IBSMFO approach is to enhance the power quality as for the real and reactive power variations. To accomplish the objective, MFOA is optimized for minimizing the power variations and the operational cost of the RESs in light of weekly and daily prediction of data for grid electricity price, electrical load, and environmental parameters. The proposed IBSMFO procedure deals with the performance of energy storage components as far as the enhancement of power in the entire system. By at that point, the proposed model is executed in MATLAB/Simulink working stage and the execution is surveyed with the current procedures.

Keywords: Power Quality Enhancement (PHE), Microgrid, control scheme, IBSA, MFOA.

1. Introduction

Energy shortage problem concerted with contemporary high petroleum price has resulted in severe impacts to several technical aspects [1]. Efficiency improvement of high-power apparatuses, research, and development of alternative energy, studies of integrated various renewable energy resources, etc., have been eagerly progressing [2]. During the past several decades, a large amount of natural resources of the earth have been unlimitedly consumed, and our living environment has been severely destroyed and polluted [3]. Global environmental protection concepts and concerns have been widely excited and several new forms of renewable resources such as photovoltaic systems (PV) and wind power generation systems (WPGS) to supplement fossil fuels have been examined, integrated, and developed in the whole world [4-6].
A Renewable energy storage system (RES) system may combine all different kinds of available renewable energy associated with available energy storage units [7]. The required power for the connected loads can be effectively delivered and supplied by the hybrid power generation/energy storage system with appropriate control and effective coordination among various subsystems [8]. Due to the international technological progress and promoted experience on the WPGS, the cost of generating electricity from the WPGS has already been reduced and the cost of electricity generating of the WPGS may close to one of traditional fossil fuel energies [9-11]. With the improvement of semiconductor manufacture technology, PV has enhanced efficiency, the cost of PV becomes much lower and the installed capacity becomes much higher in recent years [12]. However, the PV have lower energy conversion efficiency, lower power density, and higher cost compared with WTGs. Large PV may generate enough electricity for supplying isolated loads or delivering energy to a utility grid through dc–ac converters [13].
RES system for power quality (PQ) enhancement is done by using several controllers [14]. Many researchers are worked with the latest controllers such as a predictive controller, sliding mode controller, H-infinity controller for better steady-state and transient response of systems. These control techniques depend on complex mathematical analysis. In order to avoid the difficulties in controller designing, intelligent controllers are used [15, 16]. For better results, intelligent controller is now applied to various hybrid energy system problems. An application of fuzzy logic based controller (FLC) for inverter voltage and frequency control works very well even after variations in system parameter and operating conditions [17, 18]. Here an FLC for battery charging or discharging is implemented for system PQ enhancement to suppress the power fluctuation and to supply a quality power to load [19]. In spite of all the system parameters are known, there may be parameter variations during the operation of the system. So it is difficult to design controller parameters and more time is required [20].
This paper proposed an IBSMFO control scheme for the power quality enhancement in the microgrid using the RESs. The main goal of the present work is to enhance the power quality as for the real and reactive power variations. The error function is minimized by using the searching technique named as MFO. The remaining section of the paper is depicted in the section underneath. Section 2 delineates the recent research works about the PQ enhancement. Section 3 depicts the overview of the proposed system. Section 4 and 5 includes the experimental results and the conclusion.

2. Recent Research Works: A Brief Review

Numerous research works have previously existed in the literature which was based on the optimal control strategy for power quality enhancement of the renewable energy sources using various techniques and various aspects. Some of the works are reviewed here.

G. Talapur *et al.* [21] have presented a reliable micro-grid for a residential community with modified control techniques to achieve enhanced operation during grid-connected, islanded and resynchronization mode. A modified power control technique was developed such that, local load reactive power demand, harmonic currents, and load unbalance compensated by respective residential local DG. An additional modified control technique was also have developed to achieve a seamless transition of micro-grid between grid-connected mode and islanded mode. M. Mosaad and H. Ramadan [22] have presented the power quality improvement of the Fuel Cell (FC) integrated to the power network through a chopper and an inverter using the conventional PI controller. Two PI controllers tuned by three recent different evolutionary computing techniques namely Harmony Search (HS), Modified Flower Pollination Algorithm (MFPA) and Electromagnetic Field Optimization (EFO) methods are considered by the author. The two PI controllers are used for driving the inverter connected the on-grid FC in order to govern the PCC voltage between the FC and the power network. The control of an interface inverter for application of a hybrid photovoltaic and battery energy storage system (BESS) was proposed by S. Mousazadeh Mousavi *et al.* [23]. A control approach for battery state of charge and power management was employed for improving the performance of BESS and load leveling purpose.

For controlling the shunt active power filter (SAPF), S. Prince et al. [24] have proposed a Kalman filter (KF) based proportional integral (PI) current control strategy. To achieve accuracy in the KF performance, Particle Swarm Optimization (PSO) algorithm was adopted for tuning parameters. So, the tuning and parallel resonance problems are eliminated associated with the existing proportional integral (PI) technique. V. Lopez-Martin et al. [25] have employed a modification for PFC controllers by adapting the operation mode depending on the measured T HDV. As a result, the PFCs operate either in a low current Total Harmonic Distortion (T HDI) mode or in the conventional resistor emulator mode and contribute to the regulation of the T HDV and the PF at the distribution feeders. To prove the concept, the modification was applied to a current sensorless Non-Linear Controller (NLC) applied to a single-phase Boost rectifier.

2.1. Background of the Research Work

The survey of the recent research work demonstrates that the power quality (PQ) enhancement of renewable energy sources (RESs) utilizing energy storage system is an imperative contributing variable. Be that as it may, the RESs unsettling influences, for example, frequency drop, environmental dependency, noisy operation in wind energy systems, harmonics, intermittency, and variation of solar irradiation with the sun intensity are the absolute most ruling PQ problems in RES. These disturbances result in malfunctions decreased lifetime and failure of electrical equipment. Be that as it may, there are numerous procedures have been actualized for the power flow control, for example, adiabatic compressed air energy system (A-CAES) and flywheel energy storage system (FESS), proton exchange membrane (PEM) fuel cell (FC), model predictive control (MPC) technique and so on. A-CAES has been connected for enlarging the operational ranges yet the primary downsides are poor upkeep of transmission and distribution system prompts loss of energy, inefficient control, and leakages prompts loss of compressed air. The flywheel energy storage system has the capacity to accelerating a rotor (flywheel) to a high speed and maintaining the energy in the system as rotational energy however it displays constraints like short discharge time. MPC method can enhance the control execution and inherent compensation for dead times. However, the impediments like computation complexity and the solutions are not ensured. Despite the fact that the above techniques are utilized for enhancing the power quality in RESs, the complexity of the algorithm is high because of the increased number of samples required. To conquer these challenges, optimal control using advanced technology is required. In related works, few control techniques are exhibited to tackle the RESs issue; the previously mentioned impediments have inspired to do this research work.

