An Intelligent Technique for Optimal Power Quality Enhancement (OPQE) in a HRES Grid Connected System: ESA Technique

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Abstract- In recent decade, the sustainable energy sources are promoted to use for the day to day application. In this sense the renewable energies such as wind and solar are motivated to produce electric energy. But the integration of these renewable energy source may cause some power quality issues while integrating it to power grid. Hence researchers intend to develop a better technique for the mitigation of power quality issues. But most of the techniques in the literature concentrating on one of the power quality issues due to any one of the sources. But in the recent days, the power quality issue is severing due to the large integration of different renewable in the distribution system. Thus, in this paper the power quality issue is formulated as an optimization problem. An Extended Search Algorithm (ESA) is proposed to solve the optimization problem. The objective function is formulated based on the voltage, power loss and harmonic distortion. The proposed system evaluated based on the MATLAB/Simulink simulation and execution is compared with the conventional PI controller. The proposed ESA based control system mitigated the power quality issues and maintained the desired output power while the integration of wind, PV and battery to the HRES Grid Connected System. The performance of the proposed model is validated using seven test cases, in every cases the wind, PV and battery combinedly connected with different load. Ultimately, analysis proves the effectiveness of the proposed system.

Keywords Power Quality improvement, hybrid grid system, PV, Wind, Battery.

Acronyms and Abbreviations:

Acronyms	Abbreviations
BESS	Battery Energy Storage System
ESA	Extended Search Algorithm
OPQE	Optimal Power Quality Enhancement
PLL	Phase Lock Loop
PCC	Point of Common Coupling
PQ	Power Quality
PV	Photovoltaic
THD	Total Harmonic Distortion
VSI	Voltage Source Inverter

1. Introduction

Renewable energy resource-based distributed generators are predominantly gaining a lot of importance due to the advancement in technology and environmental concerns due to the huge demand for power to the utility grid [1]. Many optimization techniques have been developed to control various power electronics and control technology with better flexibility while integrating various alternative sources like solar wind batter etc., [2] which are playing an increasing role in meeting the huge power demands [3].

Due to the limitation of generating power from conventional energy sources distribution generation has a lot of importance because it gives more productive, best quality and dependable power to the commercial loads which require continuous administration [4]. Now a day's generation of power became a challenging issue due to the increase in population as well increase in demand, so conventional sources can alone not meet these requirements so alternative sources like solar, wind, battery are widely used in distribution generators [5].

In the proposed paper DG system contains a source connected to the DC link of grid interconnected inverter controlled with estimated search algorithm which is strongly controlled in such a way that it feeds real power from the DG to the grid [6]. The proposed approach compensates the harmonics and unbalances even under distorted supply voltage conditions if the load is connected at the point of common coupling which is non-linear or unbalanced and both [7]. In addition to real power injection from RES to the grid and grid-interfacing inverters, we desired to compensate the load wattles power, current harmonics and current unbalance [8].

Various research works have recently existed in the literature dependent on the PQ reinforcement of grid-connected HRES systems utilizing different strategies [9]. Some of them are assessed here.

R.W. Mosobi, et al. [10] have explored how to improve load voltage and current and mitigation of harmonics using a static compensator. S.K. Dash, and P.K. Ray [11] proposed the JAYA algorithm which has two objective functions used in shunt and series inverter control of PV-UPQC for improvement in voltage and control at various operational conditions.

G. Mehta, and S.P. Singh [7] presented three-phase renewable energy sources based on DG where the inverters are controlled to perform multi-functions using Active power filter. K. Ravinder, and H.O. Bansal [12] implemented a SAPF used in HES to mitigate the power quality problems. F. Chishti, et al. [13] have proposed power quality enhancement using LMMN adaptive control in an integrated grid.

M. Karami, and R.M. Cuzner [14] proposed an algorithm to improve the current quality at the Point of Common Coupling (PCC) of a three-phase grid connected photovoltaic system supplying unbalanced and nonlinear loads. J. Hussain et al. [15] have presented a strategy to improve the power quality in grid connected wind power plant using DSTATCOM with Battery Energy Storage System (BESS).

In the recent decade the usage of renewable energy source is emerging, it has many advantages. But while the integration of renewable source to the electric grid it will create some power quality issues. So, in the literatures many techniques have proposed, but the problem is not yet completely solved. For example, authors in [7] have presented a strategy to improve the power quality while the usage of renewable energy. Still the power quality issue is not completely rectified. Hence in this paper an optimization-based control strategy is proposed to enhance the power quality while the integration of renewable energy source.

The major contribution of the proposed work is as follows;

- Developed a HRES Grid Connected System with three power sources as Wind, PV and Battery.
- Modelled Extended Search Algorithm for the controlling the system and balance the power quality issues in terms of current, voltage, and real and reactive power.
- An error value with respect to the current and voltage is formulated as the fitness function for the ESA.

Then the proposed system is simulated and analyzed using MATLAB/Simulink. The rest of the paper is organized as follows; The section 2 gives the detail description of ES Algorithm. Then the proposed HRE system with Estimated Search Optimization is described in section 3. Results and discussion are given in section 4 and the subsequent section gives the conclusion of the paper.

2. Proposed HRE system with Extended Search Optimization

The developed system circuit is as shown in fig1. Which consists of Distribution Generation comprising PV-Wind connected to CC-VSI for interfacing to the grid via-an energy-storing dc-link capacitor [16, 17]. By using the Extended Search Algorithm, the PV and Wind greatest power is extracted. From ESA a reference DC link voltage is created. The reference DC link voltage is set to its default value when the solar energy is missing [18]. An inductive filter is connected to the AC-Side of the VSI. In order to increase the voltage level, a step-up transformer is used before the system is connected to PCC. An uncontrolled rectifier non-linear load is connected at the PCC [19,20]. To minimize the load current harmonics and power factor and regulate the DG power flow to the PCC an inverter control is used [16].

