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Comparative analysis on power quality improvement in autonomous micro grids using PSO, HHO and hybrid controller

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ABSTRACT

RES based distributed generation (DG)'s is effectively used in DS due to government initiations and benefits. These are also support customer power demands in DS. However, few problems are facing in operation DG's with existing DS, like parallel operation, islanding detection and majorly power quality problems due go harmonics. In this paper a hybrid control technique proposed to improve the power quality and conversion efficiency. A test case of single phase 3.5 kW PV system based autonomous micro grid is considered. PSO and HHO optimal control strategies are implemented under standard test case and variable test cases. In all the cases Vmpv (V), Impv (A), Vrms (V), Irms (A), Ppv (W), Pg (W), efficiency (%), THD (%), inverter losses (%) are evaluated. In all the cases HHO optimal control strategy for autonomous microgrid exhibits the best performance in comparison with PSO optimal control strategy. The inverter efficiency is improved, inverter losses are reduced and the THD is improved.

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1. INTRODUCTION

Distributed generation (DG) in connected with MG is the best way to address the issue of ever-increasing load [1]. The proximity of DG and loads in a distribution system allows for a continuous and quickly regulated power supply. In recent years due to technology advancements, MGs design and operations are increased, especially in grated community systems, medium power scale utilization centers, Islands [2]. MG's can operate in two modes, grid connected and autonomous modes. Autonomous mode also called standalone/islanding mode, in this operation, power delver directly local loads irrespective of main grid connection i.e. independent from conventional grid [3]. This autonomous MG connected to loads through power electronic converters, for flexible in control of power supply, but these creates power quality problems. A lot of literature available on this, which discussed in next section. Due to unpredicted nature of wind and solar DG's, it's difficult to maintain power balance between DG and loads. In this paper power quality problems are analyzed for a PV based autonomous microgrid simulation model. Shahgholian [4] illustrated microgrid classifications, presented in Figure 1 (see Appendix). Schematic diagram of grid connected MG system is presented in Figure 2 (see Appendix).

2. RECENT RESEARCH WORK

Power quality is a major issue, when RES connected to grid or loads. PQ problems are in terms of voltage sag, swell, voltage and current harmonics, reactive power compensation, voltage and current unbalance, islanding's and current reversal. Verma *et al.* [5] introduced overview of different control techniques to improve the system power quality. Hornik and Zhong [6] discussed different control methods with their % THD levels to maintain the power quality in system, it is tabulated in table. Lavanya and Kumar [7] presented about DG, power quality problems and control methods, optimization techniques, APF for reactive power compensation and advantages & disadvantages. Karimi *et al.* [8] proposed a dynamic model and control system (LQG control) for autonomous distributed resource operation. Miveh *et al.* [9] designed an optimal operating strategy and cost optimization technique for a microgrid including RES (wind turbine, diesel generator and solar array). The four-leg inverter (VSI) is gaining popularity as an interface for renewable and sustainable DERs. The Four-leg VSIs are used in autonomous four-wire microgrids. These are common in four-wire microgrids because they can achieve an independent control system and meet power quality standards [9]. Like Grid connected mode the autonomous MG also same power quality standard need to follow. The VUF and THD should have ≤ 2% and 5%, respectively, in accordance with the IEEE standards [10]–[12]. Controlling voltage and frequency, controlling active and reactive power sharing, controlling power quality, and operation cost optimization are fundamental principles in islanding control mode [13], [14]. Al-Saedi *et al.* [15] discussed the work related to improves power quality, where DG units are connected to the grid. This paper considers dynamic response and harmonics distortion, especially when the microgrid is islanded, and compare THD with PI and PSO self-tuning method. The word in [16] provides research on in-depth analysis of control techniques for improving power quality and stability in autonomous microgrids by utilizing multi-functional VSIs.

Lavanya and Kumar [7] has been done research work focus on microgrids, these are separated into two categories based on feasibility and economic studies, and also focusing on control and optimization. The article discussed on introduction to the uses and types of microgrids, an explanation of the purpose of microgrid control. Control of a microgrid divided into two categories: i) coordinated control and ii) local control. The stability of the small signal and the many ways in which it might be improved are examined. Evaluation is being done on the load frequency control in microgrids. Different comparisons are also discussed by Lavanya and Senthil Kumar in [7]. Miveh *et al.* [16] discussed multi-functional voltage source inverters (VSI). Ebrahim *et al.* [17] introduced multi objective function for optimal parameters selection in controller of AC micro grids to minimize tracking error, and increasing power quality. Bouaouda and Sayouti [18] designed different optimal tuning methods for optimal sizing of hybrid renewable energy systems. Tinajero *et al.* [19] discussed overview on micro grid EMS with different control strategies and challenges. Hathiyaldeniye *et al.* [20] used a synthesis and modeling of a power inverter's optimal control scheme, which considers the various characteristics of the system, such as its dynamic behavior and the reactive and active power. This allows the system to provide robust and efficient power management. Nair *et al.* [21] presented a method for storing energy in the sub-system capacitors of a modular-multi-level converter. This method can help boost the current limit of the power inverter. Increasing the ratings of the system will lead to higher costs. Inaolaji *et al.* [22] introduced a hybrid control architecture that is based on a nonlinear optimization method. Chakraborty *et al.* [23] adopted a LinDist3Flow version of the DOPF algorithm. This allows us to perform multiperiod linear programming. Chavali *et al.* [24] presented a framework for controlling a power inverter that is based on the dynamic duality of the plant's voltage-current model. Majumdar *et al.* [25] developed a pulse width modulation technique that is suitable for the space vector current controller (SVHCC). The detailed power losses analysis is presented in [26]–[29].