3. Overview of the System with Proposed PQ Enhancement of Grid Connected HRESs

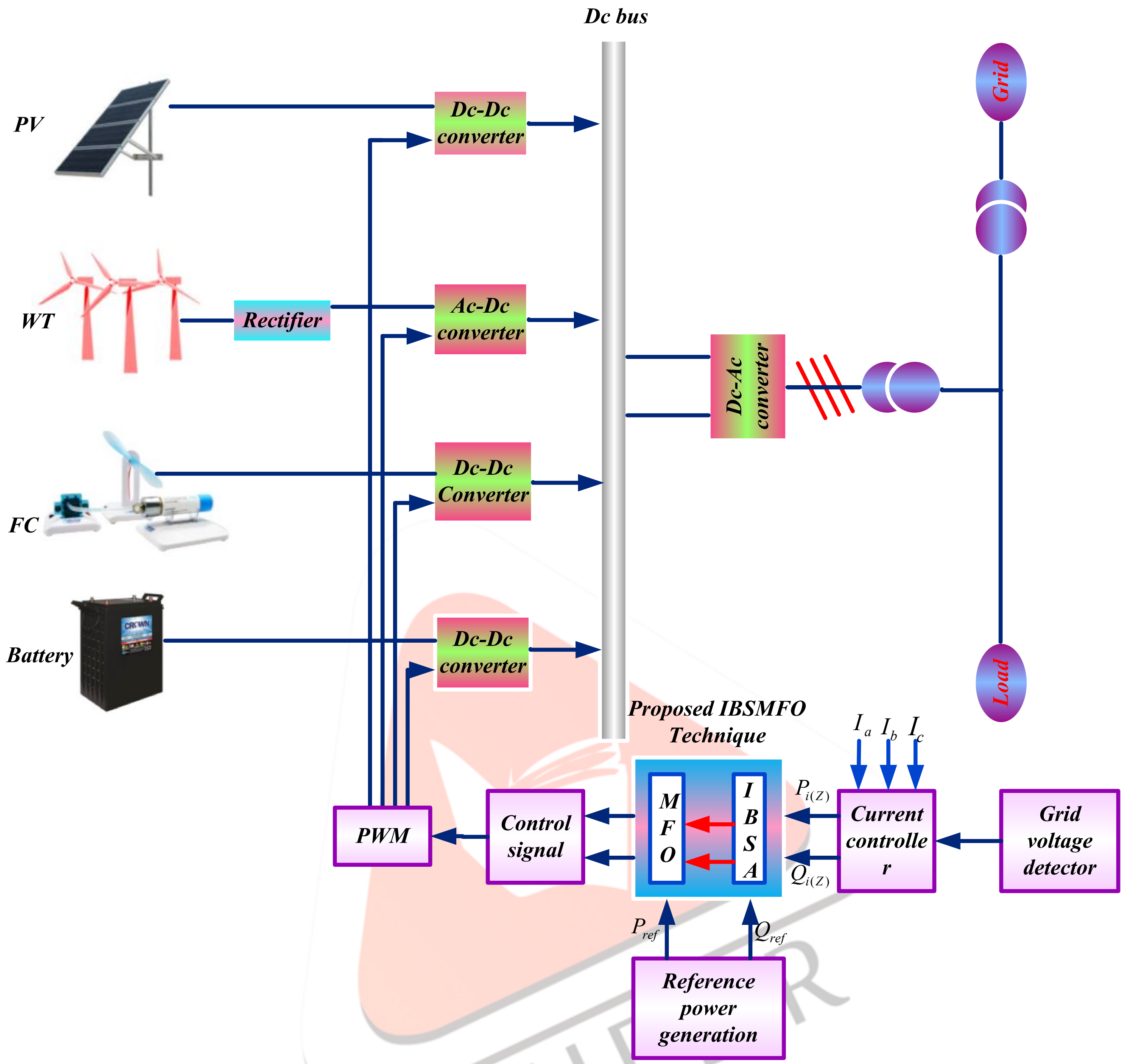

Figure 1: Control Structure of HRES with the proposed controller

Figure 1 illustrates the proposed IBSMFO control scheme of RESs to enhance the PQ in the MG system. Here, the control strategy based proposed technique is the parallel execution of the IBSA and MFDOA technique. In the proposed approach, the RESs are the compilation of the PV, wind turbine, fuel cell, and battery. By using these resources, the energy is transmitted to the DC bus. Moreover, to enhance the dynamic optimal PQ and also to analyze the electrical energy the load and the grid side parameters are determined optimally in this system. The architecture also specifies the VSI based RESs unit with the control modules for the PQE. Here, the VSI is used to adopt the appropriate power control mode due to the active and reactive power of the HRES unit should be regulated under grid-connected mode based on their reference values. At the time of load demand changes, the power supplied by the main grid and RESs must be properly changed. The power delivered from the main grid and PV array as well as FC must be coordinated to meet load demand. Here, the constant active and reactive power is necessary to control PQ issues between the HRES and the utility. The active and reactive power control strategy of the grid-connected operation mode is obviously depicted in the section underneath.

3.1. Active and Reactive Control Strategies for Grid-Connected PQE

This section analyzed the power quality enhancement with the gird and load mode of the HRESs. The power generated from the main grid and HRES must be changed when the load demand changes. Furthermore, the power generated from the main grid and PV array as well as FC must be coordinated to meet the load demand. In order to participate with constant active and reactive power, it is necessary to control power flow between the HRES and the utility. The power balance from sources to AC bus and to/from storage devices are controlled to satisfy the active and reactive power demand by the load. Here, the power balance should be satisfied both at the DC-link and at the Point of Common Coupling (PCC), which is expressed in equation (1).

$$P_{HRES}(t) = \sum_{i} P_{WT}(t) + P_{PV}(t) + P_{FC}(t) + P_{Bat}(t) \qquad (1)$$

From the available renewable energy sources at the time t, the generation of total power is denoted as $P_{HRES}(t)$. The need of the load and the output of the HRES are used to derive the power balancing of the system and also for the active and reactive power control process, $P_{Grid}(t)$, and $P_{Load}(t)$ in the grid and load connected mode is determined from the following equation.

$$P_{Grid}(t) = P_{Load}(t) - P_{HRES}(t) \quad (2)$$

$$P_{Load}(t) = P_{HRES}(t) + P_{Grid}(t) \quad (3)$$

$$Q_{Grid}(t) = Q_{Load}(t) - Q_{HRES}(t) \quad (4)$$

$$Q_{Load}(t) = Q_{HRES}(t) + Q_{Grid}(t) \quad (5)$$

In all the time, due to the uncertainty of the RESs and the variation of non-linear load demand, the above-mentioned power balanced conditions are not satisfied. The result of the power control mode is almost based on the high-performance operation of the HRES unit. Moreover, the control mode should be dedicated to improving the quality of power supply as PQ issues like voltage and frequency deviation, and harmonic distortion rises. Here, the active and reactive power should be computed as follows,

$$P_I(t) = \frac{3}{2}\left[V_d^I * i_d^I + V_q^I * i_q^I\right] \quad (6)$$

$$Q_I(t) = \frac{3}{2}\left[V_q^I * i_d^I - V_d^I * i_q^I\right] \quad (7)$$

In this case, in order to inject the pre-set active and reactive power values, the amplitude and phase angle of the inverter current are controlled, which can be defined locally by the grid. In the grid-connected mode, the active and reactive power control strategy is achieved based on the voltage regulation and frequency regulation. To analyze the HRES units, the real and reactive power process is considered and with the help of irradiance the PV is varied and in the WT parts the Battery is utilized. For the grid-connected operation mode, the following subsection presents the most relevant power and current control strategy.

