Optimization of PID controller for Hybrid Renewable Energy System using Adaptive Sine Cosine Algorithm

Ali M. Yousef*, Mohamed Ebeed***‡, Farag K. Abo-Elyousr***, Ahmed Elnozohy*, Moayed Mohamed****, Saad A. Mohamed Abdelwahab**, *****

* Department of Electrical Engineering, Faculty of engineering, Assuit University, Assuit, Egypt.

** Electrical Department, Faculty of Industrial Education, Suez University, Suez, Egypt

*** Department of Electrical Engineering, Faculty of engineering, Sohag University, Sohag, Egypt.

**** Department of Electrical Engineering, Faculty of Industrial Education, Sohag University, Sohag, Egypt.

***** High Institute of Electronic Engineering, Ministry of Higher Education, Bilbis- Sharqiya, Egypt

(drali_yousef@yahoo.com, mebeed@eng.sohag.edu.eg, eng_farag_k_usr@yahoo.com, ahmed.alnozahy@gmail.com, moayedm1990@gmail.com, saad.abdelwahab@suezuniv.edu.eg)

‡ Corresponding Author; Mohamed Ebeed, Postal address: 82524, Tel: +90 312 123 4567, mebeed@eng.sohag.edu.eg

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Abstract- This paper proposed a new application of an efficient Adaptive Sine Cosine Algorithm (ASCA) to determine the optimal settings of the PID controllers in hybrid renewable energy system (HRES). The ASCA is proposed to enhance the searching capabilities of the traditional Sine Cosine Optimization (SCA) and its stagnation to local optima. The ASCA is based on modifying traditional SCA by applying the Levy flight distribution and adaptive operators. The HRES consists of three sources photovoltaic (PV) source, wind turbine and battery storage. These sources are connected to a DC/DC boost converter for converting the DC voltage to an AC voltage through three-phase inverter. The considered objective function is formulated in terms of the current and voltage errors to enable the HRES to participate effectively within the connected micro-grid via optimal gains of the PID controllers. The results verify that the performance of the HRES is enhanced considerably by optimizing the parameters of the HRES controllers using the ASCA under several operating conditions of solar irradiation, temperature and wind speed.

Keyword: PID controller, Optimization, Renewable Energy System, Micro-grid, Sine Cosine Algorithm, Levy flight distribution.

1. Introduction

Due to the environmental problems and energy crises, the clean and renewable energy generation resources occupy significant priorities by several governments around the world [1]. Renewable energy projects are established around the world as main sources and the important sources of energy [2]. The world is seeking for renewable energy such as solar sun and wind turbine because don't make any pollution such as carbon dioxide [3]. The most common components in the HRES in this paper are the PV, wind turbine and battery storage have been connected with DC-DC boost converter, and Inverter is used to convert DC to AC power. Authors make an optimization for PID controller in the inverter by two types of optimization.

Power sharing among renewable energy resources requires robust controllers design for proper renewable energy injection to the main grid. Many of researchers are interested of algorithm at PID control in one source. At [4] authors are interested to one type of optimization algorithm in smart grid.

Authors are used binary sine cosine algorithm at [5] but don't use it in hybrid renewable energy source in micro grid. In [6], used hybrid renewable energy and one type of algorithm. In [7], authors used one type of optimization algorithm at hybrid PV and wind energy sources. In [8], analysing wind turbine at variable renewable energy has been interested. One type of algorithm is used at [9]. PV to the grid connection with one type of optimization was reviewed at [10]. Energy storage in hybrid renewable source was reported [11] but don't use any optimization at it. The authors in [12] has presented an optimal design of the Proportional–Integral (PI) using Harris Hawks Optimizer (HHO) for load frequency control with renewable energy systems. In [13] the parameters of the PID has been assigned optimally using PSO with for load frequency control under large-scale photovoltaic farms. In [14] Salp swarm algorithm has been applied fractional-order proportional integral derivative for load frequency control containing Electric vehicles (EVs). Annamraju and Nandiraju [15] determined the optimal parameters of the PID controller using Jaya algorithm considering Plug-in Hybrid Electric Vehicles (PHEVs) and renewable energy resources. X. Zhao et al. [16] proposed a predictive optimal proportional integral differential plus second order derivative (PO-PID + DD) for load frequency control considering photovoltaic and wind power.

Many researchers and this entire works were interested in one problem or two problems in hybrid renewable sources with optimal PID controller. But in this work authors used SCA and the modifying type of its (LSCA) optimization in hybrid Photovoltaic, wind turbine and battery. This encourages the authors of this work to develop optimization techniques to delimit the PID controllers scaling factor for robust inverter operation.

Normally, voltage and current controllers are used for renewable energy grid connected systems. Thereafter, six PID gains are obtained. In this paper, two advanced optimization techniques SCA and LSCA are compared to get the best enhancement of the results from the modify optimization.