3. AUTONOMOUS MICRO GRID

3.1. Autonomous micro grid block diagram

An autonomous microgrid is a localized energy system that operates independently of the larger electrical grid, serving a specific area or community. It integrates various distributed energy resources (DERs), such as solar panels, wind turbines, energy storage systems (batteries), and sometimes even small-scale generators like gas or diesel units. The main characteristic of an autonomous microgrid is its ability to function in both connected and disconnected modes. Figure 3 represents, autonomous microgrid block diagram, PV, Wind, energy storage devices connected to existing industrial loads and residential loads with the help of AC/DC/AC converters, without involvement of main grid connection.

3.2. Design model

3.2.1. Test case

In this study, a single-phase, 3.5-kilowatt photovoltaic (PV) microgrid that is completely autonomous is studied. The photovoltaic (PV) array was provided by Trina solar manufacturer. In this particular scenario, the H-bridge type of inverter is taken into account, and the traditional LCL control method is utilized, as can be seen in Figure 4. The system parameters are tabulated in Table 1.

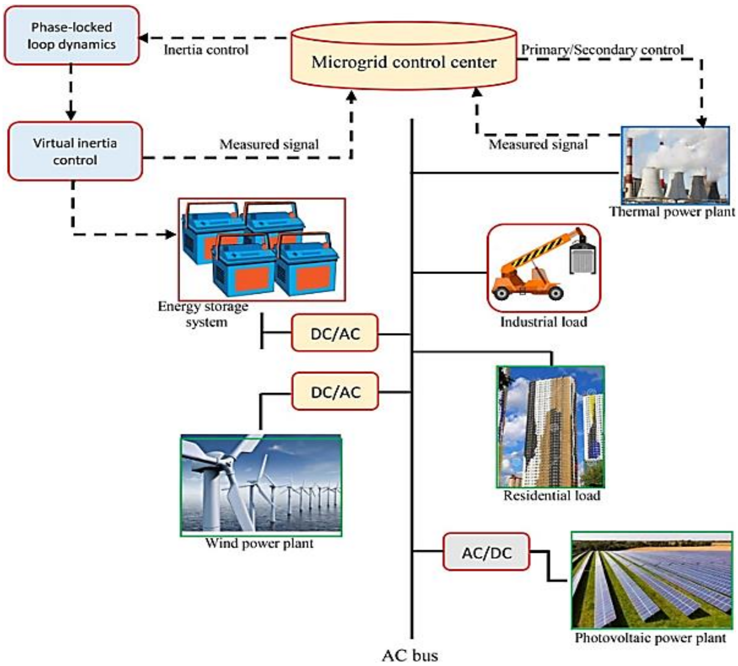

Figure 3. Autonomous microgrid

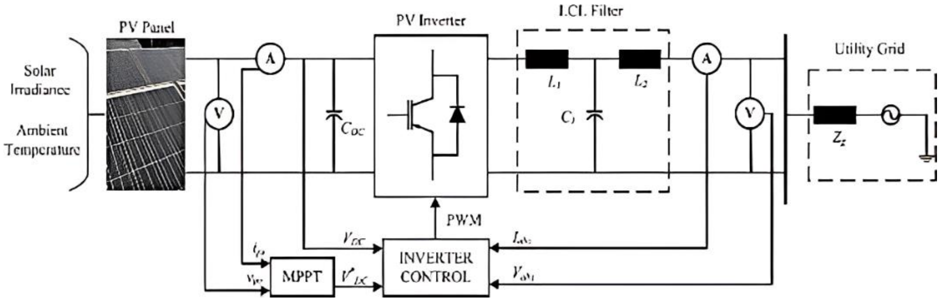

Figure 4. 3.5 kW PV system design model

Table 1. System design parameters

PV Model	TSM-250
Maximum power (Pmax)	250 W
Voc	37.6 V
Dc link capacitor voltage	425 V
C_{dc}	3 mF
Isc	8.55 A
Ls	2.183 e^{-3} H
Cs	525 var
Grid voltage	240 V (RMS)

