An IBSMF Optimization Technique used Distribution system with Renewable Energy Sources

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Abstract. In this paper, the interconnection of renewable energy sources is proposed for power quality improvement of renewable energy sources (RESs) with an energy storage system. The proposed system is the combined execution of Improved Bat Search Algorithm (IBSA) through Moth Flame Optimization Algorithm (MFOA) named as IBSMFO. The searching behaviour of the bats is modified with efficient neighborhood search functions like crossover & mutation. In the proposed method, 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 was to enhance the power quality as for the real and reactive power variations. To accomplish the objective, MFOA is optimized for minimize power variations as well as the operational cost of the RESs in light of weekly and daily forecast of data for grid electricity charge, electrical load and environmental parameter. The proposed IBSMFO procedure deals with the performance of the energy storage apparatus as far as the enhancement of power in the entire system. By at that point, the proposed system is executed in MATLAB/SIMULINK working model and the execution is surveyed with the current procedure.

Index Terms-Power Quality Enhancement (PHE), control scheme, IBSA, MFOA.

1. Introduction

Energy deficiency problem concerted by contemporary high petroleum cost has resulted in a severe impact to several technological aspects [1]. Efficiency development of high power apparatus, research and improvement of alternative energy, the study of integrated various renewable energy resources, etc. have been eagerly progressing [2]. All through the past several decades, a huge quantity of natural resources of the earth has been unlimitedly consumed and our living environment has been severely destroyed as well as contaminated [3]. Global environmental protection concept and concern have been widely excited with several innovative forms of renewable energy sources such as solar photovoltaic systems (PV) and wind power generation systems (WPGS) to supplement fossil fuels have been examined, integrated and developed in the entire world [4-6].

A Renewable energy storage system (RES) system can combine all different kinds of existing renewable energy linked with available energy storage systems [7]. The necessary power for the connected loads can be efficiently delivered and supplied through the hybrid power energy storage system with suitable control with efficient coordination among different subsystems [8]. Due to the global technological development and promoted experience on the Wind Power Generation System, the charge of generating electricity from the WPGS has been reduced and the price of electricity-generating of the WPGS might close to one of the conventional energies [9-11]. With the enhancement of semiconductor manufacture technology, Solar PV has enhanced efficiency and the cost of Solar PV becomes much lower with the
installed capacity becomes much higher in recent years [12]. However, the Solar PV contains lower energy conversion efficiency, lower power density and higher cost compared with WTGs. Huge Solar PV may generate sufficient 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]. Several researchers are worked with the most modern controllers such as a predictive controller, sliding mode controller, H-infinity controller used for better steady-state and transient response of systems. This control technique depends on complex mathematical analysis. In order to avoid the problems in controller designing, intelligent controllers are used [15, 16]. For enhanced result, intelligent controller is now applied to different hybrid energy system problems. An application of fuzzy logic-based controller (FLC) for inverter voltage and frequency control works thoroughly even after variation in system constraint and operating circumstances [17, 18]. Here an Fuzzy Logic Controller used for battery charging or discharging is implemented for system Power Quality Improvement to suppress the power oscillation and to supply a quality power to load [19]. In spite of all the system parameter are recognized, there may be parameter variations through 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 improvement in the micro grid using the RES. The main objective of the present work is to improve 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 a summary of the proposed system. Section 4 and section 5 includes the experimental results and the conclusion.