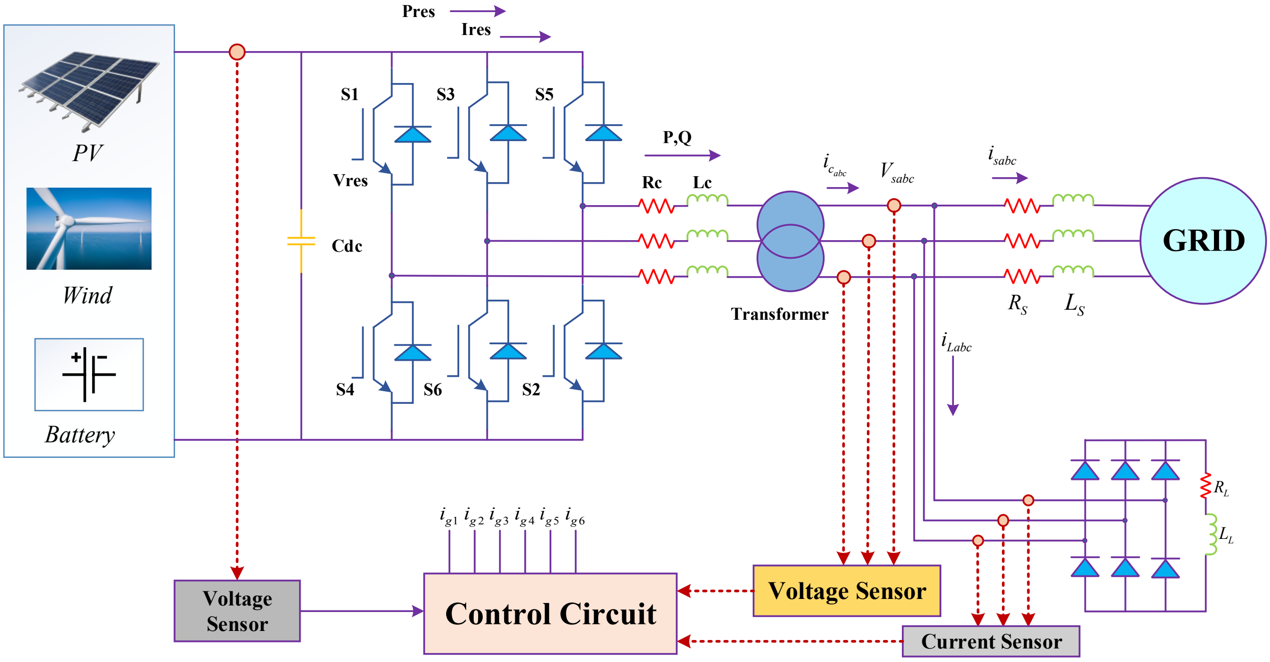

Fig.1. Architecture of the Proposed Power Quality Enhancement System

2.1. Design and analysis of controller for Grid-Interface unit

Elimination of zero steady-state error of the delivered currents a double-loop current controller which is an outer loop with proportional resonant is used and the Proportional controller is used to improving stability along with the inner capacitor current control loop. Figure 2 shows the controller structure of the grid interfacing inverter [17]. In the control circuit, a PLL is used to extract the sin and cos feature of the V_{sabc}. Then the unit vector is calculated from the PLL signal to produce the compensation signal during PQ issue.

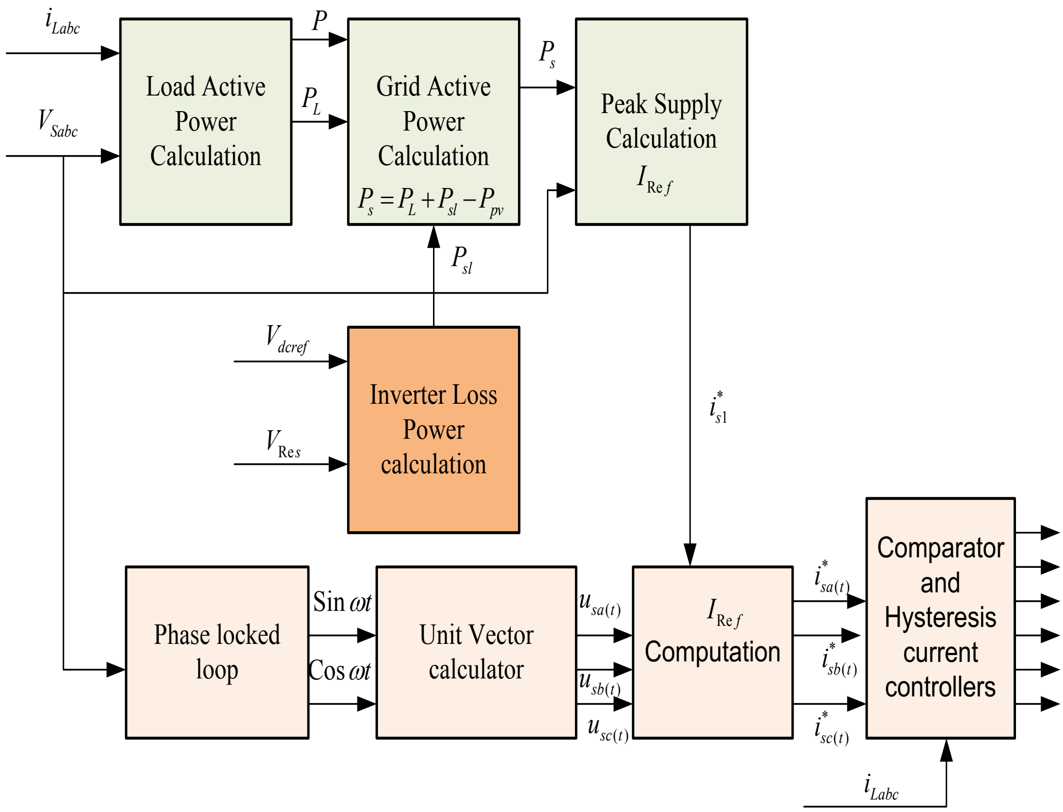

Fig. 2. Control Diagram

A set of harmonic n, n= {1,2,3…. N}, components are present at common point whose Voltage $V_s(t)$ and current $I_L(t)$ can be written as:

$$V_s(t) = \begin{bmatrix} V_{s1} \\ V_{s2} \\ V_{s3} \end{bmatrix} = \begin{bmatrix} \sum_{n=1}^{N} V_{sn1}\, sin(n(\omega t)) \\ \sum_{n=1}^{N} V_{sn2}\, sin(n(\omega t - 120^0)) \\ \sum_{n=1}^{N} V_{sn3}\, sin(n(\omega t - 240^0)) \end{bmatrix} \quad (1)$$

$$i_L(t) = \begin{bmatrix} i_{l1} \\ i_{l2} \\ i_{l3} \end{bmatrix} = \begin{bmatrix} \sum_{n=1}^{N} I_{Ln1}\, sin(n\omega t - \phi_{n1}) \\ \sum_{n=1}^{N} I_{Ln2}\, sin(n(\omega t - 120^0) - \phi_{n2}) \\ \sum_{n=1}^{N} I_{Ln3}\, sin(n(\omega t + 120^0) - \phi_{n3}) \end{bmatrix} \quad (2)$$

The (V_{s1}, V_{s2}, V_{s3}) PCC Voltages peak values (I_{Ln1}, I_{Ln2}, I_{Ln3}) Load current peal values Φ_{n1}, Φ_{n2}, Φ_{n3} n^{th} order harmonic component phase angles. Real and Wattles power which is flowing from the output of the inverter to the common point can be written as

$$P = \frac{V_s V_c}{X_c} sin\,\delta_c = \frac{m_a V_{fc} V}{X_c}{}_{s}\, sin\,\delta_c \quad (3)$$

$$Q = \frac{V_s}{X_c}(V_c\, cos\,\delta_c - V_s)$$

$$= \frac{V_s}{X_c(m_a V_{fc}\, cos\,\delta_c - V_c)} \quad (4)$$

Where $V_c<\delta_c$ is the inverter output, m_a is the modulation depth of the inverter, $V_s<0$is the PCC Voltage and $X_c=R_c+j\omega L_c$ is the impedance of inductive filter impedance. The real power supplied by the grid P_s should be equal to the grid apparent power for compensation at unit power factor is given by:

$$P_s = P_L + P_l - P = \frac{3}{2} V_{s1} I_{s1}^* \quad (5)$$

Where the real power of the load is P_L, the real power loss is P_l, real power supplied by the RES is P, the maximum value of the fundamental component of common point Voltage is a fundamental component and I_{s1}^*source current component, therefore,

$$I_{s1}^* = \frac{2P_s}{3V_{s1}} \quad (6)$$

$$u_{s1}(t) = u_a(t)$$

$$u_{s2}(t) = -0.5u_a(t) + 0.866u_b(t)$$

$$u_{s3}(t) = -0.5u_a(t) - 0.866u_b(t) \quad (7)$$

Where $u_a(t)= sin\omega t$ and $u_b(t)= cos\omega t$ on computing the dissimilar between instant reference currents. Reference inverter current and the existing inverter current error (Δ_{ic1},Δ_{ic2},Δ_{ic3}) given to hysteresis current controller which controls the duty cycle of the PWM inverter.

$$\Delta i_{c1} = I_{c1}^*(t) - i_{c1}$$

$$\Delta i_{c2} = I_{c2}^*(t) - i_{c2}$$

$$\Delta i_{c3} = I_{c3}^*(t) - i_{c3} \quad (8)$$

The error produced between the true and measurable current of the inverter the hysteresis controller controls and regulates pulses for the gate drives of the grid-connected inverter. S_1 switch is on when Δ_{ic1}>H_b and S_4 are off in phase A of inverter and vise-Versa if Δ_{ic1}<H_b. H_b is the width of the hysteresis band. This switching pulses for the other two legs operate on the same frequency.