The PID controller is by the most common control algorithm, the PID algorithm can be approached from many different directions. Many of industrial control system at [17] use the PID control. This paper presents the optimal PID controller design by two advanced optimization techniques; a novel population-based optimization algorithm called Sine Cosine Algorithm (SCA) for solving optimization problems. Optimization techniques used to find the parameters that provide the maximum or the minimum value of a target function. SCA is used in this paper to get the solution in the six gain, (Kp, Ki, Kd) in current control and (Kp, Ki, Kd) in voltage source control, compare the results with a modify sine cosine, Levy flight distribution (LSCA).

Sine Cosine Algorithm (SCA) technique is a new population-based optimization technique proposed by S. Mirjalili [18]. in SCA a random population are produced then their positions are updated in sine cosine path around the best obtained position. Several random and adaptive variables in this algorithm are integrated. The SCA algorithm obtains a smooth shape for the air foil with a very low drag, which demonstrates that this algorithm can highly be effective in solving real problems with constrained and unknown search spaces.

The Levy flight theory is a random process proposed by French mathematician Paul Levy. The Levy flight is a random walk class or a random movement [19]. The levy flight can enhance performance algorithm significantly by improving the global search ability and the exploration capability in other hand avoid the optimization algorithm to stuck in local minima. Recently, the levy flight is widely use in meta-heuristic optimization algorithms such as moth flame algorithm [20], Ant Lion Optimizer [21], biogeography-based optimization algorithm [22], krill herd algorithm [23], Artificial Bee Colony [24], Cuckoo Search algorithm [25].

The main contributions of this paper can be summarized as follows:

- The optimal parameters of PID controllers are determined optimally for a hybrid renewable energy system (HRES).
- The proposed HRES includes a photovoltaic (PV) source, wind turbine and battery storage connected to grid through DC/DC converter and DC/AC inverter
- A new Adaptive Sine Cosine Algorithm (ASCA) is proposed based on the Levy flight for enhancing the searching capability of the traditional SCA.
- ASCA is applied to find the optimal gains voltage source controller and current controller of the DC/AC inverter.
- The system performance is investigated under the optimized parameters of the PID controllers.
- An investigation is performed related to the system performance under variation of solar irradiance and wind speed and a comparison between the traditional SCA and ASCA is carried out to verify the validity of the proposed algorithm.

The rest of paper is arranged as follows: Section 2 presents the structure of the hybrid renewable energy system including the modelling of the PV System wind turbine and battery storage. Section 3 presents an overview of the SCA. Section 4 illustrates the concepts and the step procedure of ASCA. Section 5 explain the problem formulation the simulation results are discussed in Section 7. Finally, the conclusion of paper is depicted in Section 7.

2. Structure and Modelling of The Proposed System

Fig. 1 shows the HERS generation system under consideration. The HRES consist of PV system, wind turbine generation system, rectifier, battery storage, boost-converter, DC link, three phase inverter, controller, filter, high transformer, and the utility grid and AC loads. Normally, an inverter is employed to change form the DC side to the grid the utility grid side. Besides, the DC side renewable resources are connected at a point of common coupling via DC-DC converters. The HRES in this research consists of three resources connected in parallel: the PV, Wind turbine and battery storage system.

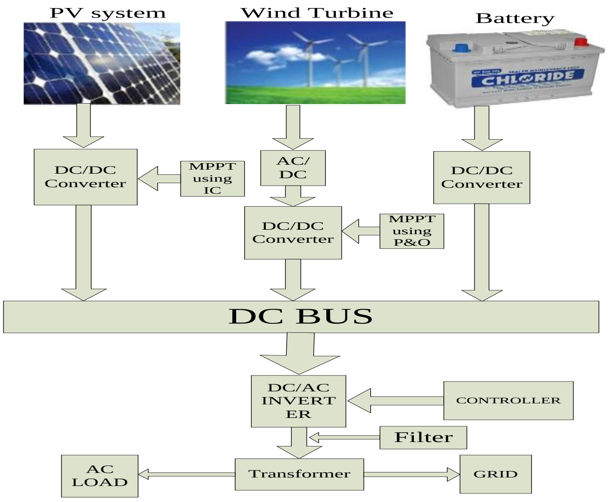
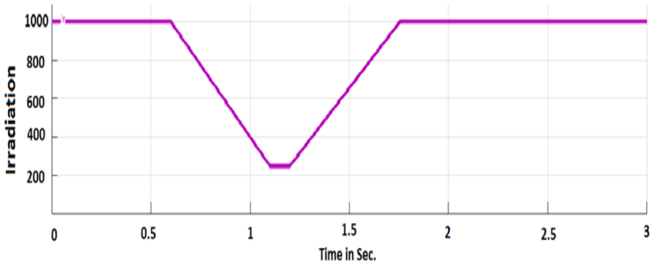


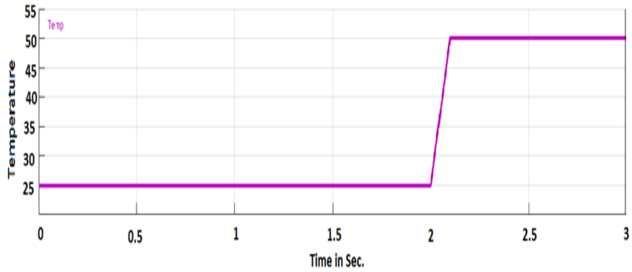
Fig. 1. Hybrid renewable energy generation system configuration.