2. Literature survey

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

G. Talapur et al. [21] have presented a reliable micro grid used for a residential population with modified control techniques to attain improved 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 particular residential local DG. A supplementary modified control technique was also having 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 PQ enhancement of the Fuel Cell (FC) integrated to the power network through a chopper and an inverter with the conventional PI controller. Two PI controllers tuned by three recent dissimilar evolutionary computing techniques namely Harmony Search (HS), Modified Flower Pollination Algorithm (MFFPA) and Electromagnetic Field Optimization (EFO) methods are measured by the author. The two PI controllers are used for driving the inverter connected the on-grid Fuel Cell in order to govern the PCC voltage between the Fuel Cell and the power network. The control of an interface inverter for the application of a hybrid solar photovoltaic and battery energy storage system (BESS) was planned by S. Mousazadeh Mousavi et al. [23]. A control approach for battery state of charge and power management was working 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 Kalman Filter performance, Particle Swarm Optimization (PSO) algorithm was adopted for tuning parameter. Thus, the tuning and parallel resonance problems are eliminated associated through the existing proportional integral (PI) technique. V. Lopez-Martinet al. [25] has employed a modification for PFC controllers by adapting the operation mode depending on the measured THDV. As a result, the PFCs operate either in a low current Total Harmonic Distortion (THD) mode or in the conventional resistor emulator mode and contribute to the regulation of the THDV and the PF at the distribution feeders. To verify the concept, the modification was applied to a current sensor less Non Linear Controller (NLC) applied to a single phase Boost rectifier.
2.1. Background of the Research Work
The review of the recent research work demonstrates that the power quality (PQ) improvement of renewable energy sources (RESs) utilizing an energy storage system is an essential 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 through the sun intensity are the absolute most ruling PQ problems in RES. These disturbances result in malfunctions decreased duration and failure of electrical apparatus. Be that as it may, there are several procedures have been actualized for the power flow control, for example adiabatic compressed air energy system (ACAES), flywheel energy storage system (FESS), proton exchange membrane (PEM), fuel cell (FC), model predictive control (MPC) technique etc., ACAES has been connected used for enlarging the operational ranges yet the primary downsides are poor maintenance of transmission and distribution system prompts loss of energy, inefficient control and leakages prompt loss of compressed air. The flywheel energy storage system has the capacity to accelerating a rotor (flywheel) to high speed with maintaining the energy in the system as rotational energy though it displays constraints like short discharge time. MPC technique can improve the control execution and inherent compensation for dead times. However, impediment like computation complexity and the solutions are not ensured. Despite the fact that the exceeding techniques are utilized for attractive the power quality in RES, the complexity of the algorithm is high because of the increased number of samples required. To overcome these challenges, optimal control using advanced technology is necessary. In interconnected works few control techniques are exhibited to tackle the RES issue. The earlier mentioned impediments have inspired to do this research work.

3. Outline of the System with Proposed system
Figure 1 illustrate the proposed IBSMFO control scheme of RES to improve the Power Quality (PQ) in the MG system. Here, the control strategy based proposed method is the parallel implementation of the IBSA and MFDOA technique. In the proposed approach the RES are the compilation of the Solar PV, wind turbine, fuel cell and battery. By using these techniques the energy is transmitted to the DC bus. Furthermore to improve the dynamic optimal PQ and also to study the electrical energy, the load and the grid side parameters are determined optimally in this system. The architecture also specify the Voltage Source Inverter (VSI) based RES unit with the control modules for the Power Quality Enhancement (PQE). Here the VSI is used to implement the suitable power control mode due to the active and reactive power of the HRES unit must 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 RES must be suitably changed. The power delivered commencing the main grid, Solar PV array as well as Fuel Cell must be coordinated to meet the load demand. Here the constant active and reactive power is essential to control Power Quality issues between the HRES and the utility grid. The active and reactive power control strategy of the grid connected operation mode is clearly depicted in the part underneath.
3.1. Active and Reactive Control strategy for Grid Connected Power Quality Enhancement

This part analyzed the power quality improvement with the grid and load of the HRES. The power generated from the main grid and HRES should be changed when the load demand changes. Furthermore, the power generated from the main grid, Solar PV array and Fuel Cell must be synchronized to meet the load demand. In order to contribute with constant active and reactive power, it is required to control the power flow between the HRES as well as the utility. The power balance from sources to AC bus and to storage devices are controlled to satisfy the active and reactive power demand in the load. Here the power balance should be satisfy both at the DC link and at the Point of Common Coupling (PCC) which is expressed in equation (1).

\[
P_{HRES}(t) = \sum_{i} P_{WT}(t) + P_{PV}(t) + P_{FC}(t) + P_{Bat}(t)
\]  