3.1.1. Current and Power Control Strategy

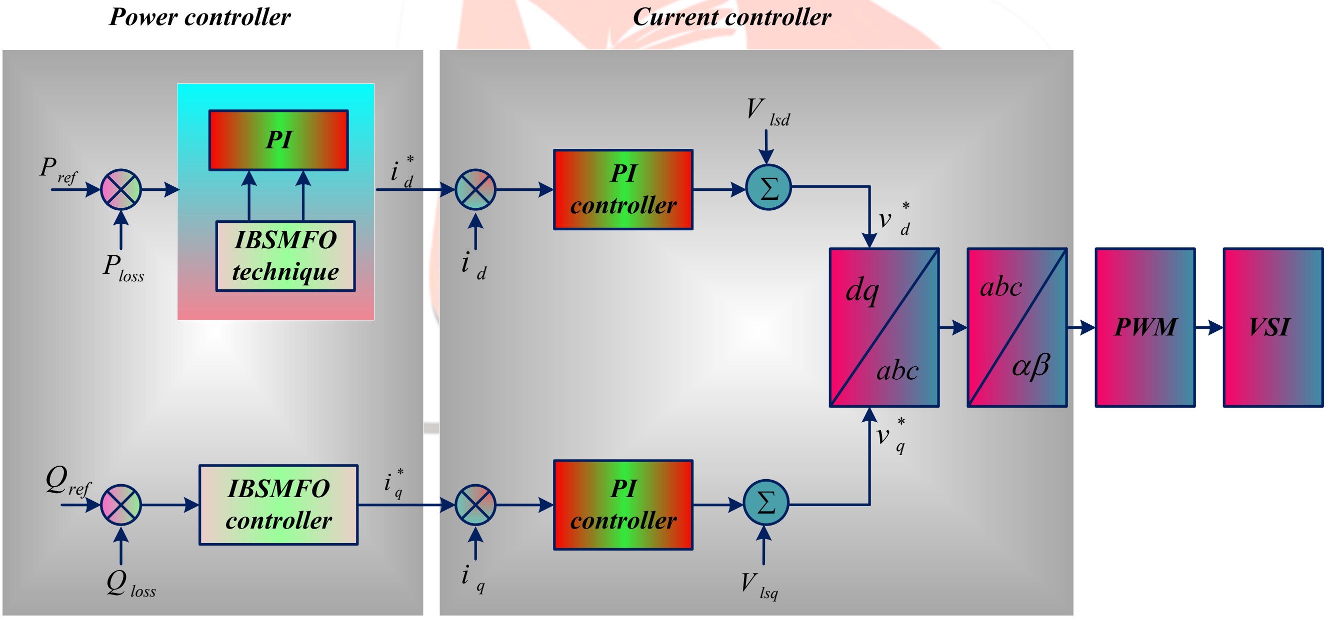

Figure 4: Proposed Controller for PQ enhancement

The purpose of using this strategy is, to control the supplying of active and reactive power to the load and also control the PQ issues between the grid and the utility. Here, Figure 2 illustrates the proposed controller scheme for enhancing the PQ in the MG system based on the two PI regulators. This control scheme employed the outer control loop to generate the reference current vectors I_D and I_Q. Indicating that the control objective has been achieved a high quality of the inverter output power, moreover, which is ensured by relatively slow changes of the reference current trajectory consequently. And also, the VSI based DG unit and PQ control strategy based on the IBSMFO technique is proposed. This IBSMFO is an efficient process to release qualified reference current vectors, which also provides optimum control parameters. The active and reactive power must be achieved when the DG unit connects to the grid, or at the load change condition. The active and reactive power outputs of the inverter are regulated by the controller based on their reference values ($P_{ref}(t)$ and $Q_{ref}(t)$) while the decoupling between the active and reactive power which has been achieved by using equations (8) and (9). Here, the reference current vectors in a DQ reference frame can be expressed based on PI regulators which can be given as follows,

$$I_D^*(t) = \left(P_{ref}(t) - P_I(t)\right) * \left(\delta_p^P + \frac{\delta_I^P}{t}\right) \quad (8)$$

$$I_Q^*(t) = \left(Q_{ref}(t) - Q_I(t)\right) * \left(\delta_p^Q + \frac{\delta_I^Q}{t}\right) \quad (9)$$

The objective function of the controller is to ensure accurate tracking and short transients of the inverter output current. To improve the steady-state and dynamic performance, both the inverter current loop and the grid voltage feed-forward loop are employed by both converter and also the current error is eliminated by using two PI regulators. Consequently, the output signal of the controller is represented by the reference voltage signals in the DQ frame. Here, the controller generates the reference voltage signals in ab stationary frame to synthesizing six pulses for the SVPWM and also in order to fire the IGBT inverter by the inverse Park's transformation and Clarke's transformation. Moreover, the controller technique provides the desired output voltage vectors with less harmonic distortion by the use of the PWM technique. Here, the reference voltage signal is expressed as follows,

$$\begin{bmatrix} V_D^* \\ V_Q^* \end{bmatrix} = \begin{bmatrix} -K_p & -\omega L_t \\ \omega L_t & -K_p \end{bmatrix} \cdot \begin{bmatrix} I_D \\ I_Q \end{bmatrix} + \begin{bmatrix} K_p & 0 \\ 0 & K_p \end{bmatrix} \cdot \begin{bmatrix} I_D^* \\ I_Q^* \end{bmatrix} + \begin{bmatrix} K_I & 0 \\ 0 & K_I \end{bmatrix} \cdot \begin{bmatrix} X_D \\ X_Q \end{bmatrix} + \begin{bmatrix} V_{tD} \\ V_{tQ} \end{bmatrix} \quad (10)$$

$$\frac{dX_D}{dt} = I_D^* - I_D \text{ and } \frac{dX_Q}{dt} = I_Q^* - I_Q$$

As shown in the following equation (10) and (11) can be transformed into α, β a stationary frame Using Clarke's transformation.

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \cdot \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \quad (11)$$

Furthermore, the inductor current is obtained by using a low pass filter (LPF). Equation (12) gives the LPF presented as a first-order transfer function in this work.

$$f \cdot \frac{1}{1 + tT_i} = f_i \quad (12)$$

Where the filter input value is given as f the filtered value as f_i and the time constant as T_i .

4. IBSMFO Based Power Quality Enhancement of HRES

This section presented the novel scheme for the PQ enhancement of HRESs in the MG system. For this enhancement of PQ, the proposed work employed the combined execution of the Improved Bat Search Algorithm (IBSA) and Moth Flame Optimization (MFO) algorithm [26]. To enhance the PQ, the optimal gain parameters are obtained by the IBSA and the searching behavior of the IBSA is improved by the MFO algorithm. The Bat algorithm is a meta-heuristic nature-inspired algorithm which was invented by Yang [27]. The BA is formulated idealizing bats characteristics in hunting their prey. The bat algorithm is formulated by idealizing the echolocation behavior of bats at first, which includes the behavior of micro-bats and Acoustics of Echolocation. As per this work, by the improved BA is used to reduce the error function to improve the PQ of HRES system [28]. The error of the system was reduced and the optimal PQ enhancement is achieved based on the PI parameters tuning. To find the objective function, the step by step process of bat algorithm is analyzed which are described below.

4.1. Gain Parameter Optimization of PQ Enhancement using IBSMFO

Step 1: Initialization

In the initialization process, the real and reactive power values are the input of the algorithm. In the first step, the gain parameters K_p and K_i values are randomly generated and which is expressed as follows,

$$X_i = \begin{bmatrix} K_p^{11} K_i^{11} & K_p^{12} K_i^{12} & \cdots & K_p^{1n} K_i^{1n} \\ K_p^{21} K_i^{21} & K_p^{22} K_i^{22} & \cdots & K_p^{2n} K_i^{2n} \\ \vdots & \vdots & \vdots & \vdots \\ K_p^{m1} K_i^{m1} & K_p^{m2} K_i^{m2} & \cdots & K_p^{mn} K_i^{mn} \end{bmatrix} \quad (13)$$

Where, K_p and K_i is the gain parameters.

Step 2: Fitness Evaluation
The error of the system is minimized by the objective function which can be expressed through the fitness evaluation and which can be expressed as follows,

$$Obj\ F_j = Min\ E(x) \quad (14)$$

$E(x) = P_{ref}(t) - P_I(t)$, For the active PQ enhancement

$E(x) = Q_{ref}(t) - Q_I(t)$, For the reactive PQ enhancement

Where, $E(x)$ is the error function of the system. Here, once the minimum objective function is achieved, the process gets optimized and the corresponding K_p and K_i parameters are tuned [29].

Step 3: Generation of new solutions
In this step, the new solution is generated by adjusting the pulse frequency and keeping wavelength as constant [30]. During the optimization process, the position (X_i) and velocity (v_i) of each bat should be defined and updated. The new solutions X_i^t and velocity v_i^t at time step t are generated by using the following equations,

$$F_i = F_{\min} + (F_{\max} - F_{\min}) \times \eta \quad (15)$$

$$v_i^t = v_i^{t-1} + \left(X_i^{t-1} - X^*\right) \times F_i \quad (16)$$

$$X_i^t = X_i^{t-1} + v_i^t \quad (17)$$

Where η is denoted as the range of [0, 1] randomly drawn, the best location is defined as X^*. The velocity increment is represented by the product of F_i *and* θ_i. According to a problem, the velocity increment can be adjusted by changing one and keeping fixed another.

Step 4: Process of Local search using MFOA
The MFOA is a novel inspired optimization paradigm and the main inspiration of this algorithm is the navigation method of moths in nature called transverse condition [31-33]]. The use of MFOA in this paper is to improve the searching behavior of the IBSA. In MFOA, the moth is the search agent and the flame is the best position of the moth. Here, the current solution is selected among the available solution and which is given in the following equation,

$$X_{new} = (-1) + X_{old} * \left(-\frac{1}{T}\right) \quad (18)$$

Step 5: Updating
The position of the moth is updated by using the following equation,

$$X_{i,j} = S(X_i, F_j)$$

Where the i-th moth is represented as X_i and the j-th flame is represented as F_j and the spiral function is represented as S. The spiral function of moth is computed as follows,

$$S(X_i, F_j) = D_i . e^{bt} \cos(2\pi t) + F_j$$

Where the distance of i-th moth for the j-th flame is represented as D_i, the shape of the spiral motion is defined as b and t is the random number in the range {-1, 1}and which is expressed as follows,

$$D_i = \left|F_j - X_i\right|$$

The best position is updated by using the number of flames and which can be expressed as follows,

$$U = round\left(N - l * \frac{N-1}{T}\right)$$

Where the present number of iteration is l, T is the maximum number of iteration, and N is the maximum number of flame.