3. Extended Search Algorithm

The Extended Search Algorithm is a modified version of genetic algorithm. It is modelled to perform meta heuristics optimization. The ESA includes all the phases of genetic algorithm such as fitness evaluation, selection, crossover and mutation. Initially the capacitor currents are computed from response currents and the filter inductor instead of sampling and measures for overcurrent protection. The reference should be zero to eliminate zero-sequence current. Then the PR controller is choosing either of the sequence components which are difficult and time-consuming when we use conventional PI control. A fundamental frequency a quasi-proportional resonant controller where K_{pis} the proportional gain, Kr the resonant gain, and ω_{br} the equivalent bandwidth of the resonant controller is used. A detailed design for the PR controller has been presented in, it is not duplicated here [16].

The step by step procedure of ESA is given as follows;

A. Initialization

Identify the initial commands such as, dc link voltage and reference voltage of DC system with a limit of N and dimensions D. the initial population commands are expressed as,

$$X_{ab} = X_b^{max} - R * (X_b^{max} - X_a^{min}) \quad (9)$$

B. Fitness

This case is also called as comparator. In this step the dc link voltage is maintained like a reference voltage. The expression for this step is $V_{dc}^* = V_{dc}$. In this case the dc link voltage controller is maintained.

C. Crossover

In this step, the quality of the system is maintained. A two-factor crossover operation is used with in the proposed set of rules. R1 and R2 are random numbers for an individual references of dc link voltages with a dimension of d.

The set of rules are designed like, if the value of R1 is larger than R2, then the output genes are replaced with the best of individual in R1 and R2. If the crossing points are close to each other in the crossover operation, then the individual performs more exploration.

D. Mutation

The purpose of mutation is to get better output around the values of gene in the proposed algorithm.

In the mutation process, every character in the gene is mutated according to the price. The equation for mutation process is expressed as,

$$M_{ab} = \begin{Bmatrix} X_{ab} + W * R_1 * X_{ab}, R_2 \leq 0.5 \\ X_{ab} + W * R_1 * X_{ab}, O.W \end{Bmatrix} \quad (10)$$

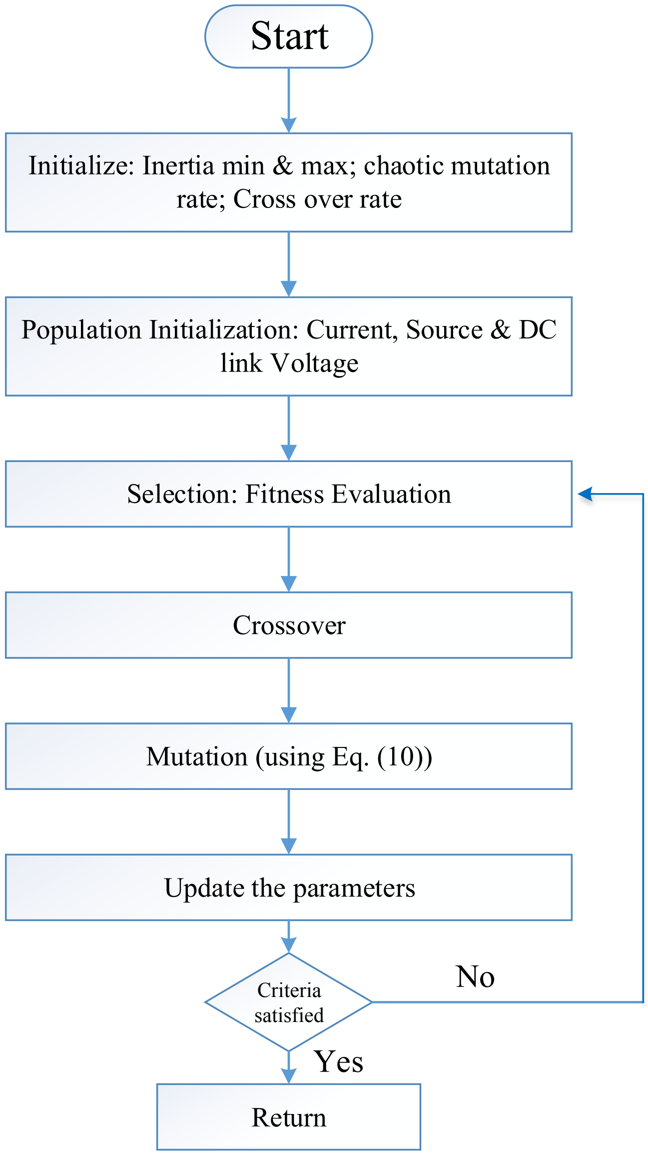

Fig. 3. Flow chart of the ES algorithm

In order to keep dc-link voltage like a regular, we used ESA with some set of rules. Here reference voltage and regular dc-link voltages are fed as inputs to the set of guidelines used in ESA. Generally, ESA is the advanced optimization technique generally applied to crossover, mutation and genetic operators. The quality factor is strongly used in the considered set of rules in order to supply a contemporary individual a set of first-rate men or women used to produce in the crossover operation by considering a fantastic individual part of the person. ESA is used to keep a DC-Link voltage in the converter by reducing the errors. The process flow of the proposed ESA is given in figure 3 and its pseudocode is given in Algorithm 1.

Algorithm 1: Pseudocode of ES Algorithm

```
Initial Population: Initialize the current & DC Link Voltage
Initialize Parameters: Crossover Rate & Mutation Rate
While (Criteria Satisfied) Repeat
{
        For (all individuals)
        {
                Fitness Calculation: DC Link error
                Crossover
                Mutation
                Update Solution
        }
}
```

4. Results and Discussions

The simulation study is carried out in MATLAB/Simulink to verify the proposed control algorithm to achieve multi-objective of PQ improvement and RES power injection to the grid. The major concern of the proposed approach is to regulate the power at PCC.