(1)
From the available renewable energy sources at the time, 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 as well as load connected mode is determined from the following equation,

\[
P_{Grid}(t) = P_{Load}(t) - P_{HRES}(t)
\]

(2)

\[
P_{Load}(t) = P_{HRES}(t) + P_{Grid}(t)
\]

(3)

\[
Q_{Grid}(t) = Q_{Load}(t) - Q_{HRES}(t)
\]

(4)

\[
Q_{Load}(t) = Q_{HRES}(t) + Q_{Grid}(t)
\]

(5)

In the entire time due to the uncertainty of the RES with the variation of non-linear load demand. The above mentioned power balanced conditions are not satisfied. The result of the power control mode is approximately based on the high performance operation of the HRES. Moreover, the control mode should be dedicated to improving the quality of power supply as PQ issue like voltage, frequency deviation and harmonic distortion rises. Her the active and reactive power should be computed as follow,

\[
P_1(t) = \frac{3}{2} \left[ V_d^* i_d^* + V_q^* i_q^* \right]
\]

(6)

\[
Q_1(t) = \frac{3}{2} \left[ V_q^* i_d^* - V_d^* i_q^* \right]
\]

(7)

In this case in order to inject the preset 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 examine the HRES units the real and reactive power process is considered and with the help of irradiance the Solar 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

The purpose of using this strategy is to control the supply of active and reactive power to the load and also control the PQ issues between the grid and the utility. Here, Figure 2 illustrate the proposed controller scheme for enhancing the Power Quality in the Micro Grid system based on the two PI regulators. This control scheme employed the outer control loop to generate the reference current vectors ID and IQ representing that the control objective has been achieved a high quality of the inverter output power. In addition 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 have to 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 equation (8) and equation (9). Here DQ reference vectors current expressed as

\[
I_D^*(t) = (P_{ref}(t) - P_1(t))^{\delta_p} \left( \delta_p + \frac{\delta_p^p}{t} \right)
\]

(8)
The objective function of proposed controller is taken as to track accurately and to reduce inverter output current transients. To develop the steady state and dynamic performance both the inverter current loop and the grid voltage feed forward loop are employed by both converter as well as the current error is eliminated by using two PI regulators. Thus the output signal of the controller is represented by the reference voltage signals in the DQ frame. Moreover, the controller technique provides the desired output voltage vectors with less harmonic distortion by the use of the Pulse Width Modulation technique. Here the reference voltage signal is expressed as follows,

\[
\begin{bmatrix}
V_D^* \\
V_Q^*
\end{bmatrix} = \begin{bmatrix}
-K_p & -\omega K_I \\
\omega K_I & -K_p
\end{bmatrix} \begin{bmatrix}
I_D^* \\
I_Q^*
\end{bmatrix} + \begin{bmatrix}
K_p & 0 \\
0 & K_p
\end{bmatrix} \begin{bmatrix}
I_D^* \\
I_Q^*
\end{bmatrix} + \begin{bmatrix}
K_I & 0 \\
0 & K_I
\end{bmatrix} \begin{bmatrix}
X_D \\
X_Q
\end{bmatrix} + \begin{bmatrix}
V_{id} \\
V_{iq}
\end{bmatrix}
\]

(10)

As shown in the following equation (10) and (11) can be transformed into \( \alpha, \beta \) a stationary frame Using Clarke’s transformation.

\[
\begin{bmatrix}
V_\alpha \\
V_\beta \\
V_0
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} \begin{bmatrix}
1 & -0.5 & -0.5 \\
0 & 0.866 & -0.866 \\
0.5 & 0.5 & 0.5
\end{bmatrix}
\]

(11)