Step 6: Termination
The process of computation is terminated if the maximum count of iterations is reached which satisfies the stopping criterion. Otherwise, repeat the process going to steps 2 and 4 [34, 35]. The error minimization output for PQ enhancement is given as follows,

$$\begin{bmatrix} E^{11} & E^{12} & \cdots & E^{1n} \\ E^{21} & E^{22} & \cdots & E^{2n} \\ \vdots & \vdots & \vdots & \vdots \\ E^{m1} & E^{m2} & \cdots & E^{mn} \end{bmatrix} = \begin{bmatrix} G_p^{11} G_i^{11} & G_p^{12} G_i^{12} & \cdots & G_p^{1n} G_i^{1n} \\ G_p^{21} G_i^{21} & G_p^{22} G_i^{22} & \cdots & G_p^{2n} G_i^{2n} \\ \vdots & \vdots & \vdots & \vdots \\ G_p^{m1} G_i^{m1} & G_p^{m2} G_i^{m2} & \cdots & G_p^{mn} G_i^{mn} \end{bmatrix}$$

Once the above steps of the algorithm are completed, the system is able to enhance the PQof HRES based on the optimal gain parameters and the limited error. The flowchart explanation of the proposed IBSMFO is illustrated as follows.

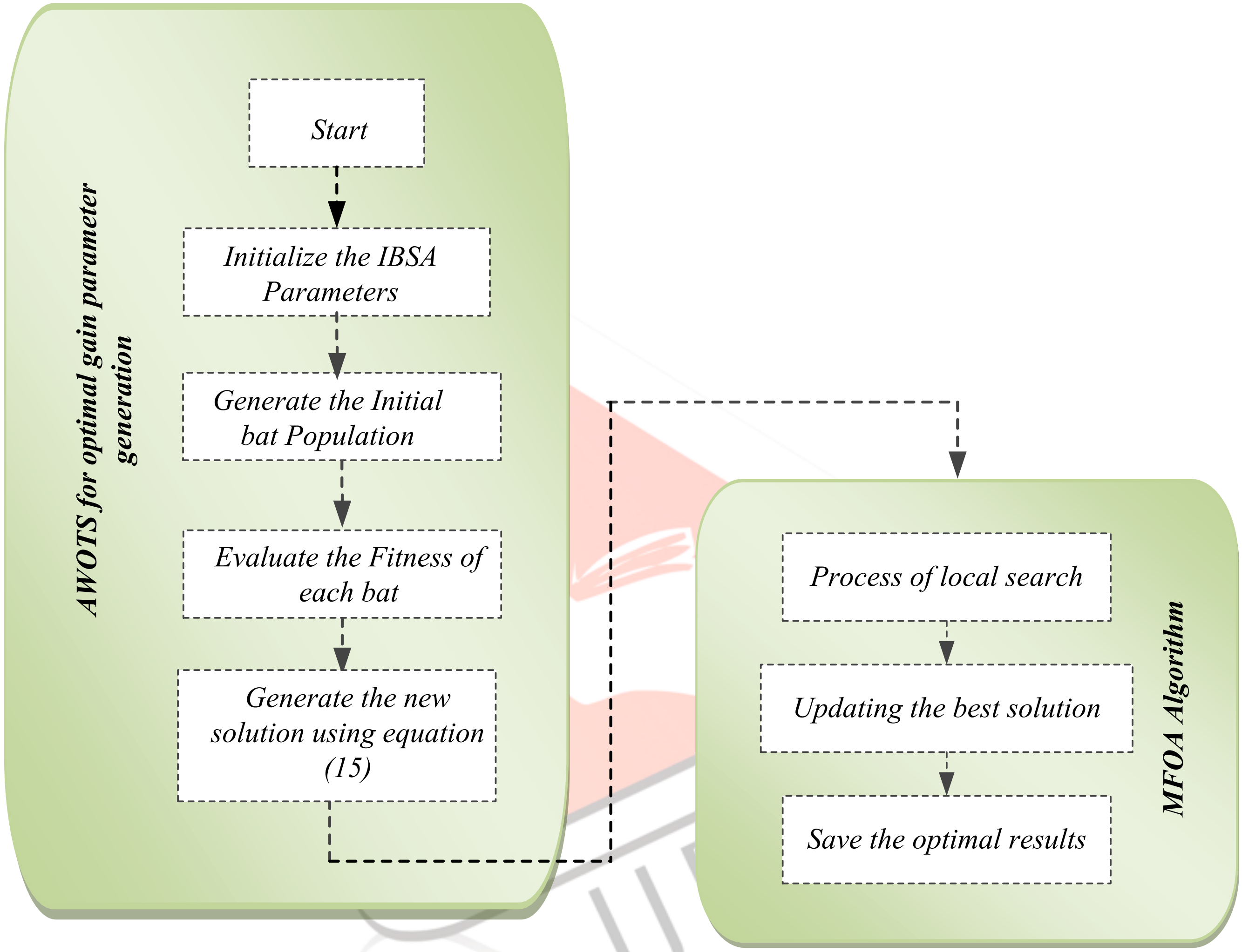

Figure 3: *Flowchart of the Proposed IBSMFO technique*

4. Experimental Results and Discussions

In this section, the IBSMFO technique based PI controller is proposed and implemented in MATLAB/Simulink platform. The proposed method is used to enhance the power quality of HRES unit. At this point, the projected process is rooted in HRES unit which is picked to organize for constructing orientation signals of the DC/DC converter. Through this projected technique, the real and reactive power quality optimization is done through the IBSMFO technique. Afterward, the prohibited signals are generated from the projected technique that can construct the scheming pulses for developing the presentation of DC/DC converter. So, the projected process is utilized to progress the presentation of converter also to recompense the PQ troubles. The projected process is experienced and its presentation is demonstrated. In order to estimate the performance of the proposed tuning controller, the simulation results are compared with those of Artificial Bee Colony (ABC) algorithm [36-39], Gravitational Search Algorithm (GSA) [40-42]and the Firefly Algorithm (FA) [43-45] and IBSMFO controllers.

4.1. Performance Analysis

In the subsection, the performance of the proposed method is analyzed by using the combined IBSA and MFO for the enhancement of PQ of the HRES unit in the MG system. Here, the design of the proposed controller is developed in light of the PQ control mode for the HRES. For the viability of the proposed work, this experimental section of this paper is analyzed by using two cases named as,

Case 1: Balanced supply with the unbalanced load condition

Case 2: Unbalanced supply with the balanced load condition

In the above cases, the case study 2 has two conditions; they are given as follows,

Condition A: Analysis of step response in the PV system
Condition B: Analysis of zero response in the PV system

The unbalanced supply arises when there is a sudden deviation in voltage or current signal from the normal sinusoidal waveform. Here, the unbalanced PQ issue of PV arises during the fault condition and it is evaluated by the proposed technique. In this section, the performance of the proposed IBSMFO technique is compared with the existing techniques for PQE such as ABC algorithm, GSA and the FA. The two case studies analyzing the performance of the proposed technique is beneath section.