4. OPTIMAL TUNNING PI CONTROLLER USING PSO–HHO CONTROLLER

PI controllers are popular and conventional method for controlling applications, but these are facing tunning problems in practice, this problem can be minimized by introducing optimum tuning algorithms, in this paper a hybrid PSO-HHO based optimum tunning method is proposed for tunning of PI controller gain values in voltage and current controllers. The error signal from the hybrid PSO-HHO controller, which is mentioned in (1), serves as the input for the PI controller. Figure 5 depicts the flow chart for the proposed hybrid optimum controller. Optimal gain values will reduce the THD. This leads to decrease in inverter losses and hence efficiency is improved.

$$\text{Integral Time Absolute Error } (ITAE) = \int_0^t t|e(t)|dt \quad (1)$$

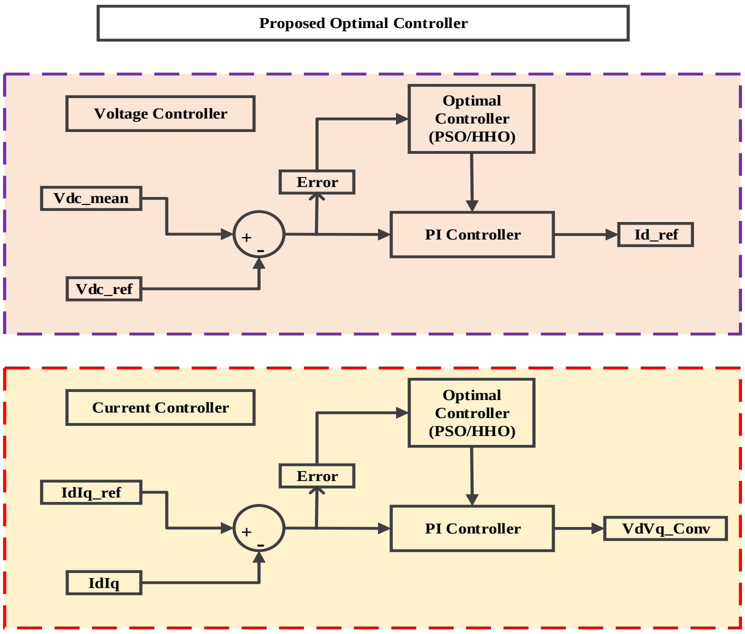

Figure 5. Proposed hybrid PSO-HHO controller

5. RESULTS AND DISCUSSION

The proposed PSO-HHO hybrid optimization algorithm is implemented on a 3.5 kW PV autonomous microgrid. The effectiveness of the proposed controller is evaluated by comparing it with PSO and HHO optimization algorithms. In this paper the following cases are implemented: i) Performance evaluation using PSO algorithm; ii) Performance evaluation using HHO algorithm; and iii) Performance evaluation using PSO-HHO algorithm.

5.1. Performance evaluation using PSO algorithm

In this case the PSO algorithm is implemented on 3.5 kW PV autonomous microgrid, where the solar irradiance is 1000 W/m^2 and temperature is 25 °C as shown in Figure 6. The voltage controller and the current controller gain values are optimally tuned using PSO algorithm. The PSO parameter are tabulate in Table 2.

Using the above parameters, the voltage controller and the current controller gain values are optimally tuned and the gain values are tabulated in Table 3. PV mean voltage (Vmpv) and PV mean current (Impv) of the autonomous microgrid are presented in Figure 7. From the Figure 7, PV mean voltage (Vmpv) recorded is 433.8 V abd PV mean current (Impv) record is 8.05 A. The PV mean power (Pmpv) recorded is 3492.09 W.