The inductor current can achieved by a low pass filter Equation (12) and it is given in a first order transfer function.
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 new system for the PQ enhancement of HRES in the MG system. For this improvement of PQ the proposed work employed the combined execution of the Improved Bat Search Algorithm (IBSA) and Moth Flame Optimization (MFO) algorithm [26]. To improve 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 better 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,

$$X_i = \begin{bmatrix} K_{p1}^{11} & K_{i1}^{11} & K_{p1}^{12} & K_{i1}^{12} & \cdots & K_{p1}^{1n} & K_{i1}^{1n} \\ K_{p2}^{21} & K_{i2}^{21} & K_{p2}^{22} & K_{i2}^{22} & \cdots & K_{p2}^{2n} & K_{i2}^{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ K_{pm}^{m1} & K_{im}^{m1} & K_{pm}^{m2} & K_{im}^{m2} & \cdots & K_{pm}^{mn} & K_{im}^{mn} \end{bmatrix}$$ (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,

$$Obj_{j} = \text{Min } E(x)$$ (14)

$$E(x) = P_{ref}(t) - P_i(t), \text{ for the real PQ enhancement}$$

$$E(x) = Q_{ref}(t) - Q_i(t), \text{ for the reactive PQ enhancement}$$

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: Solution Generation:

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 $x_i'$ and velocity $v_i'$ at time step $t$ are generated by using the following equations,
\[
F_i = F_{\text{min}} + (F_{\text{max}} - F_{\text{min}}) \times \eta
\]
\[
v_i = v_i^{t-1} + \left( X_i^{t-1} - X^* \right) \times F_i
\]
\[
X_i^t = X_i^{t-1} + v_i^t
\]

where \( \eta \) 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 \( \theta_i \). According to a problem the velocity increment can be adjusted by changing one and keeping fixed another.

**Step 4: Local search process by 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 develop 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,

\[
X_{\text{new}} = (-1) + X_{\text{old}} \times \left( -\frac{1}{T} \right)
\]

**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 ith moth is represented as \( X_i \) and the jth flame is represented as \( F_j \) and the spiral function is represented as \( S \). The spiral function of a 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,

\[
D_i = |F_j - X_i|
\]

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

\[
U = \text{round} \left( N - l \times \frac{N - 1}{T} \right)
\]

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
This procedure of computation is terminated if the maximum count of iterations is reached which satisfy the stopping criterion or else repeat the process going to steps 2 and 4 [34, 35]. The error minimization output for PQ enhancement is given as follows,

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

After completion of above steps shown in algorithm the system achieves improvement in PQ of proposed system by making the optimal gain parameters with possible limit error. The flowchart justification of the proposed IBSMFO is illustrate as follows.

Fig. 3 Flowchart of the Proposed IBSMFO technique

5. Experimental Results and Discussions
In this section the IBSMFO method based PI controller is proposed and implemented in MATLAB/SIMULINK platform. The proposed system is used to improve 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 method. Subsequently 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 the 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], the Firefly Algorithm (FA) [43-45] and IBSMFO controllers.

5.1. 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 modes;
They are given as follows:
Mode A: Step response in the Solar system
Mode B: Zero response in the Solar 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 Solar PV arises during the fault condition and it is evaluated by the proposed method. 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 are beneath section.

Case 1: Balanced power supply with the unbalanced load condition

In the first case the PQ enhancement of HRES is analyzed under balance supply with unbalance load condition. The main objective of this case is to evaluate the response of the power controller when the necessity of the load is unbalanced. The performance of Solar PV irradiance and power is shown in figures 4 (a) and (b). At the range of 1000 within t= 0 to1 sec, the irradiance under Solar PV runs at a constant level. The Solar PV power performance, where the power starts at zero range is shown in figure 4 (b). The output of the Solar PV power is performed at constant level after the time period t=0.25 sec. The power analysis of the HRES such as Solar PV, WT, FC, battery, grid and the load is analyzed by figures 5 (a) to (d). Here, the performance of the HRES is satisfied with the balance power condition. In the analysis of figures 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 Solar 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.
kW and suddenly falls at 0.03 sec. The power of the battery is kept in peak variation at 14000 kW at time t=0.01sec 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 figures 5(e) and (f). At time t= 0.25 sec the power of the grid is 2kW after that it goes constantly till the end of the operation. At time t= 0.25 sec the power of the load is 3500kW after that it goes constantly till the end of the operation.