2.1. PV System

PV energy system provides the direct method to convert solar energy or sun light into electricity [26]. PV is working with different conditions, changing the irradiance and changing the temperature seen that illustrated in Fig. 2. This changing of conditions affects to the input and output power.



(a)



(b)

Fig. 2. (a) Changing irradiation of PV and (b) Changing Temperature for PV array.

2.2. Wind Turbine

Wind speed (Wind profile) is the important factory of affecting of wind turbine [27]. Changing of the power at wind turbine is reason for changing of conditions of wind speed. Wind profile is shown in Fig.3.

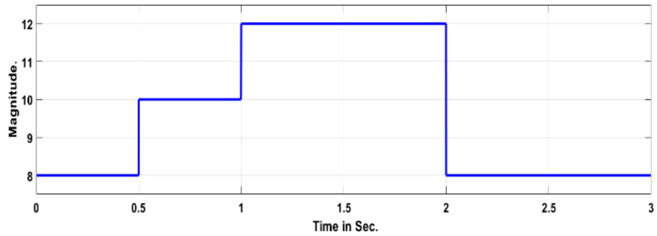


Fig.3. Wind profile for wind turbine.

2.3. Battery Storage

Electric energy generated from renewable sources depends on changing weather conditions such as wind speed and sunlight. Power Storage is the key concerns worldwide when developing the HRES [28]. PV panels work in sun light at all days and wind turbine work in all the best of time the conditions allow to it. Because intermittent nature of renewables, A battery storage is utilized to get the power demand to the grid and the loads connect with the system. The type of the used battery is Ni-MH battery connected to a DC-DC boost converter.

2.4. DC-DC Converter

The maximum power from the hybrid renewable generation resources voltage level is raised to a suitable level, then transferred to the three-phase inverter and to the grid or AC load through DC-DC converter [29]. Therefore, a DC-DC boost converter is utilized. The output voltage can be expressed as the next equation. The topology of boost converter is shown in Fig. 4.

$$V_o = {}^{V_S}\!/_{(1-D)} \qquad (1)$$

where, D is the duty ratio, V_S is voltage source and V_o is output Voltage.

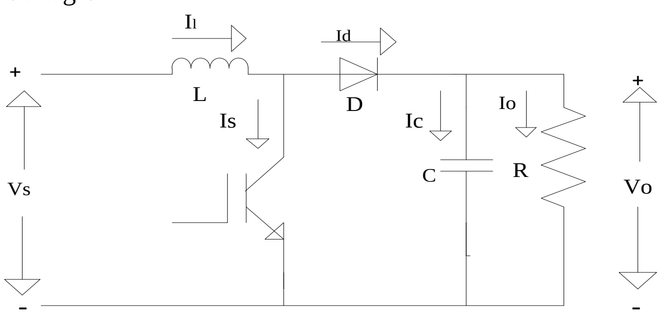


Fig. 4. DC-DC Boost Converter.

2.5. PID Controller

In this paper used two types of optimization for PID controller in three phases (DC-AC inverter) for voltage source controller and current controller with d-axis, q-axis, which equal to zero. To convert three phase a, b, c to α, β, γ to control in d-axis, q-axis. Use PLL in [30], make easy control in this method. To control in the three-phase inverter is used PID controller and make three types of optimal PID controller. The block diagram shows the operation of controlling in inverter which has been shown in Fig.5. Current regulator (current control) has a gain PID controller which has been shown in Fig.6. Voltage source control has a gain PID controller, which has been shown in Fig.7.

PID has three constant parameters K_p for proportional, K_i for integral and K_d for derivative control. PID controller is a simple method to get. Furthermore, any method of optimal feedback control can be used [31]. Fig. 8 shows a block diagram of the internal structure of the PID block. The summation of three terms adjusts the process through a control element as in (2).

$$G(s) = K_p + \frac{K_i}{s} + K_d s \qquad (2)$$

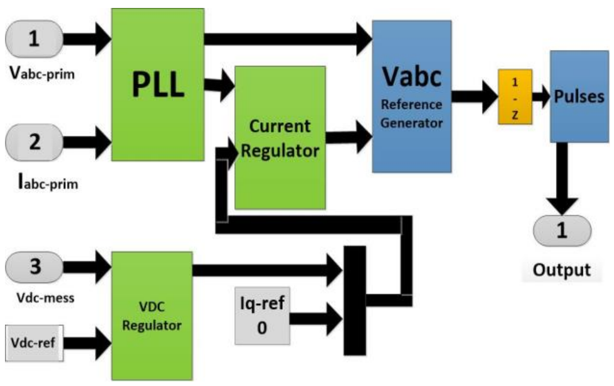


Fig.5. Block of controller in inverter of the system.