Table 1: Parameters Settings

Parameters	Device	Values
Nominal Voltage	Battery	26.4 V
Rated Capacity		6.5 Ah
Discharge Current		2.86 A
Open circuit Voltage	PV	64.2 V
Short circuit current		5.96 A
MPP Voltage		54.7 V
MPP Current		5.58 A
Irradiance		800-1000
Maximum Current	Wind	25 A
Maximum Voltage		500 V
Wind Speed		12- 15

The proposed HRES Grid Connected System is evaluated using seven cases; such as

- ***Case 1***: Condition for Linear
- ***Case 2***: Condition during step changes for Non-Linear Load
- ***Case 3***: Condition for Unbalanced Non-Linear Load
- ***Case 4***: Condition for Unbalanced Non-Linear Load during a step change

- ***Case 5***: Linear Load Variation with Extended Search Algorithm
- ***Case 6***: Linear Un-Balance Load Variation with Extended Search Algorithm
- ***Case 7***: Non-Linear Load Variation with Extended Search Algorithm

All the models includes three sources as wind, PV and battery. Then the voltage and frequency of grid is set as 450V and 50Hz respectively and some other important parameters of the system is given in table 1.

4.1. CASE-1: Condition for Non-Linear Load

In this case, the proposed hybrid system is developed under a linear load. And also the power management strategy is considered. The test results for this system are shown in the following cases. The power management strategy between battery, wind and solar systems to meet the load requirement is also shown in figure 4. Here, the system load is raised from 10Kw to 13kw during t=4sec to 5sec. and observe the variation and effective management between the sharing of power between solar, wind and battery to meet the demand.

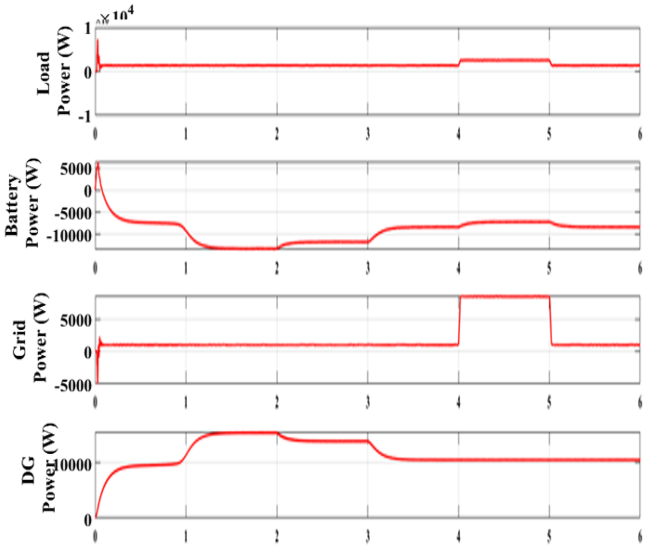

Fig. 4. Load Demand, Solar Power, Grid Power and Battery Power of Case 1

Figure 4, shows the simulation result for the proposed system to show the power management strategies. Here, the load sharing is chosen between PV, battery and grid system according to their generations. Here, the load variation is considered at 3s and 5s.

Figure 5 shows the simulation results for the power factors of ABC Phases of load voltage and current. Here, in this case, the load is taken as a linear balanced load, so that the power factor almost reaches unity.

In the figure 6, shows the simulation results for load voltage and current. In the figure 6 the Grid current (I_{grid}), Load current (I_l), Inverter current (I_c), and Voltage (V_s) signal in three phase is plotted.

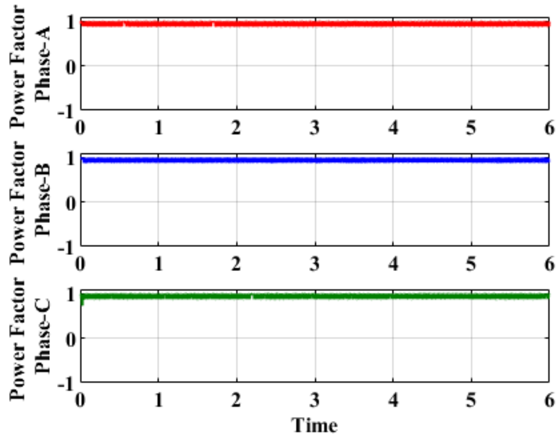

Fig. 5. Power Factors for Inverter Load Current in Case 1

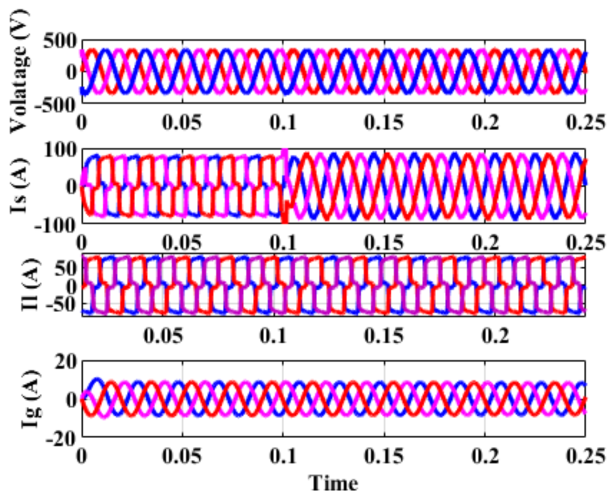

Fig. 6. Grid current, Load current, Inverter current, Voltage of Case 1

Then the waveforms for real and wattles powers for grid, load, and source are shown in figure 7.

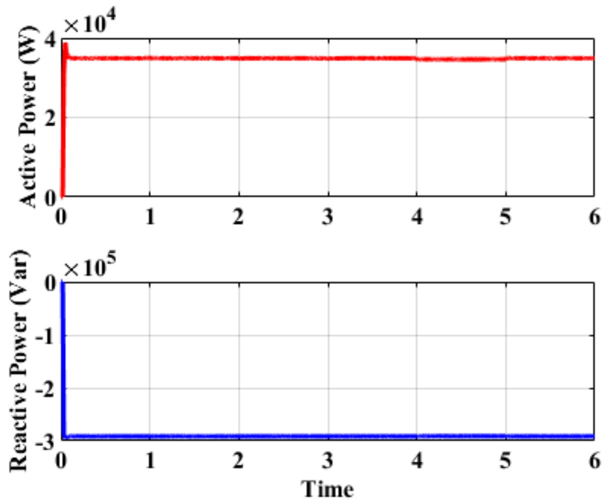

Fig. 7. Active and Reactive Power for Grid load and Source of Case 1

The figure 8 shows the power factor variation of source load voltage and current during changes of load. In this case, the proposed hybrid system is implemented to operate two loads such as linear and non-linear load. The non-linear load consists of a diode rectifier with a series combination of inductor and resistor.

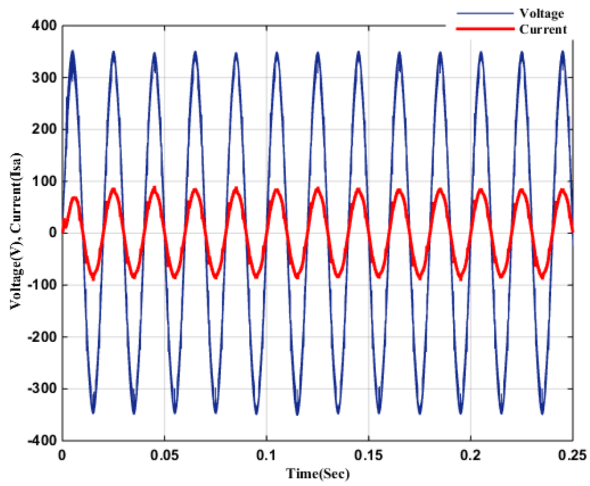

Fig. 8. Power factor variation of source load voltage and current during changes of load in Case 1

The linear balance is connected from start to end while the non-linear load is connected at t=0.1sec. Thus the load current is increased from 80A to 85A. in this case, the system effected by harmonics because of a non-linear load. The proposed inverter eliminates harmonic effects. From t=0 to t=0.1 sec the compensated inverter is in off state condition and at t=0.1 sec, the inverter is connected to the proposed system and eliminates the harmonic.