Case 1: Balanced power supply with the unbalanced load condition

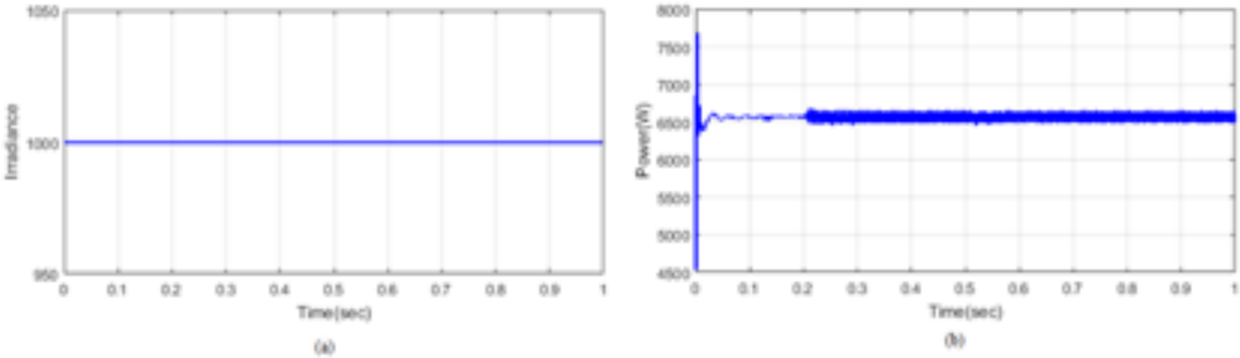

Figure 4: *Analysis of (a) PV irradiance (b) PV power*

In the first case, the PQ enhancement of HRES is analyzed under balance supply with unbalance load condition. The main aim of this case is to evaluate the response of the power controller when the requirement of the load is unbalanced. The performance of PV irradiance and power is shown in figure 4 (a) and (b). At the range of 1000 within t= 0 to1 sec, the irradiance under PV runs at a constant level. The PV power performance, where the power starts at zero range is shown in figure 4 (b). The output of the PV power is performed in constant level after the time period t=0.25 sec. The power analysis of the HRES such as PV, WT, and FC, battery, grid and the load is analyzed by the figure 5 (a) to (d). Here, the performance of the HRES is satisfied with the balance power condition. In the analysis of figure 5(a) to (d), the power (w) is represented in the x-axis and the time in sec is represented in the y-axis. At time t=0.023 sec, the power of PV is kept in peak variation at 3500 kW and suddenly falls at 0.08 sec. The power of WT is kept in peak variation at 4200 kW at time t=0.01 sec and suddenly falls at 0.023 sec. At time t=0.01 sec, the power of FC is kept in peak variation at 1500 kW and suddenly falls at 0.03 sec. The power of the battery is kept in peak variation at 14000 kW at time t=0.01 sec and suddenly falls at 0.02 sec. In the particular time period, the system starts to operate in a grid-connected mode, at that time; the power generated from the grid is illustrated in figure 5(e). Based on the designed, the control operation of the HRES system is expected that the load would be shared. The performance of the load and grid under the unbalanced condition is analyzed from figure 5(e) and (f).). At time t= 0.25 sec, the power of grid is 2kW, after that, it goes constantly till the end of the operation. At time t= 0.25 sec, the power of load is 3500kW, after that it goes constantly till the end of the operation.

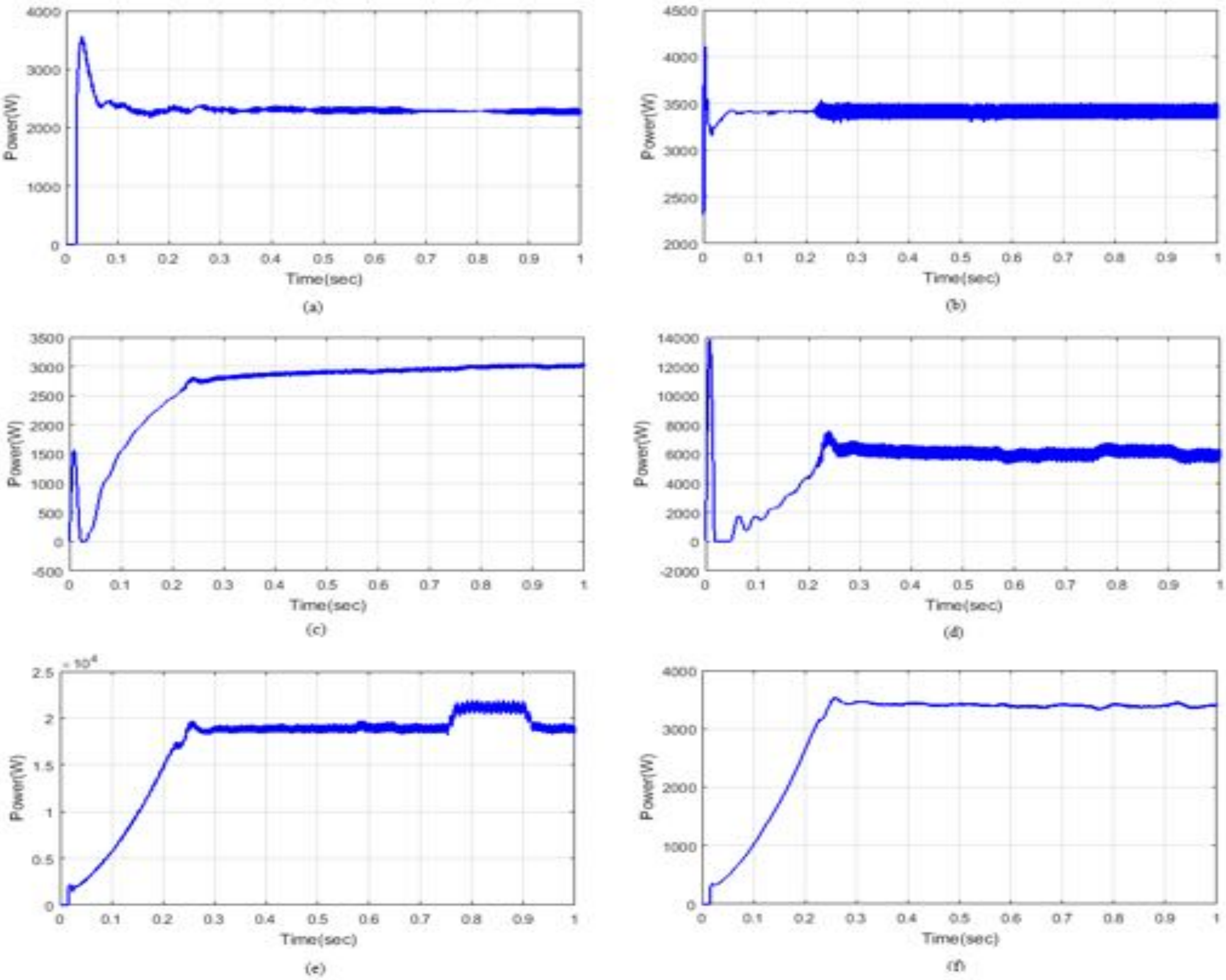

Figure 5: *Power analysis of (a) PV (b) WT(c) FC (d) Battery (e) Grid and (f) Load*

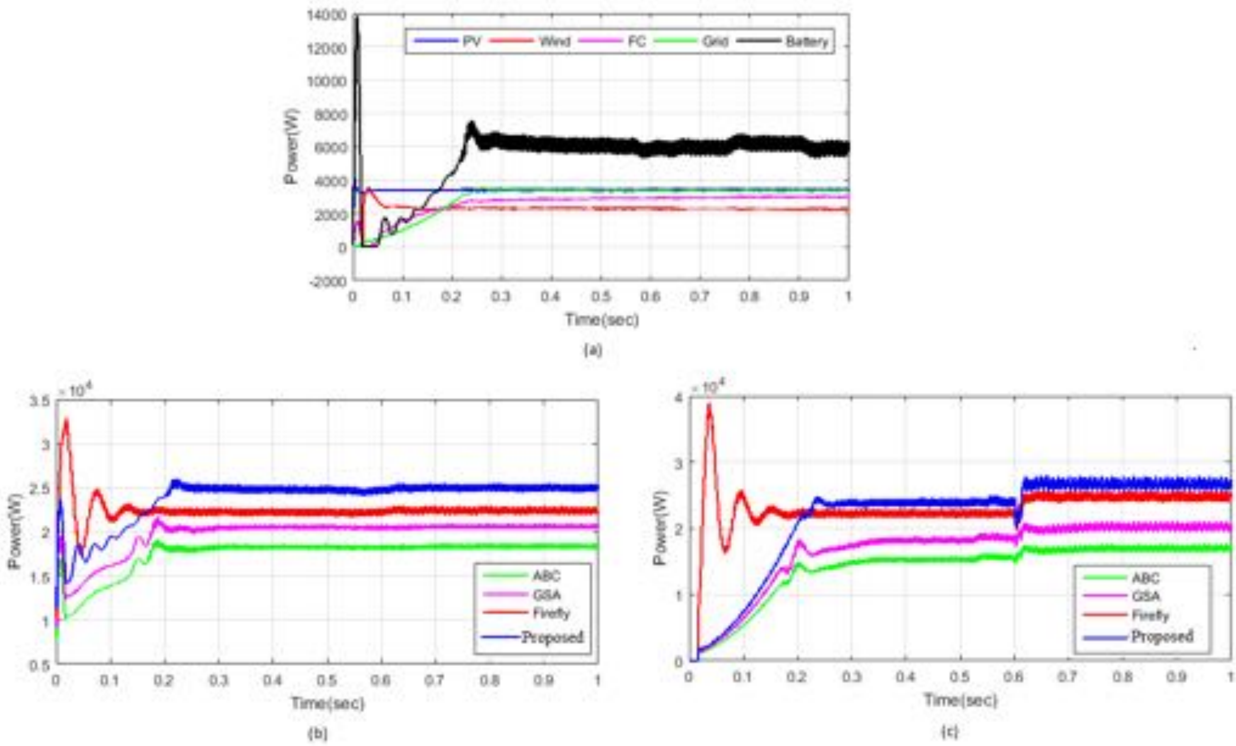

Figure 6: *Analysis of (a) Total power in HRES using proposed method (b) Total power comparison (c) Load power comparison*

Figure 6(a) to (c) illustrates the total power of the HRES using a proposed controller, total power comparison and the Load power comparison. In figure 6(a), the power variation of PV, wind, FC, Grid, and Battery are 4000 MW, 3800 MW, 1800 MW, 3900 MW and 7800 MW respectively. The effectiveness of the proposed method is compared with the existing techniques such as ABC, GSA, and FA respectively. The comparison of total power and load power under load changes is shown in figure 6(b) and (c). In this section, the peak overshoot time is zero by using the proposed method. The settling time of the proposed, ABC, GSA and the FA method is t=0.22sec, 0.28 sec, 0.32 sec, and 0.4 sec respectively and likewise the rising time of the proposed, ABC, GSA and the FA method t= 0.04 sec, 0.03sec, 0.028 sec and 0.03 sec respectively. The above results of the comparison analysis show, the settling time, rising time and peak overshoot time of the proposed method is highly less when compared with the existing method.