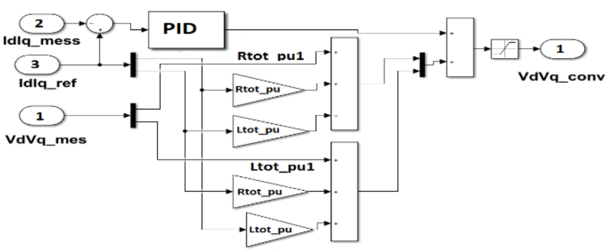


Fig.6. Matlab image for current controller.

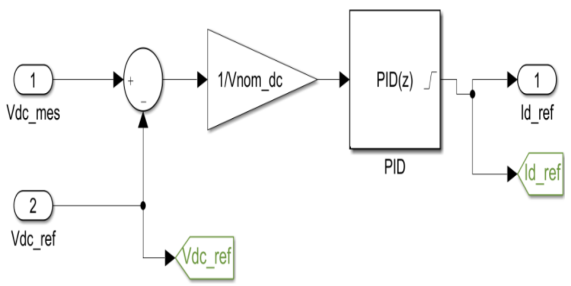


Fig.7. MATLAB image of voltage source controller.

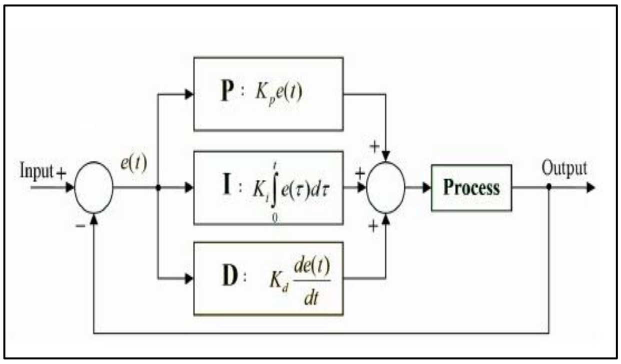


Fig. 8. Internal structure of PID block.

3. Sine Cosine Algorithm (SCA)

SCA is an efficient algorithm which is conceptualized from the sine and cosine function trends [18-32]. The orientation of the search agents around the best solution with iterative process based on sine cosine trends is depicted in Eq. (3) as follows:

$$X_i^{t+1} = \begin{cases} X_i^t + C_1 \times sin(C_2) \times \left|C_3 X_{best}^t - X_i^t\right| & C_4 < 0.5 \\ X_i^t + C_1 \times cos(C_2) \times \left|C_3 X_{best}^t - X_i^t\right| & C_4 > 0.5 \end{cases} \qquad (3)$$

where, t denotes the iteration number. X_{best}^t denotes the best location from the search agents. C_2, C_3 and C_4 denotes to random variables within [0, 1]. C_1 represents an adaptive factor can be given as follows:

$$C_1 = k - t\frac{K}{T_{max}} \qquad (4)$$

where, k denotes a constant number. T_{max} denotes the iterations maximum number. Fig. 9 shows motion of the search agents or the populations around the best solution. It should be point out here that C_1 can regulate the new position of the populations to go inward or outward the best solution as depicted in Fig. 10.

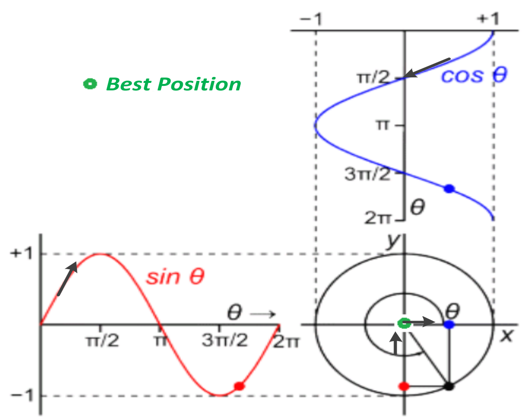


Fig. 9. Movement of populations around the best solution [33].

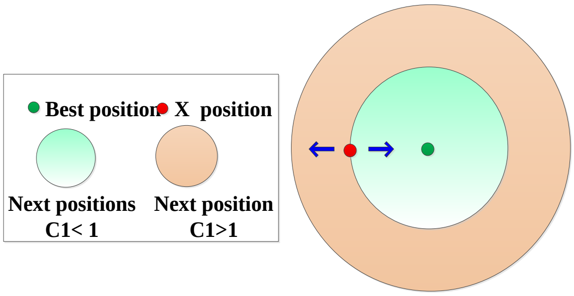


Fig. 10. Movement of the new populations based on C_1[33].