Fig. 5 Power analysis of (a) Solar PV (b) WT(c) FC (d) Battery (e) Grid and (f) Load
Fig. 6 Analysis of (a) Total power in HRES using proposed method (b) Total power comparison (c) Load power comparison

Figures 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 Solar 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 figures 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 $t=0.22$ sec, $0.28$ 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, $0.03$ sec, $0.028$ sec and $0.03$ sec respectively. The above results of the comparison analysis shows 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 system. 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. An 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 Solar PV variations two sets of analysis is presented here. (i) Mode A: Step response in the Solar system (ii) Mode B: Zero response in the Solar system.

Mode A: Step response in the Solar system

Fig. 7 Performance of (a) Solar irradiance (b) Solar power
In the subsection the power analysis of Solar PV, WT, FC and battery is analyzed. Figures 7(a) and (b) specified the irradiance and power of Solar PV under unbalanced condition. In the time instant $t=0$ to 0.5 sec the irradiance of Solar PV is 1000w/m² power is produced by the Solar PV under the step irradiation conditions which is then reduced to 500w/m² at the period of 0.5 second to 1 second and which is shown in figure 7 (a). Figure 7(b) shows the Solar PV power generation under unbalanced load condition using the proposed methodology. Figures 8 (a)-(f) shows the maximum power of Solar PV, WT, FC, battery, grid and load. The maximum power of 3500kW is produced by the Solar 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 power1500kW 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 figures 8(e) and (f). At time $t=0$ the power of the grid is 2kW after that it goes constant till the end of the operation. At time $t=0.25$ sec the power of the load is 3500kW after that it goes constant till the end of the operation.

![Figure 7(a)](image1)
![Figure 7(b)](image2)
![Figure 7(c)](image3)
![Figure 7(d)](image4)

**Fig. 8** Power representation of (a) Solar (b) WT(c) Fuel cell (d) Battery (e) Grid & (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 the 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 improve the PQ of the energy storage connected smart grid system the proposed method has much more efficient when compared to the other techniques.

![Graph](image)

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

**Mode B: Zero response in the Solar system**
The zero response analysis of Solar PV is illustrated in figures 10 (a) to (c). It shows the resulting controlled total and Solar 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 optimal PQE is achieved in the proposed method.
Fig. 10 Performance of Solar (a) Irradiance (b) power (c) Inverter voltage

Fig. 11 Analysis of (a) Total power in HRES using proposed method (b) Total power comparison (c) Load power comparison
Figures 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 Solar 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 figures 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=0.22 sec, 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, 0.03 sec, 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.

| 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 | 2.3652 | 1.6580 | 1.8569 |
| Reactive power controller parameters | $K_{qp}$ | 5.0978 | 8.3699 | 8.1657 | 8.1657 |
| $K_{qi}$                  | 0.0020 | 2.3652 | 1.6559 | 1.5698 |

| Solution techniques | Mean | Median | Std. deviation |
|--------------------|------|--------|----------------|
| Case 1             | 0.8493 | 0.8496 | 0.0257 |
| GSA                | Case 2 (Mode- A) | 0.8620 | 0.8623 | 0.0050 |
|                    | Case 2 (Mode-B) | 0.8993 | 0.8989 | 0.0058 |
|                    | Case 1         | 0.7478 | 0.7443 | 0.0291 |
| FA                 | Case 2 (Mode - A) | 0.7787 | 0.7789 | 0.0248 |
|                    | Case 2 (Mode -B) | 0.8101 | 0.8098 | 0.0055 |
| IBSMFO method      | Case 1        | 0.7023 | 0.6976 | 0.0264 |
|                    | Case 2 (Mode- A) | 0.7235 | 0.7534 | 0.0323 |
|                    | Case 2 (Mode -B) | 0.7634 | 0.7568 | 0.0167 |
Table 3 Statistical analysis for Hundred iterations (Q)