Case 2: Unbalanced supply with the balanced load condition

In this section, the optimal power quality of the proposed method is analyzed. To achieve the optimal PQ, the active and reactive power balanced is controlled by using the proposed method. The high-quality output power of the inverter and the control objective has been achieved by a relatively slow change of the reference current/voltage trajectory consequently. Active and reactive power control strategy is analyzed with the HRES unit connecting to the grid, or at the load change condition. In this research, both the inverter current loop and two PI regulators are used to eliminate the current error. To ensure the PQ enhancement, the unbalanced supply, and balanced load condition is considered. Based on the PV variations two set of analysis is presented here. (i) Condition A: Analysis of step response in PV, (ii) Condition B: Analysis of Zero response in PV.

Condition A: Analysis of step response in PV

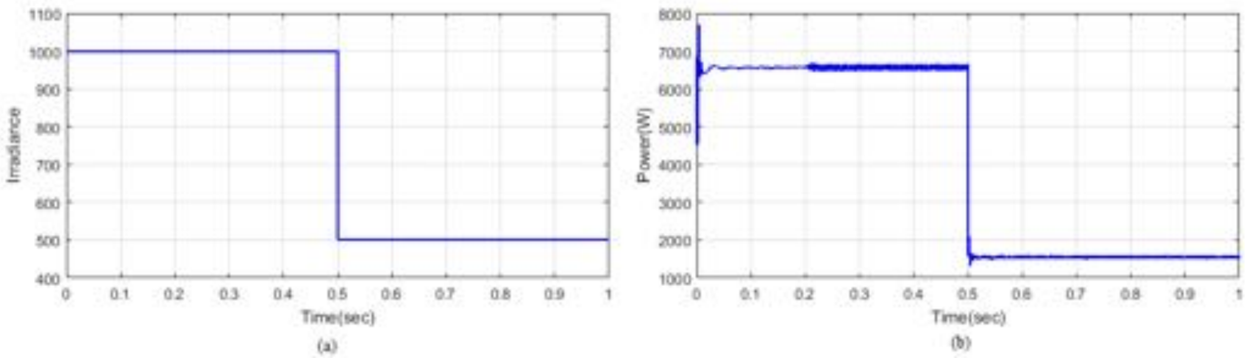

Figure 7: *Analysis of (a) PV irradiance (b) PV power*

In the subsection, the power analysis of PV, WT, FC, and battery is analyzed. Figure 7(a) and (b) specified the irradiance and power of PV under unbalanced condition. In the time instant t=0 to 0.5 sec, the irradiance of PV is 1000w/m^2 power is produced by the PV under the step irradiation conditions which is then reduced to 500w/m^2 at the period of 0.5 second to 1 second and which is shown in figure 7 (a). Figure 7(b) shows the PV power generation under unbalanced load condition using the proposed methodology. Figure 8 (a)-(f) shows the maximum power of PV, WT, FC, battery, grid, and load. The maximum power of 3500kW is produced by the PV at the time of t=0.02 sec, after that, the maximum power is reduced to 2500kW in the period of 0.06 sec. Figure 8 (b) shows the power of WT; here, the maximum power WT is 4100kW at the starting time and it can be reduced to 3250kW at the time period of 0.2 sec. Figure 7(c) shows the extraction of FC power; 1500kW power is extracted from the FC at the initial stage by the proposed method without any oscillations. At normal conditions, 2700kW power has been delivered and changes slightly at the time of unbalanced load conditions. The power of the battery is kept in peak variation at 14000 kW at time t=0.01 sec, and suddenly falls at 0.02 sec and which is shown in figure 8(d). The performance of the load and grid under the unbalanced condition is analyzed from figure 8(e) and (f).). At time t= 0.25 sec, the power of grid is 2kW, after that, it goes constant till the end of the operation. At time t= 0.25 sec, the power of load is 3500kW, after that it goes constant till the end of the operation.

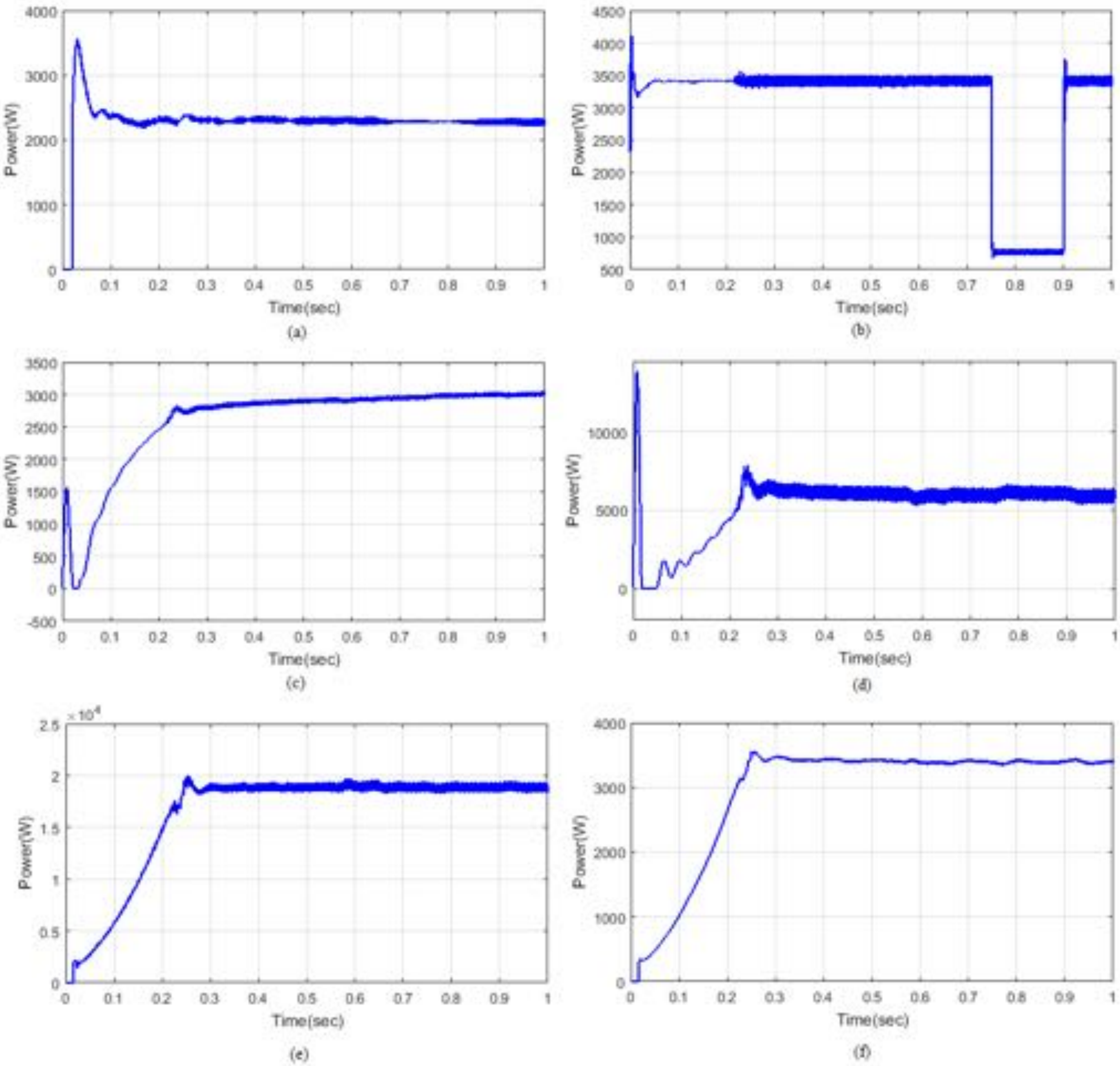

Figure 8: *Power analysis of (a) PV (b) WT(c) FC (d) Battery (e) Grid and (f) Load*

Figure 9 (a) shows the total power in the HRES unit and figure 9(b) shows the comparison of total power generation by using various PQE scheme. The extraction of the required power by the proposed control scheme is obtained from the renewable energy sources, energy storage and grid. Due to the unawareness of the environment, $1.5*10^4$kW power generated by the ABC is not a required power. The GSA based controller develops the power generation from the sources by slightly observing the need of the system. Constant power generation is maintained until the end of operating condition by the FA methodology but it does not meet the required criteria. Figure 9(c), shows the load power comparison using different techniques. Due to low power generation, the ABC does not meet the load requirements and slight deviations are found in the GSA based controller. From the high power generation of the FA technique, it is observed that the load variation is not identified by this method. The figure describes how effectively the proposed method identifies the situation and solves the power requirement of the load. To enhance the PQ of the energy storage connected smart grid system, the proposed method has much more efficiency when compared to the other techniques.