4. Adaptive Sine Cosine Optimization Algorithm (ASCA)

ASCA is a new version of the SCA to overcome its stagnation. in the ASCA, the Lévy flight distribution (LDF) is utilized to improve the algorithm exploration ability where it enables the populations to jump to new areas. The new population position that is based on Lévy distribution can be found as follows [34]:

$$X_i^{new} = X_i + \propto \oplus\, Levy(\beta) \tag{5}$$

where, $\propto$ denotes a random step size factor. $\oplus$ represents the multiplication of entry wise while β denotes a LDF. The step size is calculated given as:

$$\propto \oplus\, Levy(\beta) \sim 0.01 \frac{u}{|v|^{1/\beta}} (X_i^t - X_{best}^t) \tag{6}$$

where, u and v denoted variables obtained by normal distribution as follows:

$$u \sim N(0, \phi_u^2), v \sim N(0, \phi_v^2) \tag{7}$$

$$\phi_u = \left[\frac{\Gamma(1+\beta) \times sin(\pi \times \beta/2)}{\Gamma[(1+\beta)/2] \times \beta}\right]^{1/\beta}, \phi_v = 1 \tag{8}$$

where, Γ represents the gamma function while, $0 \leq \beta \leq 2$. For improving the exploitation phase of the SCA, the best solution is updated using bandwidth variable according to (9).

$$X_{best}^{new} = X_{best}^t \pm C_5 \times K_w \tag{9}$$

where, C_5 denotes to a random number within range [0, 1]. K_w denotes a variable bandwidth which is reduced dynamically as follows:

$$K_w = K_{max} e^{(E \times t)} \tag{10}$$

The flowchart of ASCA has been shown at Fig.11.

5. Problem formulation

In order to obtain the PID gains, a time domain objective function is formulated in terms of the voltage and current errors, authors make a comparison between these different variables, to get the best solutions and best optimization for the value of output power and current and voltage and current controller and inputs and outputs. The objective functions between the voltage, error of voltage and current, error of current at the model Simulink of VSC and current control.

$$Minimize\ F = \int_0^T (|V - V_r| + |I - I_r|)\, dt \tag{11}$$

To get the minimum and the maximum of the six gains are subjected to:

$$\begin{cases} K_{p,I}^{min} \leq K_{p,I} \leq K_{p,I}^{\max} \\ K_{d,I}^{min} \leq K_{d,I} \leq K_{d,I}^{\max} \\ K_{i,I}^{min} \leq K_{i,I} \leq K_{i,I}^{\max} \\ K_{p,V}^{min} \leq K_{p,V} \leq K_{p,V}^{\max} \\ K_{d,V}^{min} \leq K_{d,V} \leq K_{d,V}^{\max} \\ K_{i,V}^{min} \leq K_{i,V} \leq K_{i,V}^{\max} \end{cases} \tag{12}$$

6. Results and Discussion

In this section ASCA is applied to determine the optimal settings of the PID controllers of the hybrid renewable energy system (HRES). The parameters of the HRES are depicted in Table 1. The selected parameters of the ASCA are set to be 50, 20 and 10 for the maximum number of iterations, search agent numbers and K_{max}, respectively. The upper and lower limits of the PID gains are depicted in Table 2. The optimal gains of the controller that obtained by applying the ASCA and SCA are tabulated in Table 3. Fig. 12 shows trend of objective function with ASCA and SCA. according to Fig. 12, It is clear that ASCA has well and stable convergence performance while SCA converged rapidly to the local optimal solution which means SCA suffer from stagnation.

Table 1. Characteristics the System

Paramter	Value
P_{wind}	69.7KW
P_{PV}	45KW
$P_{Battery}$	22KW
V_{dc}	500 Vdc

Table 2. the Upper and lower ranges of the PID gains

Gain	Lower limit	Upper limit
$K_{p,I}$	0	0.5
$K_{d,I}$	0	0.5
$K_{i,I}$	0	0.5
$K_{p,V}$	0	10
$K_{d,V}$	700	850
$K_{i,V}$	0	0.5

Table 3. Optimal PID giants of the HRES controllers.