4.2. CASE-2: Condition for Non-Linear Load Condition During Step Changes

In this the proposed system modeled with non-linear load condition during step changes. The results obtained form the Case 2 analysis is given in fig 9 to fig 11. Fig 9 shows the power generated by various sources and the load power.

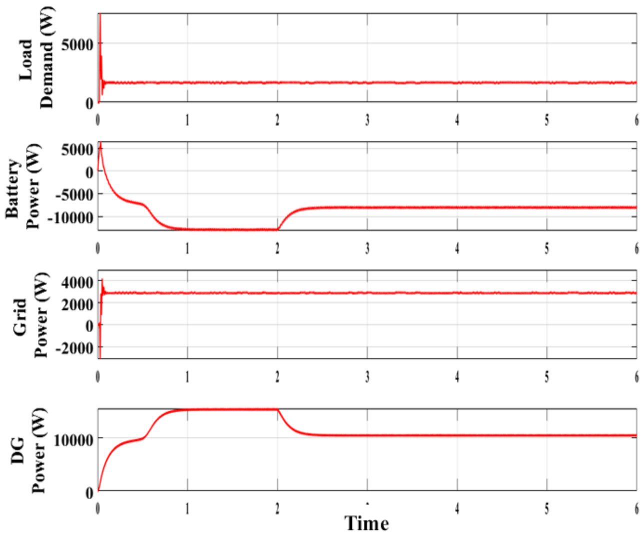

Fig. 9. Load Demand, Solar Power, Grid Power and Battery Power of Case 2

Figure 9, shows the simulation result for the proposed system to show the power management strategies. Here, the load sharing is chosen between PV, battery and grid system according to their generations. Here, the load variation is considered at 3s and 5s.

Figure 10 shows the simulation results for the power factors of ABC Phases of load voltage and current. Here, in this case, the load is taken as an unbalanced load, so that the power factor has some deviations. The figure 10, shows the simulation results in terms of load voltage and current.

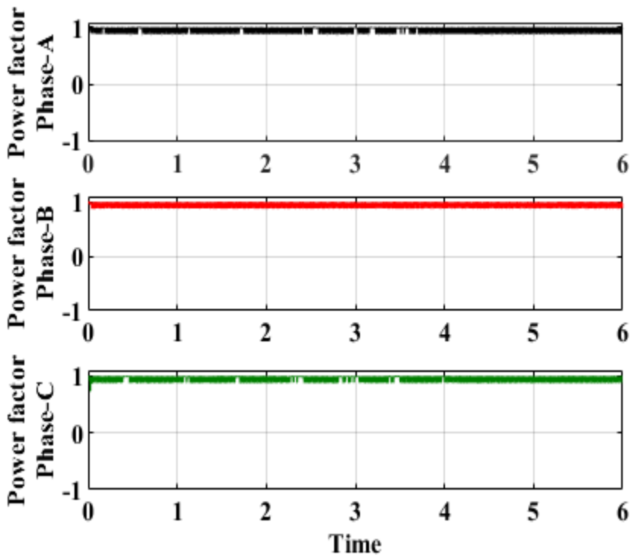

Fig. 10. Power Factors for Inverter Load Current of Case 2

The hybrid system is implemented to operate two loads such as linear and non-linear load. The non-linear load consists of a diode rectifier with a series combination of inductor and resistor. The linear balance is connected from start to end while a sudden intermittent linear load is connected between t=0.1sec to t=0.2sec. Thus, the load current is increased from 80A to 120A.

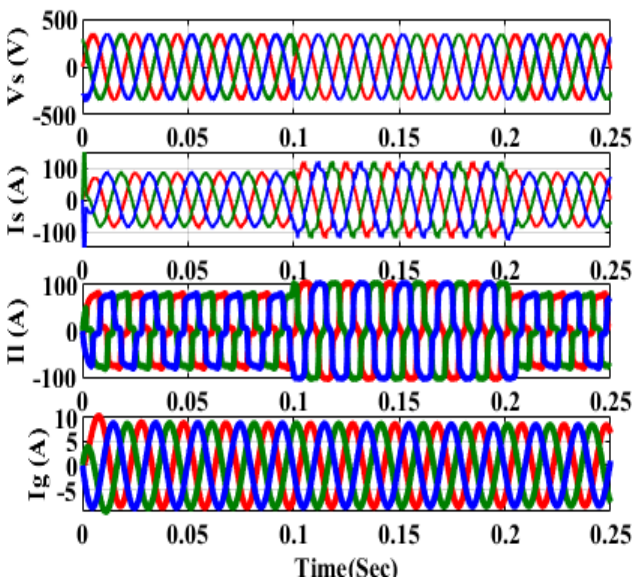

Fig. 11. Common point Voltage (Vs), Current at the Grid (Is), Load current (Il) and output current of the inverter (Ic)

The harmonics produced by these non-linear loads are reduced with the help of power quality improvement inverter. The simulation result for load, grid and source currents as shown in figure 11.

4.3. CASE-3: Condition for Non-Linear Load Variation

In the case 3 analysis the non-linear load variation is applied to the proposed distributed model and its performance is evaluated. Figure 12, shows the simulation result for the proposed system to show the power management strategies. Here, the load sharing is chosen between PV, battery and grid system according to their generations. Here, the load variation is considered at 3s and 5s.

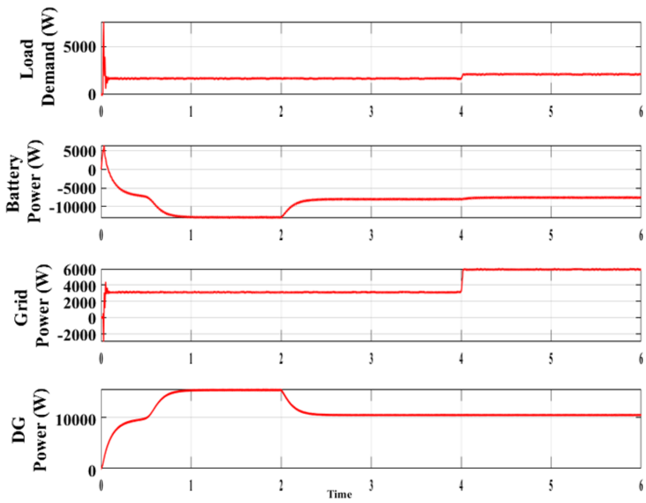

Fig. 12. Load Demand, Solar Power, Grid Power and Battery Power in Case 3

The Figure 13 shows the simulation results for the power factors of ABC Phases of load voltage and current. Here, in this case, the load is taken as a non-linear balanced load, so that the power factor has some deviations. And figure 14, shows the simulation results for load voltage and current.