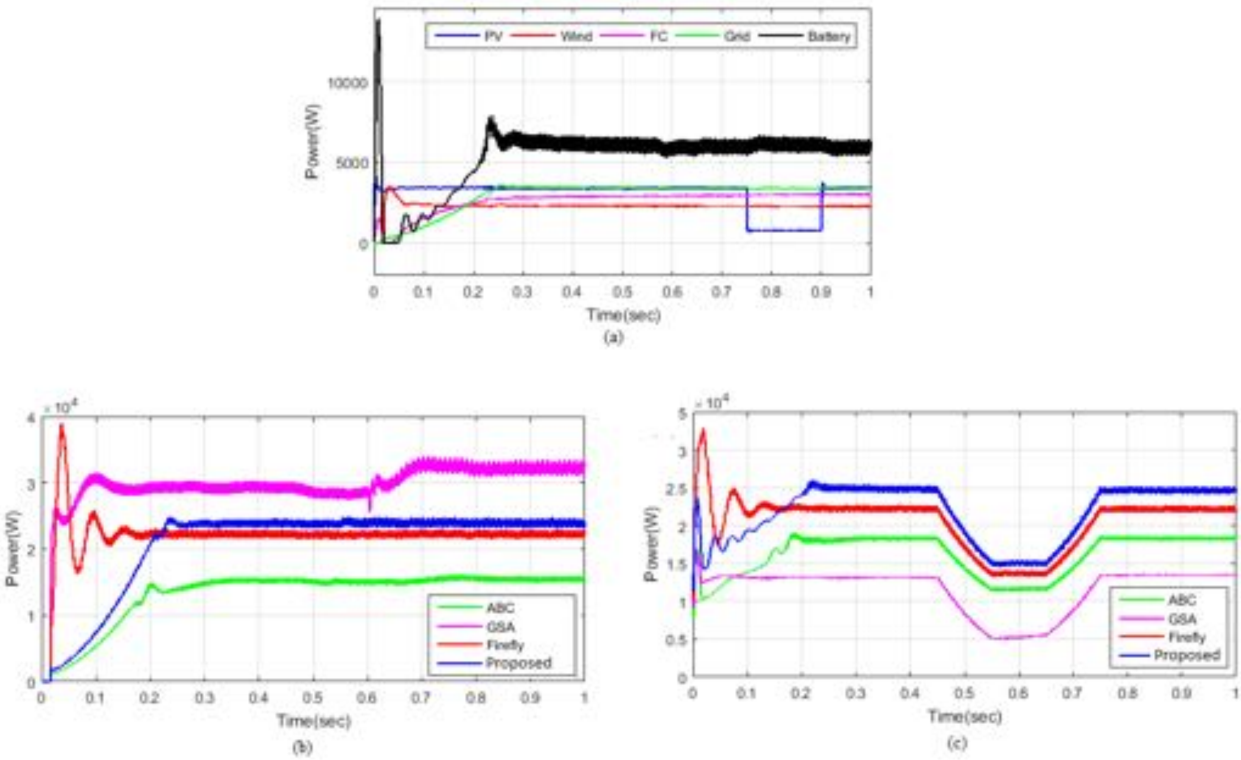

Figure 9: *Analysis of (a) Total power in HRES using proposed method (b) Total power comparison (c) Load power comparison*

Condition B: Analysis of zero response in PV

The zero response analysis of PV is illustrated in figure 10 (a) to (c). It shows the resulting controlled total and PV power flows in the HRES system. It obvious that, the PQ issues between the grid and the HRES unit is controlled perfectly. While the HRES unit still injects a sustained output power the unbalanced power is supplied by the grid in this case. In this instance, the HRES unit supplies the load automatically and its excess power is fed to the grid. With the proposed and existing methods, the total power and battery power is analyzed from the graphical representation. The maximum power and the optimal PQE is achieved in the proposed method.

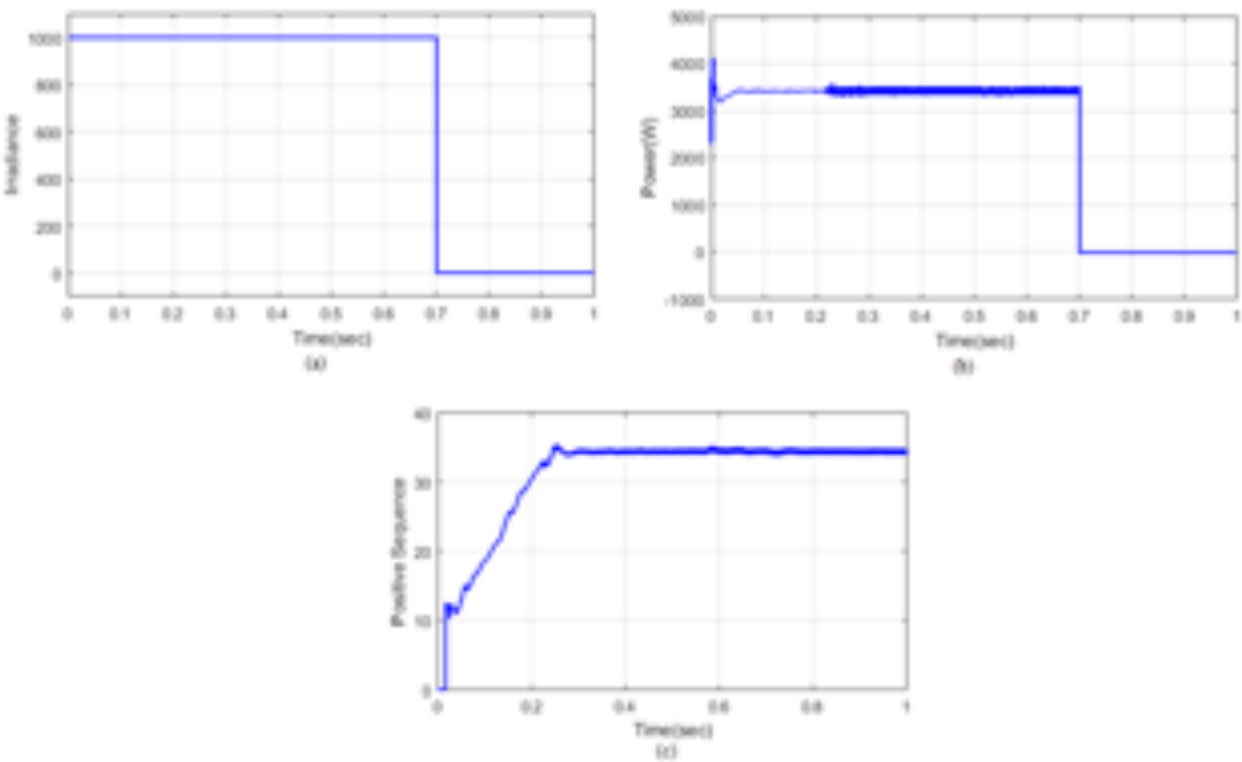

Figure 10: *Analysis of PV (a) Irradiance and (b) PV power and (c) Inverter voltage*