Type	Current controller			Voltage Source Controller		
	$K_{p,I}$	$K_{d,I}$	$K_{i,I}$	$K_{p,V}$	$K_{d,V}$	$K_{i,V}$
SCA	0.1941	2.048e-07	3.809e-05	4.9172	796.022	7.5674e-05
ASCA	0.1917	2.048e-07	1.000e-04	4.9989	794.054	9.9975e-05

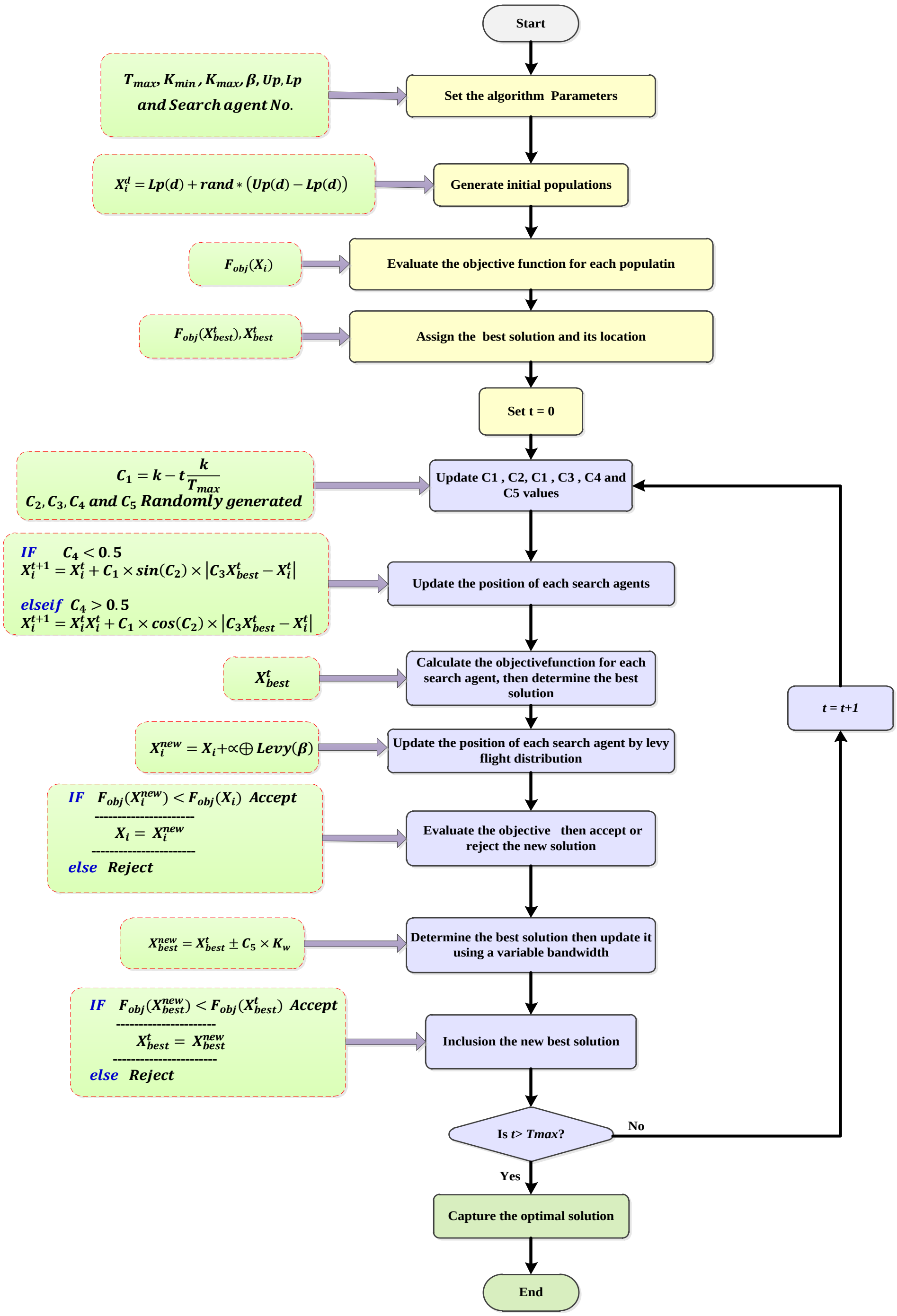


Fig.11. Flowchart of ASCA

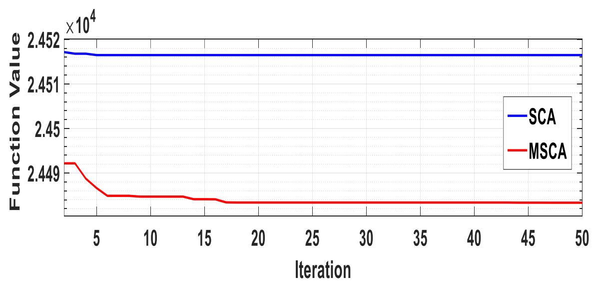
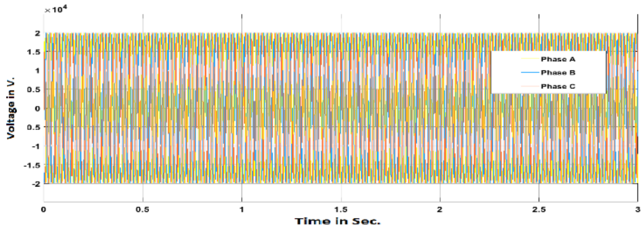
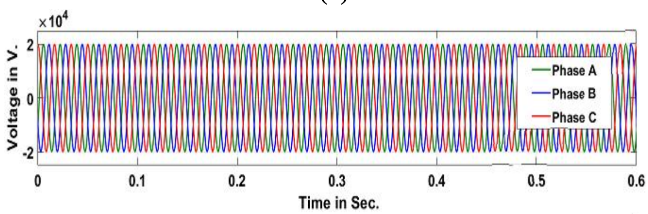


Fig.12. Objective function trend with SCA and ASCA.