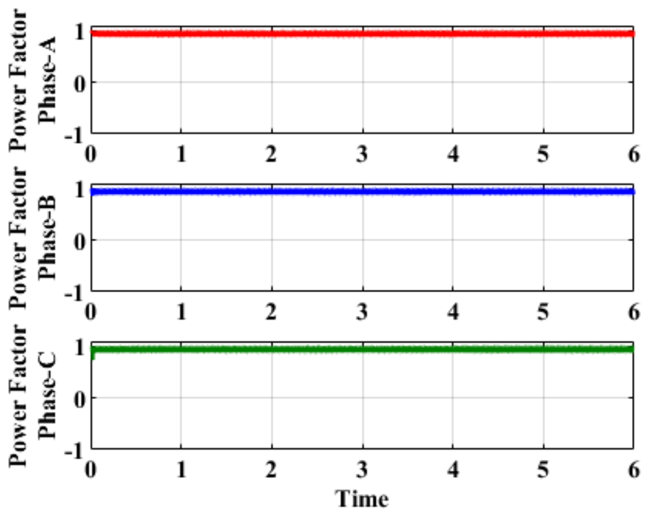

Fig. 13. Power Factors for Inverter Load Current of case 3

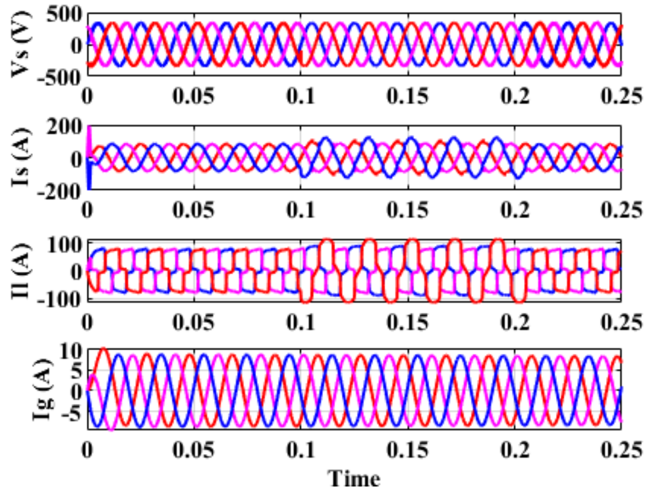

Fig. 14. Grid current, Load current, Inverter current, and Voltage signal of case 3

The hybrid system is implemented to operate two loads such as linear unbalanced load and non-linear load. The intermittent load consists of a diode rectifier with a series combination of inductor and resistor. The unbalanced load is at t=0.1sec and disconnect at t=0.2sec while the intermittent load is connected continuously. Thus, the load current is increased from 80A to unbalance approximately 110A. The harmonics produced by these non-linear loads are reduced with the help of power quality improvement inverter. The simulation result for load, grid and source currents as shown in figure 14.

4.4. Case 4: Condition for Unbalanced Non-Linear Load during a step change

In this case, the proposed hybrid system is implemented to operate two loads such as linear unbalanced load and non-linear load. Since up to t=0.1sec the excess non-linear load is not connected to the system. At t=0.1sec a sudden variable and unbalanced non-linear load are connected along with linear balanced loads.

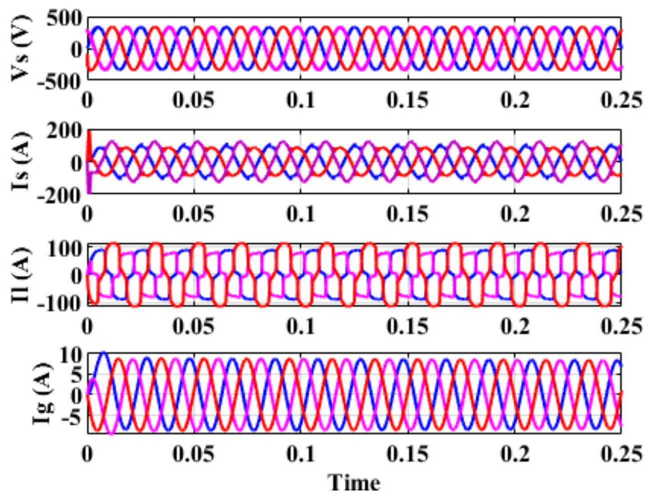

Fig. 15. Grid current, Load current, Inverter current and Voltage signal of case 4

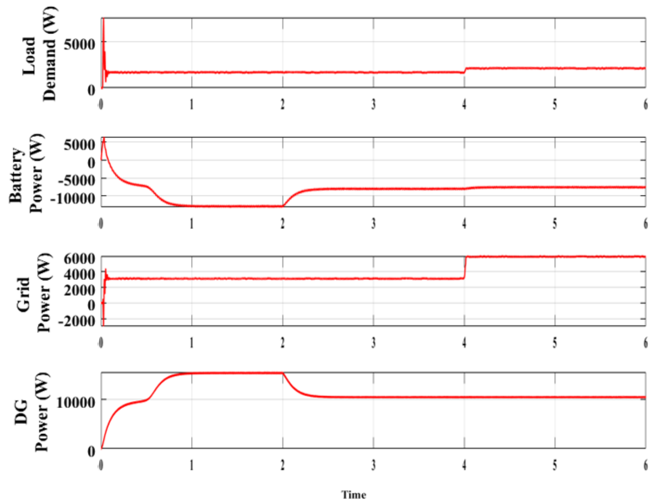

Fig. 16. Load Demand, Solar Power, Grid Power and Battery Power in case 4

The non-linear load consists of a diode rectifier with a series combination of inductor and resistor. Thus, the load current is increased from 20A to unbalance approximately 90A. The harmonics produced by these non-linear loads are reduced with the help of power quality improvement inverter. The observed Grid current (I_{grid}), Load current (I_l), Inverter current (I_c) and Voltage (V_s) signal is shown in figure 15.

The waveforms for active reactive powers for grid, load, and source are shown in figure 16. The system load is raised from 1000w to 1500w during t=4sec to 5sec. and observe the variation and effective management between the sharing of power between solar, wind and battery to meet the demand.

4.5. Case 5: Linear Load Variation with Extended Search Algorithm

In case 5 analysis the proposed distributed system with three energy source is analyzed with linear load variation. Then the performance variation of proposed system due to the usage of ESA is evaluated. The performance observed from the case 5 analysis is shown in fig 17 to fig 19.

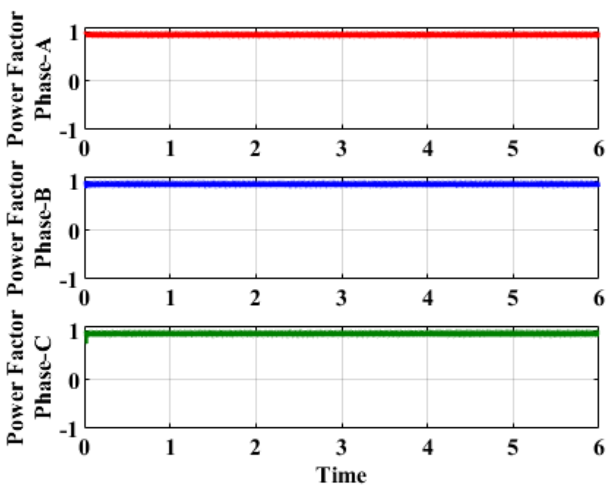

Fig. 17. Power Factors for Inverter Load Current of case 5

Figure 17 show the power factors of three phases of inverter load current. It clearly shows the stability and correlation of current among three phases. Hence it is evident that the ESA performs well at linear load variation. Then the fig 18 shows the load power and the power generated by three sources is given.