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

In the work, a novel optimization algorithm used and is known as IBSMFO by this control an optimal Power Quality enhancement in the interconnected renewable system with DC-DC converter. The proposed work, the active and reactive powers are regulated for distribution generator fed grid connected system. In this control scheme there are two loops i.e., inner current control loop and outer power control loop. In the proposed control algorithm is having two individual controls one is IBSA algorithm to locate gain parameters used for objective function with minimum error. The MFO technique is used to improve the searching performance of optimal solution. Finally, the control signal generated to enhance Power Quality of HRES. The performance analysis of proposed control technique is evaluated for 2 different load change conditions and are balanced and unbalanced supply. The simulation results are highlighted in terms of the settling time, rise time and overshoot time of the control algorithm. The results are highlighted with statistical performance of HRES unit is analysed with the mean, median and standard deviations of the proposed controller with the existing techniques. The outcomes of the simulation results demonstrate the proposed algorithm works effectively for the renewable energy sources interconnected with grid with quick settling time, overshoot time and hence the stability of the proposed system is maintained successfully.

7. References

[1] H. Nian and B. Pang "Stability and Power Quality Enhancement Strategy for DFIG System Connected to Harmonic Grid with Parallel Compensation", IEEE Transactions on Energy Conversion, pp. 1-1, 2018.
[2] Q. Tabart, I. Vechiu, A. Etxeberria, and S. Bacha,"Hybrid Energy Storage System Microgrids Integration for Power Quality Improvement Using Four-Leg Three-Level NPC Inverter and Second-Order Sliding Mode Control", IEEE Transactions on Industrial Electronics, vol. 65, no. 1, pp. 424-435, 2018.
[3] Y. Zheng, B. Jenkins, K. Kornbluth and C. Træholt, "Optimization under uncertainty of a biomass-integrated renewable energy microgrid with energy storage", Renewable Energy, vol. 123, pp. 204-217, 2018.
[4] R. Agarwal, I. Hussain and B. Singh, "Application of LMS-Based NN Structure for Power Quality Enhancement in a Distribution Network Under Abnormal Conditions", IEEE Transactions on Neural Networks and Learning Systems, vol. 29, no. 5, pp. 1598-1607, 2018.
[5] K. Fouad, H. Boulouïha, A. Allalî, A. Taïbi and M. Denai, "Multivariable control of a grid-connected wind energy conversion system with power quality enhancement", Energy Systems, vol. 9, no. 1, pp. 25-57, 2016.
[6] S. Agalar and Y. Kaplan, "Power quality improvement using SSTS and DVR in wind energy system", Renewable Energy, vol. 118, pp. 1031-1040, 2018.
[7] K. Rao and K. Srikanth, "Improvement of Power Quality using Fuzzy Logic Controller In Grid Connected Photovoltaic Cell Using UPQC", International Journal of Power Electronics and Drive Systems (IJPEDS), vol. 5, no. 1, 2014.
[8] B. Naga Pavan Kumar and D. Seshi Reddy, "Power Quality Enhancement of Integrated Grid Connected off-Shore Wind Farm and Marine Current Farm using Statcom", Indian Journal of Science and Technology, vol. 8, no. 29, 2015.
[9] R. Rouabhi, R. Abdessemed, A. Chouder and A. Djerioui, "Power Quality Enhancement of Grid Connected Doubly-Fed Induction Generator Using Sliding Mode Control", International Review of Electrical Engineering (IREE), vol. 10, no. 2, p. 266, 2015.
[10] V. Dash and P. Bajpai, "Power management control strategy for a stand-alone solar photovoltaic-fuel cell–battery hybrid system", Sustainable Energy Technologies and Assessments, vol. 9, pp. 68-80, 2015.
[11] Q. Tabart, I. Vechiu, A. Etxeberria and S. Bacha, "Hybrid Energy Storage System Micro grids Integration for Power Quality Improvement Using Four-Leg Three-Level NPC Inverter and Second-Order Sliding Mode Control", IEEE Transactions on Industrial Electronics, vol. 65, no. 1, pp. 424-435, 2018.
[12] M. Rahmani-Andebili, "Stochastic, adaptive, and dynamic control of energy storage systems integrated with renewable energy sources for power loss minimization", Renewable Energy, vol. 113, pp. 1462-1471, 2017.