The inverter output voltage to the three-phase grid is illustrated in the Fig. 13.a and b. The grid injected current via the developed controllers is shown in Fig. 14, 15. These figures give output current in two types of optimization technique SCA and LSCA respectively. From these figures, LSCA technique gives good results when compared SCA algorithm. We made zoomed to the Fig.s 14.b and 15.b, from (0 to 0.6 sec.) Output current using SCA in fig.13.b, have a ripples at the beginning of the time. But at the optimization LSCA in Fig.14.b, do not have any ripples. Give these results when the conditions of wind speed for wind turbine and irradiation and temperature for solar sun. The developed type of optimization (LSCA) responds quickly to the changing the conditions of the sources compared with PSO algorithm.

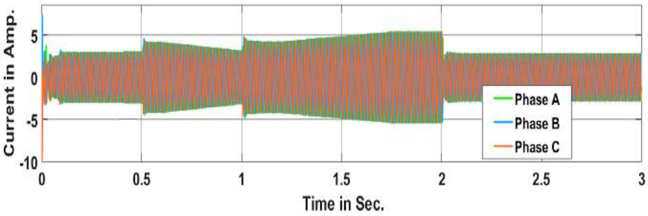


(a)

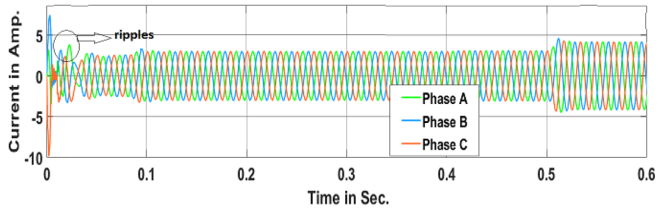


(b)

Fig. 13. Utility grid voltages

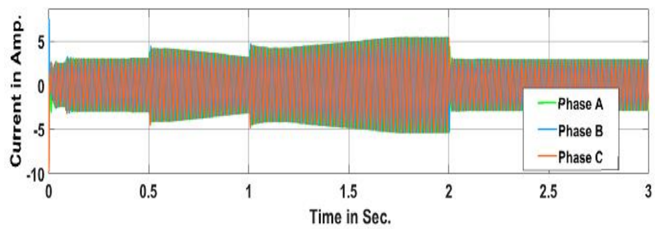


(a)

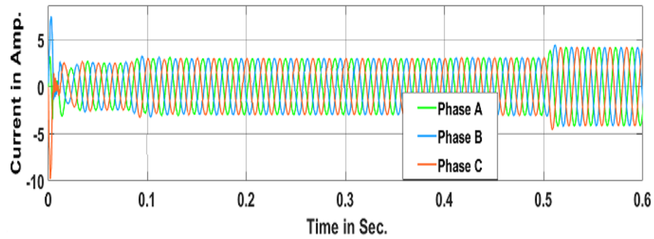


(b)

Fig. 14. (a) Output current to the grid using SCA and (b) Zoomed at Fig. 14. (a).



(a)

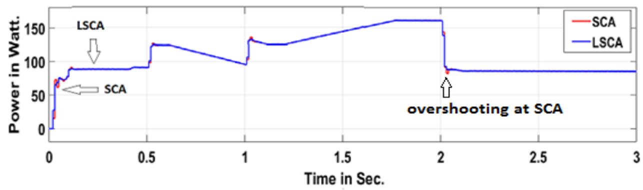


(b)

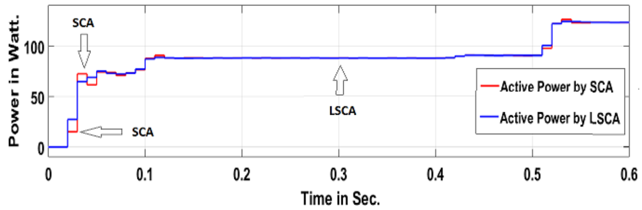
Fig. 15. (a) Output current using ASCA and (b) Zoomed part

The grid injected power via the developed SCA and LSCA optimization is demonstrated in Fig.16. a. The LSCA respond satisfactorily for all changes of the wind speed and the irradiation. However, the SCA shows unsatisfactory results at the beginning the time at the Fig.16.b, since it doesn't respond well for the wind speed and the irradiation changes when compared it with another optimization LSCA.