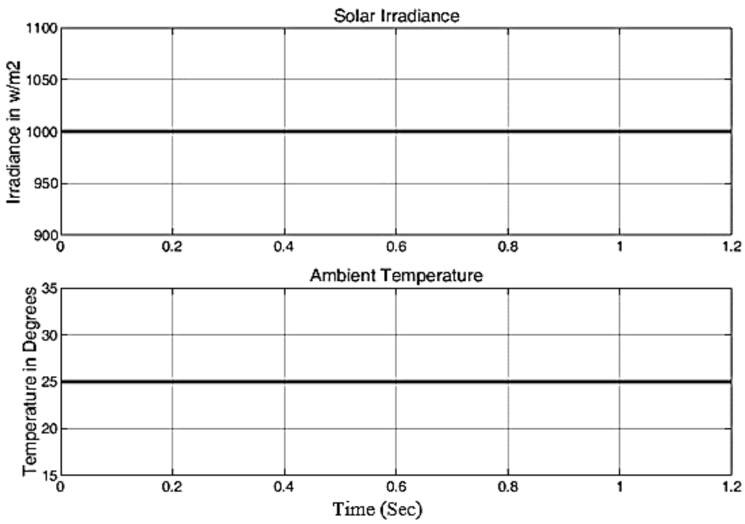

Figure 6. Solar irradiance and temperature

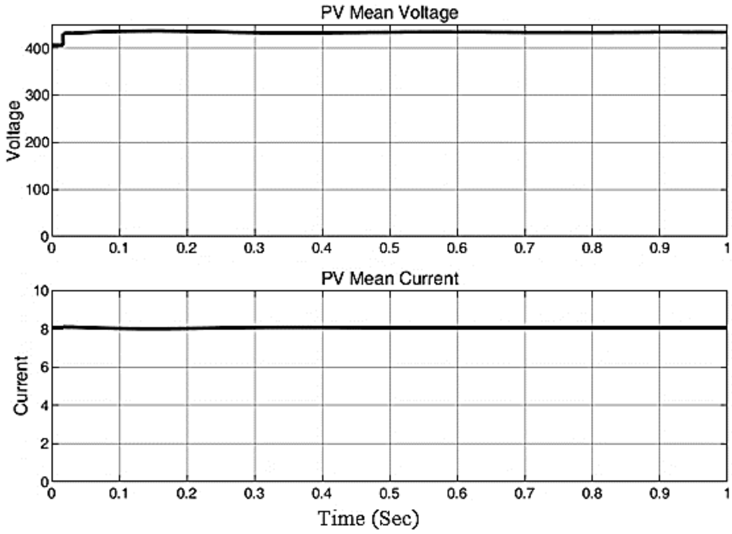

Figure 7. PV mean voltage and mean current

Table 2. PSO parameters

Parameter	Value
Population (swarm) Size	50
Iterations	200
Constant C_1	0.5
Constant C_2	1.25
Weight W	1
Velocity V	10

Table 3. Tuned parameters

Parameter	Value
Voltage controller (Kpv)	1.5016
Voltage controller (Kiv)	3.2419
Current controller (Kpc)	0.6277
Current controller (Kic)	3.5928

The autonomous microgrid rms voltage (Vrms) and rms current (Irms) are presented Figure 8. From the Figure 8, The autonomous microgrid rms voltage (Vrms) recorded is 239 V, rms current (Irms) recorded is 14.41 A. The autonomous grid power (Pg) recorded is 3433.99 W. The FFT analysis is implemented on autonomous micro grid current and obtained the THD is 3.22% as shown in Figure 9.