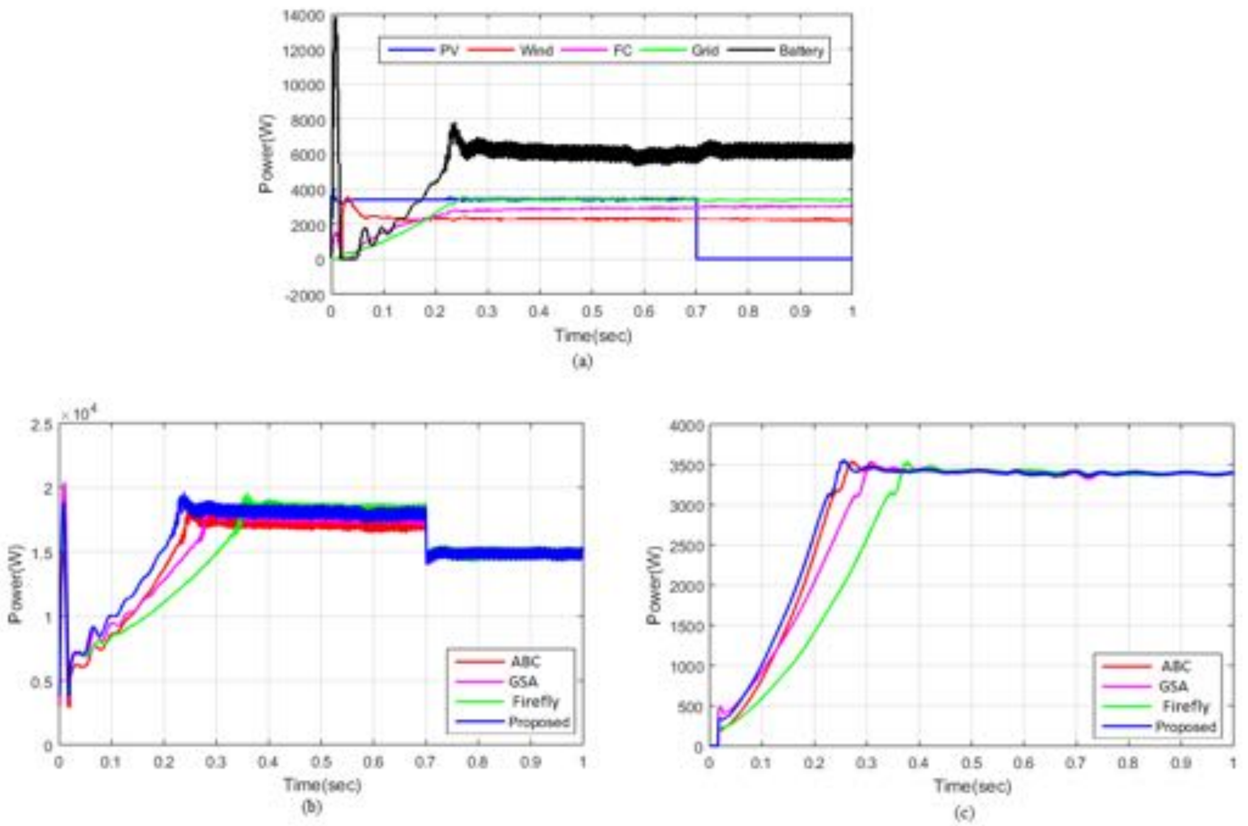

Figure 11: *Analysis of (a) Total power in HRES using proposed method (b) Total power comparison (c) Load power comparison*

Figure 11(a) to (c) illustrates the total power of the HRES using a proposed controller, total power comparison and the load power comparison. In figure 11(a), the power variation of PV, wind, FC, Grid, and Battery are 4000 MW, 3800 MW, 1800 MW, 3900 MW and 7800 MW respectively. The effectiveness of the proposed method is compared with the existing techniques such as ABC, GSA, and FA respectively. The comparison of total power and load power under load changes is shown in figure 11(b) and (c). In this section, the peak overshoot time is zero by using the proposed method. The settling time of the proposed, ABC, GSA and the FA method is t=0.22sec, 0.28 sec, 0.32 sec, and 0.4 sec respectively and likewise the rising time of the proposed, ABC, GSA and the FA method t= 0.04 sec, 0.03sec, 0.028 sec and 0.03 sec respectively. The above results of the comparison analysis show, the settling time, rising time and peak overshoot time of the proposed method is highly less when compared with the existing method.

Table 1: Optimized power controller parameters

Control parameters		**ABC**	**GSA**	**FA**	**IBSMFO method**
Active power controller parameters	K_{pp}	8.2270	9.6325	9.2545	8.8554
	K_{pi}	0.0020	2.3020	1.6580	1.8569
Reactive power controller parameters	K_{qp}	5.0978	8.3699	7.6691	8.1657
	K_{qi}	0.0020	2.3652	1.6559	1.5698

Table 2: First order statistical analysis for 100 iterations (active power)

Solution techniques		Mean	Median	Std.deviation
GSA	Case 1	0.8493	0.8496	0.0257
	Case 2 (Condition- A)	0.8620	0.8623	0.0050
	Case 2 (Condition-B)	0.8993	0.8989	0.0058
FA	Case 1	0.7478	0.7443	0.0291
	Case 2 (Condition- A)	0.7787	0.7789	0.0248
	Case 2 (Condition-B)	0.8101	0.8098	0.0055
IBSMFO method	Case 1	0.7023	0.6976	0.0264
	Case 2 (Condition- A)	0.7235	0.7534	0.0323
	Case 2 (Condition-B)	0.7634	0.7568	0.0167

Table 3: First order statistical analysis for 100 iterations (reactive power)

Solution techniques		Mean	Median	Std.deviation
GSA	Case 1	0.9212	0.9211	0.0276
	Case 2 (Condition- A)	0.9314	0.9319	0.0051
	Case 2 (Condition-B)	0.9621	0.9625	0.0056
FA	Case 1	0.8731	0.8701	0.0270
	Case 2 (Condition- A)	0.8966	0.8966	0.0025
	Case 2 (Condition-B)	0.9071	0.9073	0.0029
IBSMFO method	Case 1	0.8143	0.8143	0.0242
	Case 2 (Condition- A)	0.8543	0.8526	0.0063
	Case 2 (Condition-B)	0.8735	0.8653	0.0034

Using various methods the real and reactive powers are tabulated in both cases from the above table 1. Using other methods, the maximum real power is achieved about (8.2270, 0.0020) while by using the proposed method it is (8.8554, 1.8569). The other methods are analyzed and the reactive power is also determined similarly. Table 2 and 3 tabulates the mean, median and standard deviation of the attained real and reactive power values from different algorithms. The voltage and current values as the input are elegantly utilized by the proposed method. In the event, to generate the optimal control pulses of the HRES DC-DC converter the proposed method becomes well-geared the procedures come to an end. Better results, when compared to the other methods, are given by the proposed method in the efficiency analysis. To their corresponding real and reactive PQE, the efficiency of the converter is analyzed by utilizing the proposed controller. The proposed method has PQE, reduced the disturbance of the system and maximizes the optimal performance based on the output response of the performance of the system. Similarly, to obtain the maximum power the existing controllers are analyzed with the converter. The proposed controller accomplished optimal PQE while contrasted with different control strategies. Drawn by the same burdens the nature of HRES power, load power, grid power, and inverter voltage, PV voltage is watched. The two cases are balanced and an unbalanced supply performance is determined from the overall analysis. The proposed controller achieves better results while all the control schemes are efficient in optimal operation of DC-DC converter performances.

5. Conclusions

In this paper, a new optimization technique known as IBSMFO controller has been proposed for an optimal PQ enhancement of HRES with DC-DC converter. The proposed technique is utilized in the controller to regulate the active and reactive power by which DG unit is connected to the grid. The proposed control scheme consists of an inner and an outer loop, i.e. current control loop and power control loop, respectively. In the proposed technique, the IBSA algorithm optimally locates the gain parameters of the PI controller based on the minimum error objective function, the searching behavior of the IBSA is improved by the MFO technique. Finally, the optimal control pulses are generated by the proposed controller by enhancing the PQ of HRES. The proposed controller is implemented in MATLAB/Simulink platform and the performance is evaluated. The performance of the proposed technique is evaluated during any load changes in the balanced and unbalanced supply of the system. The proposed technique is compared with the existing techniques in order to prove the effectiveness. The simulation results are analyzed in terms of the settling time, rise in time, and overshoot time of the proposed controller. Also, the statistical analysis of HRES unit is analyzed by considering the mean, median, and standard deviations of the proposed controller with the existing techniques. The outcome of the simulation result demonstrates the superiority of the proposed technique in terms of quick settling time and overshoot time and hence the stability of the system is maintained effectively.

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