The d-axis grid injected currents by applying the SCA and LSCA are shown in Fig. 17 and Fig. 18, respectivly. The SCA algorithm technique tracks the reference current but at the cost of the settling time. Still the SCA shows unsatisfactory results at the steady state and transient conditions at the beginning controlling shows ripples in Fig. 16.b. The developed LSCA shows adequate results to track the reference current and its robustness was proved.



(a)



(b)

Fig.16. (a) Output power using two types of optimization techniques and (b) Zoomed at Fig. 16. (a).

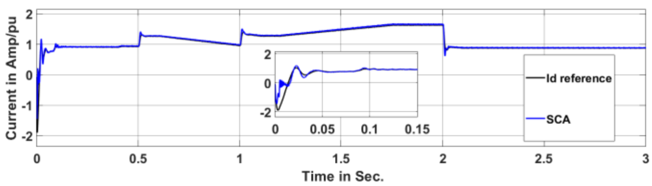


Fig. 17. Injected Current control with application SCA

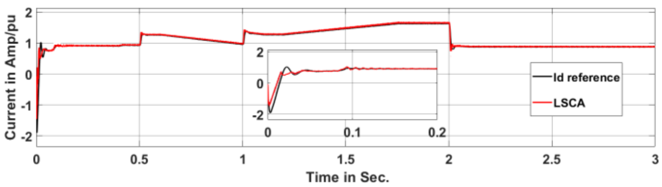


Fig. 18. Injected Current control with application ASCA

Fig. 19 shows the PV output of power for the developed optimization technique SCA and LSCA. At the beginning the time, there are ripples by using SCA technique. At the time (2 sec.) there are ripples by using SCA compared the developed optimization technique LSCA is a straight line and the result with it is good. The wind turbine output power is shown in Fig. 20. Yet, the SCA shows the worst performance compared a developed optimization technique. SCA has more overshooting and ripples at time (sec.1 and sec.2). The developed LSCA give acceptable results with diminished ripples to track reference line compared to the SCA algorithm and its robustness was verified in HRES.

The battery power is shown in Fig. 21. The SCA shows unsatisfactory results at the long-term operating conditions, at the beginning the time PSO is bad. Initially, the SCA technique shows longer settling time with limited over/undershoots compared to the LSCA. Still, the developed LSCA give satisfactory results with the shortest settling time.

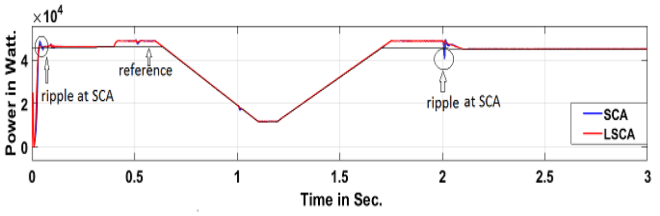


Fig. 19. Output power from PV.

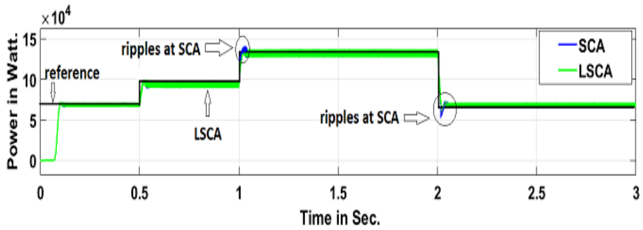


Fig. 20. Output power from wind turbine.

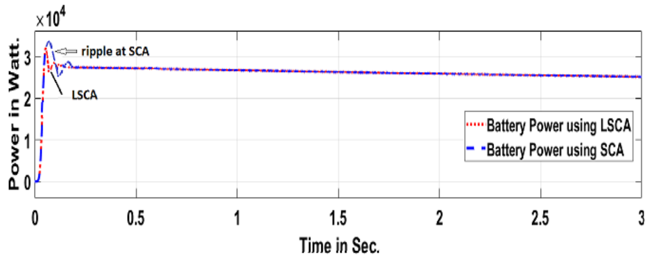


Fig. 21. Output power from battery storage.

7. Conclusion

In this paper the performance of hybrid renewable energy system (HRES) is enhanced by optimizing its PID controllers setting. The HRES includes a PV, wind turbine and battery storage system connected to a three-phase grid. an Adaptive Sine Cosine Algorithm (ASCA) was proposed which based on enhancing the performance of the traditional Sine Cosine Algorithm (SCA) based on the Levy flight distribution and adaptive transition. The optimized objective function considered the current and voltage errors simultaneously. The obtained results verified that:

- The optimal parameters of the PID controllers of the HRES have been determined efficiently using the ASCA.

- The optimal design of PID controllers enhance the performance the system where the fluctuations of the output voltage, current and power have been alleviated considerably.

- ASCA is superior for assigning the parameters PID controller in terms of the objective function and the convergence characteristics.

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