[13] A. Mohamed, M. Elshaer and O. Mohammed, "Control enhancement of power conditioning units for high quality PV systems", Electric Power Systems Research, vol. 90, pp. 30-41, 2012.
[14] S. yafaruddin, E. Karatepe and T. Hiyama, "Performance enhancement of photovoltaic array through string and central based MPPT system under non-uniform irradiance conditions", Energy Conversion and Management, vol. 62, pp. 131-140, 2012.
[15] Z. Zeng, H. Yang, R. Zhao and C. Cheng, "Topologies and control strategies of multi-functional grid-connected inverters for power quality enhancement: A comprehensive review", Renewable and Sustainable Energy Reviews, vol. 24, pp. 223-270, 2013.
[16] J. Torreglosa, P. García, L. Fernández and F. Jurado, "Energy dispatching based on predictive controller of an off-grid wind turbine/photovoltaic/hydrogen/battery hybrid system", Renewable Energy, vol. 74, pp. 326-336, 2015.
[17] S. Upadhyay and M. Sharma, "A review on configurations, control and sizing methodologies of hybrid energy systems", Renewable and Sustainable Energy Reviews, vol. 38, pp. 47-63, 2014.
[18] V. Dash and P. Bajpai, "Power management control strategy for a stand-alone solar photovoltaic-fuel cell–battery hybrid system", Sustainable Energy Technologies and Assessments, vol. 9, pp. 68-80, 2015.
[19] C. Chang, Y. Lin, Y. Chen and Y. Chang, "Simplified Reactive Power Control for Single-Phase Grid-Connected Photovoltaic Inverters", IEEE Transactions on Industrial Electronics, vol. 61, no. 5, pp. 2286-2296, 2014.
[20] C. Cecati, F. Ciancetta and P. Siano, "A Multilevel Inverter for Photovoltaic Systems With Fuzzy Logic Control", IEEE Transactions on Industrial Electronics, vol. 57, no. 12, pp. 4115-4125, 2010.
[21] G. Talapur, H. Suryawanshi, L. Xu and A. Shitole, "A Reliable Micro-grid with Seamless Transition between Grid Connected and Islanded Mode for Residential Community with Enhanced Power Quality", IEEE Transactions on Industry Applications, pp. 1-1, 2018.
[22] M. Mosaad and H. Ramadan, "Power quality enhancement of grid-connected fuel cell using evolutionary computing techniques", International Journal of Hydrogen Energy, vol. 43, no. 25, pp. 11568-11582, 2018.
[23] S. Mousazadeh Mousavi, A. Jalilian, M. Savaghebi and J. Guerrero, "Power quality enhancement and power management of a multifunctional interfacing inverter for PV and battery energy storage system", International Transactions on Electrical Engineering Systems, p. e2643, 2018.
[24] S. Prince, K. Panda, V. Kumar and G. Panda, "Power quality enhancement in a distribution network using PSO assisted Kalman filter — Based shunt active power filter", 2018 IEEMA Engineer Infinite Conference (eTechNxt), 2018.
[25] V. Lopez-Martín, F. Azcondo and A. Pigazo, "Power Quality Enhancement in Residential Smart Grids Through Power Factor Correction Stages", IEEE Transactions on Industrial Electronics, vol. 65, no. 11, pp. 8553-8564, 2018.
[26] B. Venkateswara Rao and G. Nagesh Kumar, "Optimal power flow by BAT search algorithm for generation reallocation with unified power flow controller", International Journal of Electrical Power & Energy Systems, vol. 68, pp. 81-88, 2015.
[27] E. Ali, "Optimization of Power System Stabilizers using BAT search algorithm", International Journal of Electrical Power & Energy Systems, vol. 61, pp. 683-690, 2014.
[28] A. Oshaba, E. Ali and S. Abd Elazim, "MPPT control design of PV system supplied SRM using BAT search algorithm", Sustainable Energy, Grids and Networks, vol. 2, pp. 51-60, 2015.
[29] R. Svečko and D. Kusić, "Feedforward neural network position control of a piezoelectric actuator based on a BAT search algorithm", Expert Systems with Applications, vol. 42, no. 13, pp. 5416-5423, 2015.
[30] A. Oshaba, E. Ali and S. Abd Elazim, "PI controller design for MPPT of photovoltaic system supplying SRM via BAT search algorithm", Neural Computing and Applications, vol. 28, no. 4, pp. 651-667, 2015.
[31] S. Mirjalili, "Moth-flame optimization algorithm: A novel nature-inspired heuristic paradigm", Knowledge-Based Systems, vol. 89, pp. 228-249, 2015.
[32] D. Allam, D. Yousri and M. Eteiba, "Parameters extraction of the three diode model for the multi-crystalline solar cell/module using Moth-Flame Optimization Algorithm", Energy Conversion and Management, vol. 123, pp. 535-548, 2016.