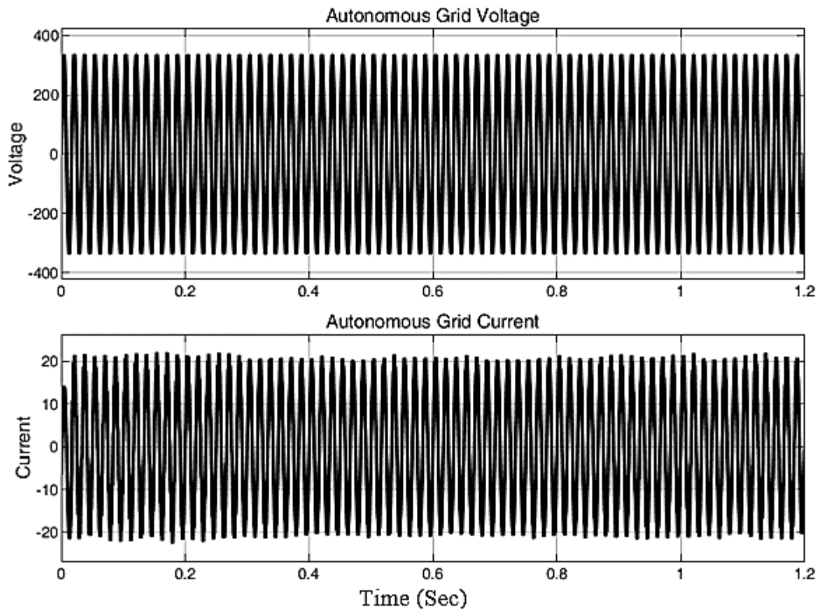

Figure 8. Autonomous grid RMS voltage and RMS current

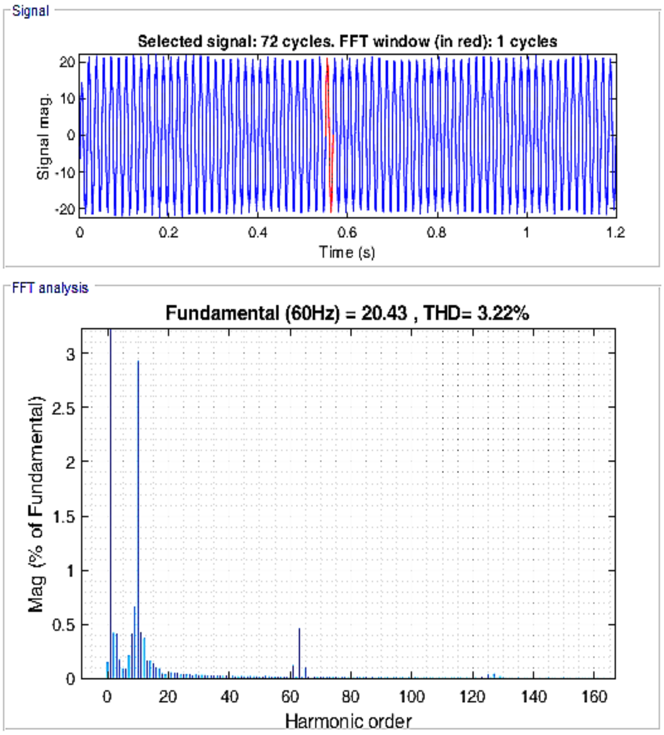

Figure 9. THD analysis with PSO algorithm

5.2. Performance evaluation using HHO algorithm

In this case the HHO algorithm is implemented on 3.5 kW PV autonomous microgrid, where the solar irradiance is 1000 W/m^2 and temperature is 25 °C as shown in Figure 10. The voltage controller and the current controller gain values are optimally tuned using HHO algorithm. The HHO parameter are tabulate in Table 4. Using the above parameters, the voltage controller and the current controller gain values are optimally tuned and the gain values are tabulated in Table 5. PV mean voltage (Vmpv) and PV mean current (Impv) of the autonomous microgrid are presented in Figure 11.

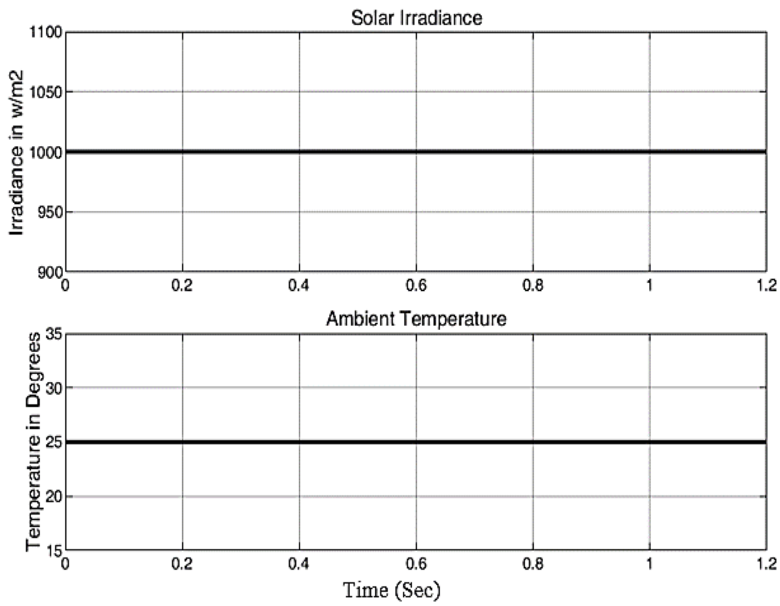

Figure 10. Solar irradiance and temperature

Table 4. HHO parameters

Parameter	Value
Size of the Hawks	50
Iterations	200
convergence probability r	0.5
r1, r2, r3, r4	0 - 1

Table 5 Tuned parameters

Parameter	Value
Voltage controller (Kpv)	1.5104
Voltage controller (Kiv)	3.2812
Current controller (Kpc)	0.5916
Current controller (Kic)	3.5896

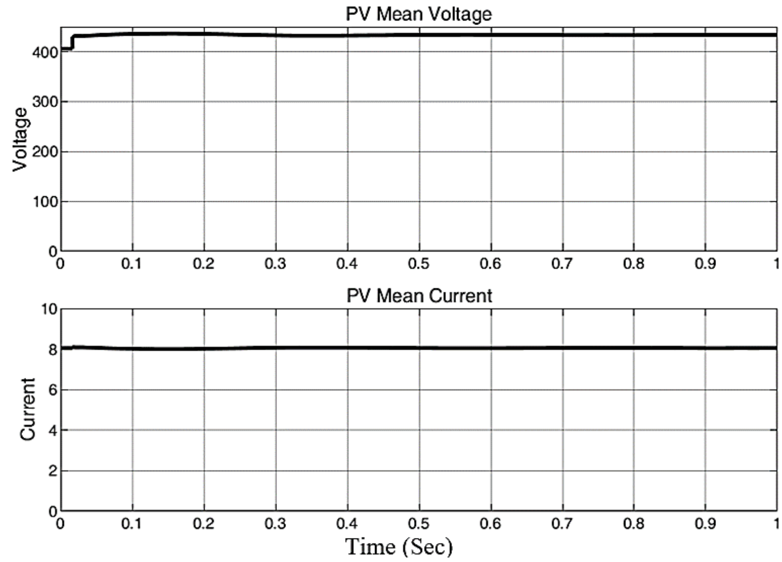

Figure 11. PV mean voltage and mean current

From the Figure 11, PV mean voltage (Vmpv) recorded is 433.8 V abd PV mean current (Impv) record is 8.05 A. The PV mean power (Pmpv) recorded is 3492.09 W. The autonomous microgrid rms voltage (Vrms) and rms current (Irms) are presented Figure 12. From the Figure 12, The autonomous microgrid rms voltage (Vrms) recorded is 239 V, rms current (Irms) recorded is 14.47 A. The autonomous grid power (Pg) recorded is 3458.33 W. The FFT analysis is implemented on autonomous micro grid current and obtained the THD is 2.31% as shown in Figure 13.