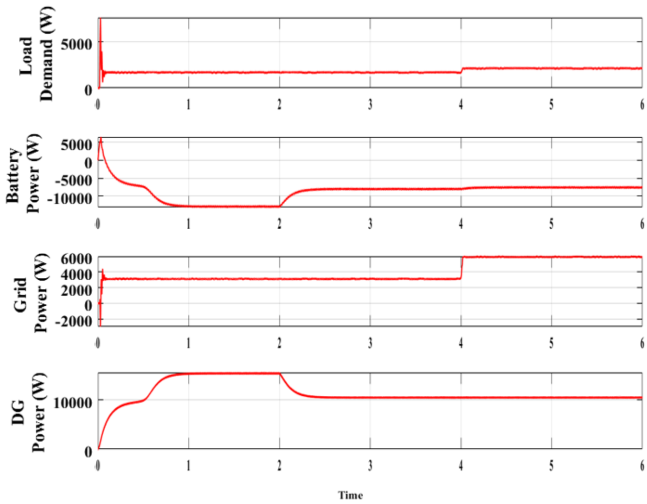

Fig. 18. Load Demand, Solar Power, Grid Power and Battery Power in Case 5

The fig 19 shows the voltage and current at the load side of case 5 is given. In case 5 the linear balanced load is used along with the ESA for the HRES Grid Connected System.

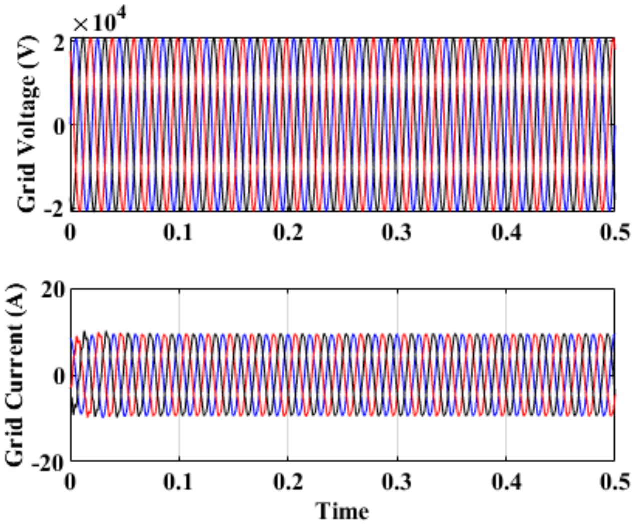

Fig. 19. Three phase Load Voltage and Current at load side in case 5.

4.6. Case 6: Linear Un-Balance Load Variation with Extended Search Algorithm

The case 6 analysis the ESA based technique with linear un-balance load variation. It analysis the ESA based technique based on the load side current, voltage, and power. The fig 20 to fig 22 shows the results obtained from the case 6 analysis.

The fig 20 shows the power factor of inverter load current. It shows the power factors of three phases of inverter load current. The inverter current is essential to compensate during power quality issue.

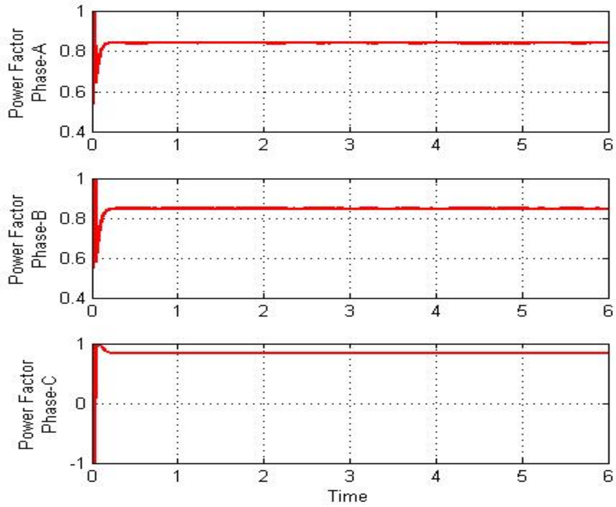

Fig.20. Power Factors for Inverter Load Current of case 6

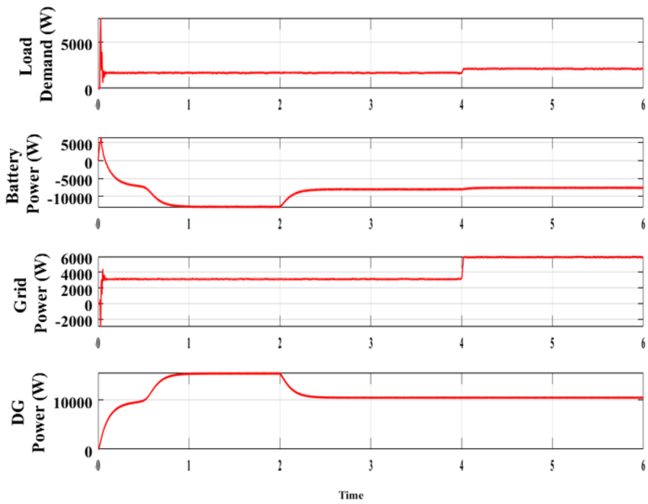

Fig. 21. Load Demand, Solar Power, Grid Power and Battery Power in Case 6

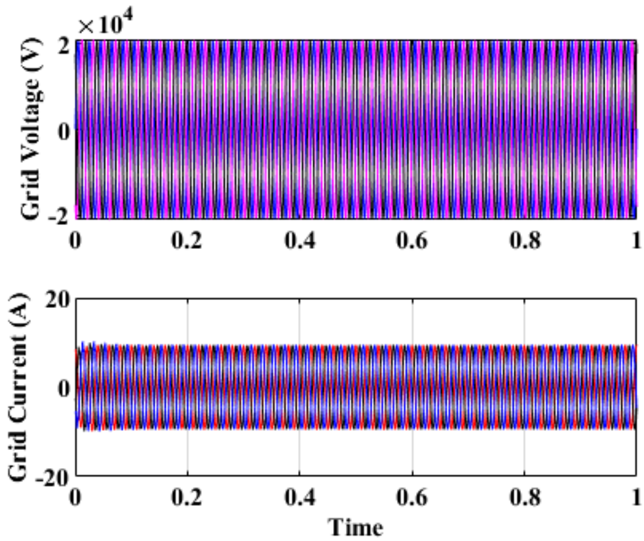

Fig. 22. Simulation result for Load Voltage and Current of Case 6

The fig 21 shows the power at load side and generated by various sources is given. From the analysis it is clear that the proposed power system can provide the average power of 5KW power at gird side.

The fig 22 show the observed load voltage and current from case 6 analysis. The figure shows the thee phase voltage and current. The analysis chart proves that the proposed ESA can provide the stable and smooth voltage and current.

4.7. Case 7: Non-Linear Load Variation with Extended Search Algorithm

Case 7 is the last case considered for the analysis of the proposed ESA controller based distribution system. The case 7 results are shown in fig 23 to fig 25. The fig 23 shows the power factor inverter load current. In this analysis the power factor of all three phases of inverter load current is given.