[33] S. Khalilpourazari and S. Pasandideh, "Multi-item EOQ model with nonlinear unit holding cost and partial backordering: moth-flame optimization algorithm", Journal of Industrial and Production Engineering, vol. 34, no. 1, pp. 42-51, 2016.

[34] M. Aziz, A. Ewees and A. Hassanien, "Whale Optimization Algorithm and Moth-Flame Optimization for multilevel thresholding image segmentation", Expert Systems with Applications, vol. 83, pp. 242-256, 2017.

[35] W. Yamany, M. Fawzy, A. Tharwat and A. Hassanien, "Moth-flame optimization for training Multi-Layer Perceptrons", 2015 11th International Computer Engineering Conference (ICENCO), 2015.

[36] D. Karaboga and B. Akay, "A comparative study of Artificial Bee Colony algorithm", Applied Mathematics and Computation, vol. 214, no. 1, pp. 108-132, 2009.

[37] R. Roy and H. Jadhav, "Optimal power flow solution of power system incorporating stochastic wind power using Gbest guided artificial bee colony algorithm", International Journal of Electrical Power & Energy Systems, vol. 64, pp. 562-578, 2015.

[38] H. Jadhav and P. Bamane, "Temperature dependent optimal power flow using g-best guided artificial bee colony algorithm", International Journal of Electrical Power & Energy Systems, vol. 77, pp. 77-90, 2016.

[39] K. Roy, K. Mandal and A. Mandal, "Modeling and managing of micro grid connected system using Improved Artificial Bee Colony algorithm", International Journal of Electrical Power & Energy Systems, vol. 75, pp. 50-58, 2016.

[40] B. Shaw, V. Mukherjee and S. Ghoshal, "Solution of reactive power dispatch of power systems by an opposition-based gravitational search algorithm", International Journal of Electrical Power & Energy Systems, vol. 55, pp. 29-40, 2014.

[41] A. Bhowmik and A. Chakraborty, "Solution of optimal power flow using non dominated sorting multi objective opposition based gravitational search algorithm", International Journal of Electrical Power & Energy Systems, vol. 64, pp. 1237-1250, 2015.

[42] M. Narimani, R. Azizipanah-Abarghoee, M. Javidsharifi and A. Azizi Vahed, "Enhanced gravitational search algorithm for multi-objective distribution feeder reconfiguration considering reliability, loss and operational cost", IET Generation, Transmission & Distribution, vol. 8, no. 1, pp. 55-69, 2014.

[43] H. Shareef, A. Ibrahim, N. Salman, A. Mohamed and W. Ling Ai, "Power quality and reliability enhancement in distribution systems via optimum network reconfiguration by using quantum firefly algorithm", International Journal of Electrical Power & Energy Systems, vol. 58, pp. 160-169, 2014.

[44] U. Vadivu and B. Keshavan, "Power quality enhancement of UPQC connected WECS using FFA with RNN", 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2017.

[45] N. Gowtham, S. Shankar and K. Rao, "Enhanced firefly algorithm for PQ improvement of wind energy conversion system with UPQC", TENCON 2017 - 2017 IEEE Region 10 Conference, 2017.