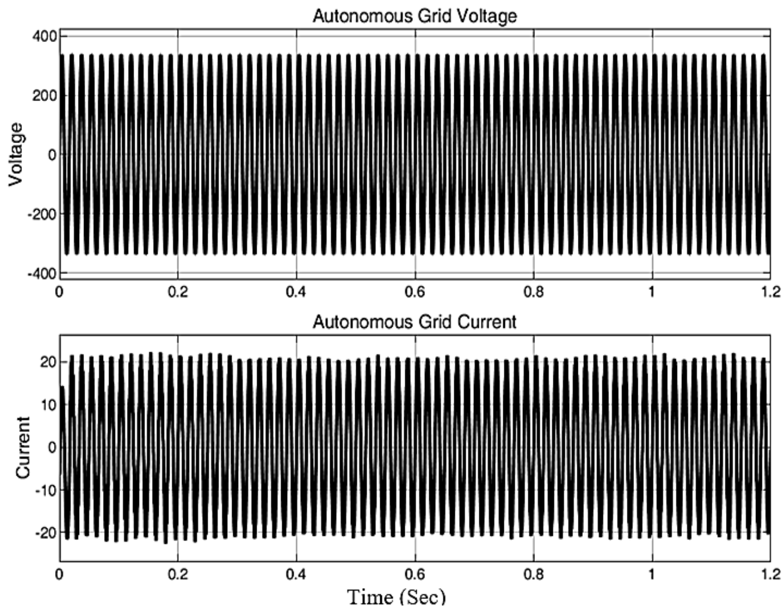

Figure 12. Autonomous grid RMS voltage and RMS current

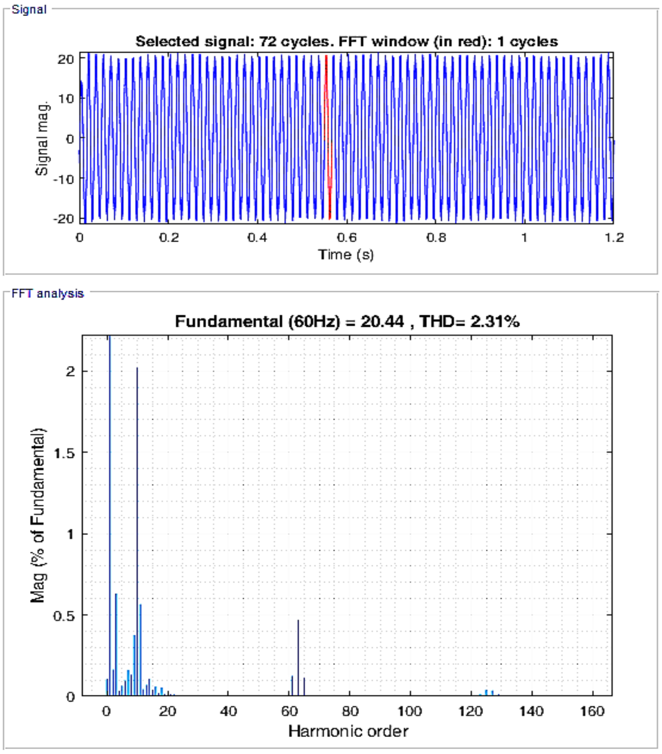

Figure 13. THD analysis with HHO algorithm

5.3. Performance evaluation using PSO-HHO algorithm

In this case the PSO-HHO algorithm is implemented on 3.5 kW PV autonomous microgrid, where the solar irradiance is 1000 W/m^2 and temperature is 25 °C as shown in Figure 14. The voltage controller and the current controller gain values are optimally tuned using PSO-HHO algorithm. The PSO-HHO parameter are tabulate in Table 6. Using the above parameters, the voltage controller and the current controller gain values are optimally tuned and the gain values are tabulated in Table 7. PV mean voltage (Vmpv) and PV mean current (Impv) of the autonomous microgrid are presented in Figure 15.