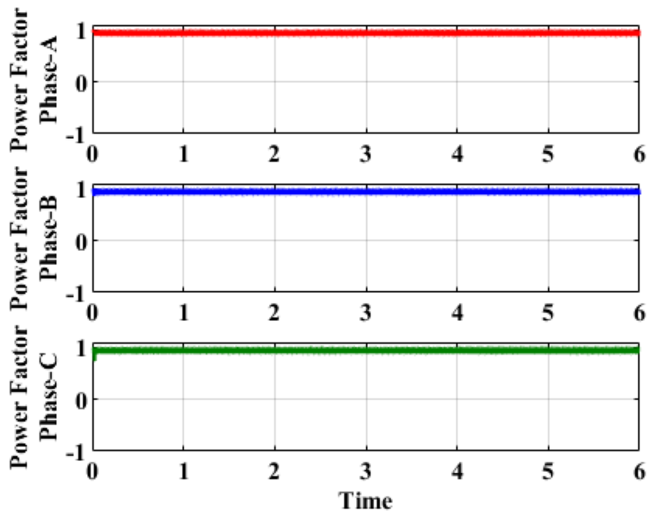

Fig. 23. Power Factors for Inverter Load Current of Case 7

Figure 24 shows the load and grid side power as well as the power generated by all three power sources. The generated load got varied in some times, still the grid side power is almost stable.

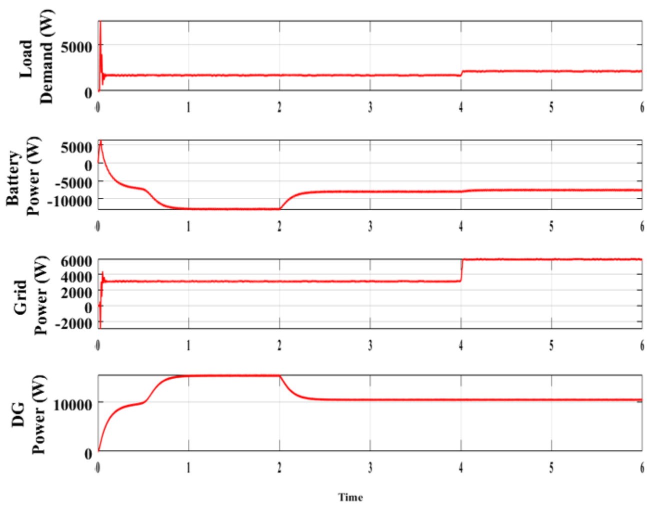

Fig. 24. Load Demand, Solar Power, Grid Power and Battery Power in Case 7

Table 2: Summary of THD results for mode1 and mode 2

			Mode 1: Load>Demand						Mode2: Load < Demand					
Load Type	Parameter	Controller	**0**	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Linear Load	Source Current	PI	2.32	1.36	1.36	1.57	1.44	1.45	3.04	2.86	2.88	2.9	2.95	2.9
		ESA	2.25	0.79	0.78	1.54	0.84	0.85	3.35	2.74	2.72	2.7	2.69	2.7
Non-Linear Load		PI	3.45	4.26	4.26	4.13	4.08	4.24	3.14	3.02	3.05	2.92	2.95	3
		ESA	3.09	2.92	2.95	2.82	2.85	2.93	3.43	4.36	4.36	4.22	4.17	4.3
Unbalanced Load		PI	3.2	2.58	2.56	2.55	2.44	2.59	2.95	2.27	2.29	2.32	2.51	2.1
		ESA	2.87	1.86	1.88	1.91	2.02	1.77	3.31	2.78	2.76	2.74	2.59	2.8
Linear Load	Voltage	PI	0.25	0.26	0.26	0.25	0.25	0.26	0.23	0.28	0.28	0.27	0.27	0.3
		ESA	0.23	0.26	0.26	0.25	0.25	0.27	0.25	0.26	0.26	0.25	0.25	0.3
Non-Linear Load		PI	0.25	0.39	0.4	0.38	0.39	0.39	0.25	0.52	0.52	0.5	0.5	0.5
		ESA	0.24	0.49	0.49	0.48	0.48	0.49	0.25	0.39	0.4	0.38	0.39	0.4
Unbalanced Load		PI	0.21	0.27	0.27	0.28	0.3	0.25	0.22	0.29	0.28	0.28	0.26	0.3
		ESA	0.21	0.25	0.25	0.25	0.23	0.25	0.21	0.27	0.27	0.28	0.3	0.3
Linear Load	Load Current	PI	5.2	4.3	4.32	4.4	4.6	4.6	5.4	4.5	4.6	4.52	4.82	4.8
		ESA	3.25	3.1	3.2	3.3	2.8	2.85	3.35	3.23	3.33	3.35	2.92	2.9
Non-Linear Load		PI	6.4	8.2	8.12	8.34	8.02	8.4	6.5	8.4	8.39	8.36	8.4	8.6
		ESA	3.4	5.3	5.3	6.2	6.3	7.1	3.43	5.4	5.5	6.4	6.4	7.3
Unbalanced Load		PI	7.2	5.21	5.18	5.32	5.42	5.44	7.6	5.45	5.34	5.6	5.8	5.9
		ESA	2.87	3.8	3.87	3.93	3.02	2.88	2.93	3.92	4.02	4.13	3.33	3

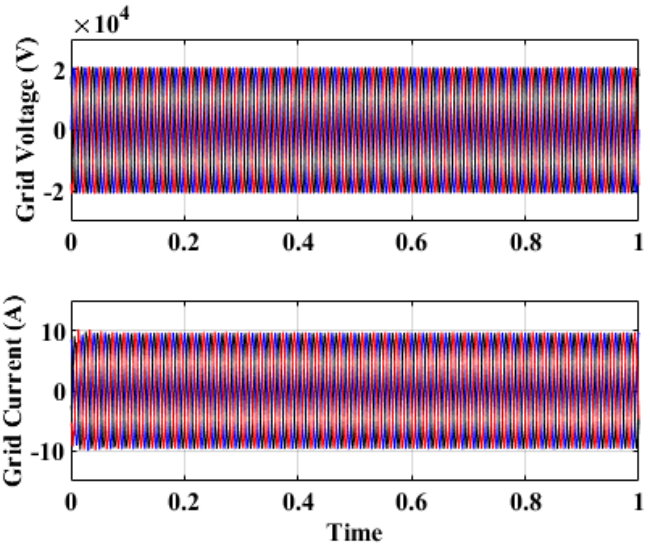

Fig. 25. Simulation result for Load Voltage and Current of case 7

The figure 25 gives the load side voltage and current while the usage of ESA is given. The three-phase voltage and current shown in fig 25 is stable and has no power quality issues. Thus, based on these analyses we can observe that the ESA become a better solution to mitigate the power quality issue while the usage of renewable energy in distributed power system. The table 2 gives the THD summary of two modes.

Table 2, shows the harmonics distortions for load voltage and currents for various loads such as linear, non-linear and unbalanced loads. In this analysis, the THD values are identified at different time conditions. For all these times THD values are measured for both load voltage and currents. Here the thd's are compared for two controllers such as conventional PI controller and ESA algorithm. From the above table, it concludes that ESA provides better harmonic compensation.

5. Conclusion

An ES algorithm is proposed as a controller for the distributed power system to improve the quality of power in a grid connected hybrid system with battery storage without affecting its normal operation of real power transfer. By utilizing the ESA, the perfect combination of parameters is generated and the optimal control signals are predicted using PI technique. Likewise, the current unbalance, current harmonics, and load reactive power, due to unbalanced non-linear load connected to the PCC, are compensated effectively such that the grid side current is balanced sinusoidal at unity power factor. By then the simulation results of proposed technique is validated in MATLAB/Simulink working platform. The final results achieved on the proposed system verified the feasibility and effectiveness of the ESA controller for eliminating the PQ problems such as THD.

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