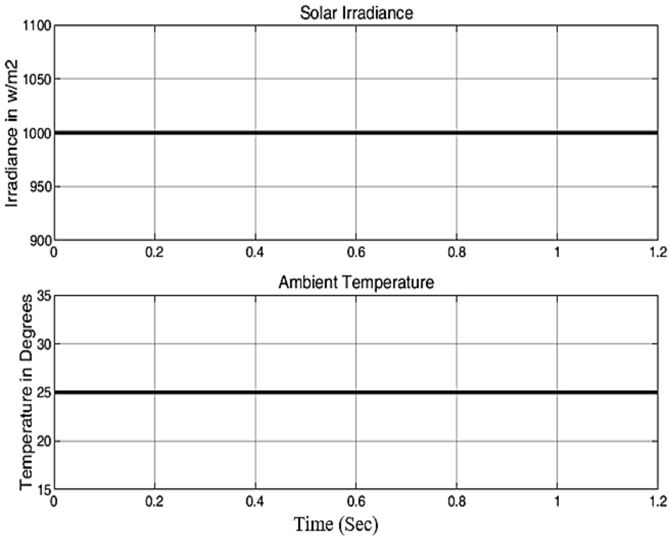

Figure 14. Solar irradiance and temperature

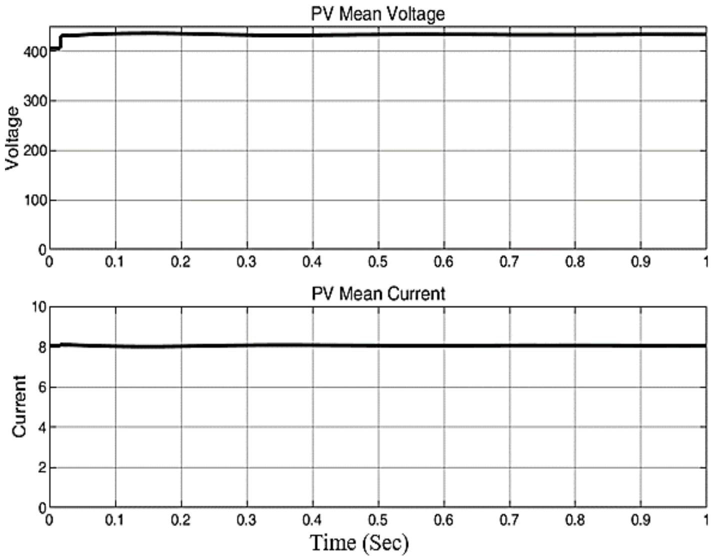

Figure 15. PV mean voltage and mean current

Table 6. PSO-HHO parameters

Parameter	Value	Parameter	Value
Population (swarm) Size	50	Velocity V	10
Iterations	200	Size of the Hawks	50
Constant C1	0.5	Iterations	200
Constant C2	1.25	convergence probability r	0.5
Weight W	1	r1, r2, r3, r4	0 - 1

Table 7. Tuned parameters

Parameter	Value
Voltage controller (Kpv)	1.1126
Voltage controller (Kiv)	3.9712
Current controller (Kpc)	0.2916
Current controller (Kic)	4.1782

From the Figure 15, PV mean voltage (Vmpv) recorded is 433.8 V abd PV mean current (Impv) record is 8.05 A. The PV mean power (Pmpv) recorded is 3492.09 W. The autonomous microgrid rms voltage (Vrms) and rms current (Irms) are presented Figure 16. From the Figure 16, The autonomous microgrid rms voltage (Vrms) recorded is 239 V, rms current (Irms) recorded is 14.56 A. The autonomous grid power (Pg) recorded is 3479.84 W. The FFT analysis is implemented on autonomous micro grid current and obtained the THD is 1.18% as shown in Figure 17.

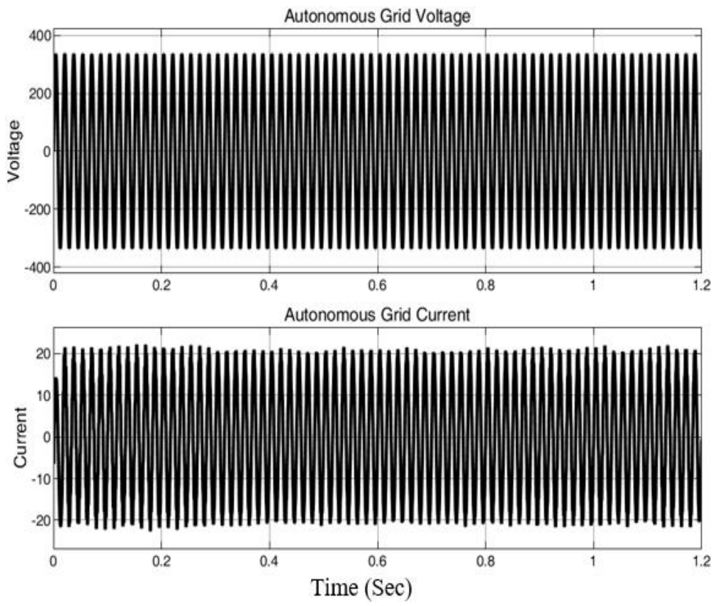

Figure 16. Autonomous grid RMS voltage and RMS current

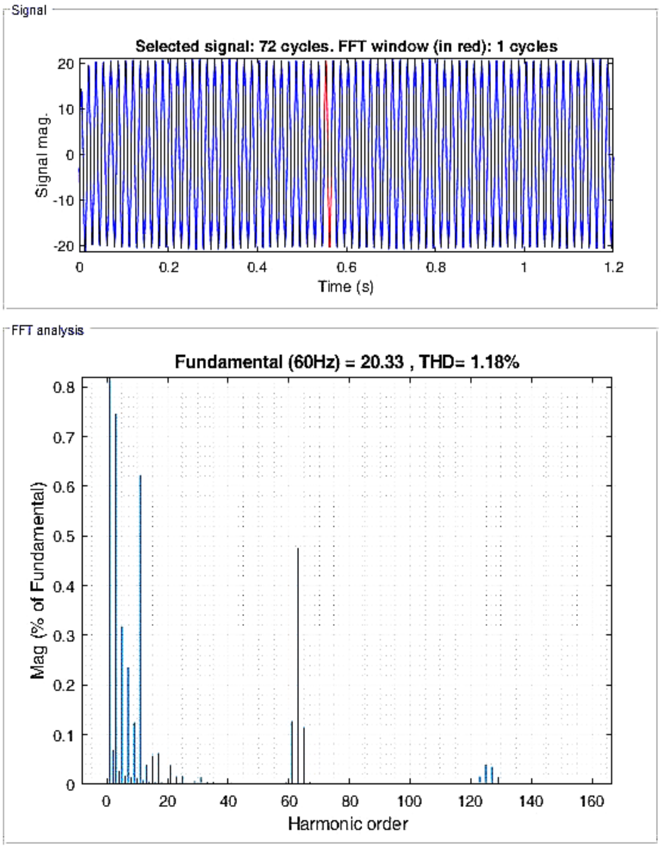

Figure 17. THD analysis with PSO-HHO algorithm

5.3. Comparison analysis

The hybrid PSO-HHO, PSO and HHO optimal control strategies are implemented. The hybrid PSO-HHO optimal control strategy for autonomous microgrid exhibits the best performance in comparison with PSO, HHO optimal control strategy. The THD is reduced from 3.21% to 1.18%. The detailed comparison analysis tabulated in Table 8.

Table 8. Comparison analysis

Algorithm	Ppv (W)	Pg (W)	Efficiency %	THD %	Inverter Losses %
PSO	3492.09	3443.99	98.6226	3.22	1.377399
HHO	3492.09	3458.33	99.03324	2.31	0.966756
PSO-HHO	3492.09	3479.84	99.64921	1.18	0.350793

6. CONCLUSION

In this paper a test case of single phase 3.5 kW PV system based autonomous micro grid is considered. Optimal control strategy of autonomous microgrid for power quality improvement is presented. In this paper PSO -HHO hybrid optimal algorithms are considered and compared. All hybrid PSO-HHO, PSO and HHO optimal control strategies are considered under standard test case. In all the cases Vmpv (V), Impv (A), Vrms (V), Irms (A), Ppv (W), Pg (W), efficiency (%), THD (%), inverter losses (%) are evaluated. In all the cases hybrid PSO-HHO optimal control strategy for autonomous microgrid exhibits the best performance in comparison with PSO, HHO optimal control strategy. The inverter efficiency is improved, inverter losses are decreased and the THD is reduced from 3.21% to 1.18%.

APPENDIX

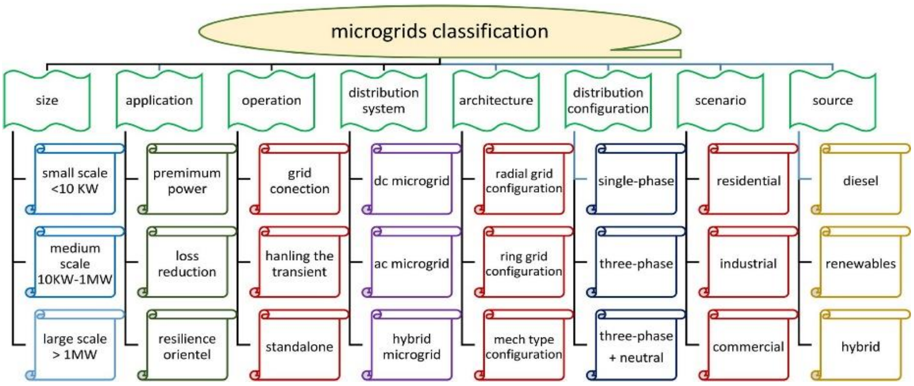

Figure 1. Basic classification of MG

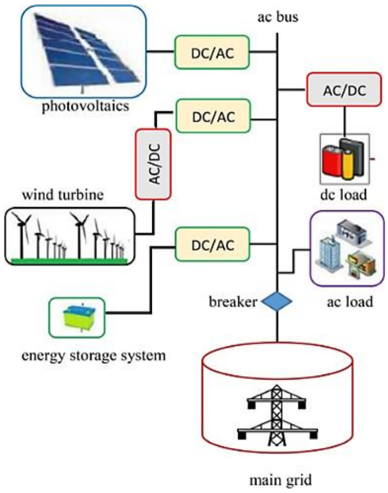

Figure 2. Grid connected MG system

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