Improving the Performance of Photovoltaic by Using Artificial Intelligence Optimization Techniques

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Abstract- Photovoltaic (PV) systems are taking a leading role as a solar-based renewable energy source (RES) because of their unique advantages. This trend is being increased in the field of Seawater desalination. This paper presents a study on the Seawater Desalination Plant (SWDP) located in Egypt feeding from the utility network. The main challenge in such a non-linear system with a high level of variability is the optimum sizing of the SWDP with the proposed whole solar-powered while keeping good dynamic performance. In this article, a solid electrical load analysis is presented to assess the optimal design of SWDP fed by the PV system. Moreover, optimal maximum power point tracking controllers (MPPTCs) are developed to enhance the dynamic performance of SWDP fed by the PV system. To accomplish this study, a real grid connected seawater desalination plant located in Egypt is implemented. The selected SWDP is producing 700 m3/day. The real experimental data of the plant were extracted through daily readings of electricity consumption and water production meters. This experimental data is then introduced to the HOMER program to suggest the optimal components of the PV system based on the minimum net present cost. The developed power plant consists of a Photovoltaic (PV) array, DC/AC converter, load and grid. Also, to tackle the challenge of the low conversion efficiency of the PV system, three MPPTCs are investigated to improve the dynamic performance of the proposed SWDP fed by the PV system. Incremental Conductance in conjunction with three artificial intelligence (AI) optimization techniques (Particle Swarm Optimization, Grey Wolf Optimization (GWO) and Harris Hawks Optimization) is developed for the assessment of the dynamic performance of the presented SWDP fed by PV. The system was constructed, modeled and simulated through MATLAB/SIMULINK. The attained results of the three methods are promising in extracting the maximum power with minimum error from the PV system while improving the performance of SWDP. The obtained simulation, as well as experimental results, proves the efficacy of the suggested optimal design strategy.

Keywords- Microgrid. Renewable energy. System Planning. HOMER Software. Optimization.

1. Introduction

The use of fossil fuels as the main source in the production of electrical energy has resulted in a large increase in carbon dioxide emissions as well as a dramatic rise in fuel prices. Recent research works presented renewable energy sources (RESs) to become the most alternative solution for electricity production from natural resources. The increased energy production cost from RESs compared to fossil fuels encourages scientists in conjunction with the industry to develop more competitive materials and technologies to reduce the electricity production cost of such resources. As a result of this industrial revolution, electricity production from solar cells had been decreased by more than 99.6% from 1976 until 2019 [1]. Thanks to modern technology that had decreased the cost of energy production from RESs, but the question still exists on how to size such systems optimally while preserving a good dynamic performance. Jamalaiah used HOMER software to achieve the best cost through grid connected photovoltaic (PV) array systems with different energy storage methods like batteries and hydrogen production [2]. The author of [2] concluded that the most economical solution to achieve minimum cost is the use of a hybrid storage strategy. Hossein Shahinzadeh examined the cost analysis for an on-grid hybrid power system (HPSs) consisting of a PV / wind turbine, storage batteries and diesel generator (DG) [3].The study is devoting to compare between different systems to select the minimum total net present cost (NPC) by using the HOMER package tool. Jagriti Kumari presented standalone hybrid RESs-based microgrid with storage batteries and DG [4]. The authors had developed three systems and selected the system with the minimum cost per kWh. Also, the savings in carbon dioxide emissions were calculated using HOMER software. After achieving the techno-economic optimal sizing of the whole system using HOMER, the most challenging issue is how the PV system will behave under partial shading conditions and environmental conditions continuous changes. M. Abdulkadir studied the effect of partial shading on the PV system using particle swarm optimization (PSO) based incremental conductance (IC) method [5]. The authors suggested an improved variant of PSO by increasing the size of the swarm to increase the speed of particle search during the initial search. The authors used the IPSO to change the value of the duty cycle for getting the maximum power point (MPP). The authors concluded that the convergence speed of the proposed method is high; the tracking speed of the IPSO technique is better than that of IC and also, the tracking accuracy of the proposed technique is superior to that of the IC technique. Mohamed I. Mosaad and M. Osama abd el-Raouf presented the maximum power point tracking (MPPT) system using a cuckoo search optimization technique [6]. This algorithm is compared with other methods such as IC based on artificial neural networks (ANN). Results show that cuckoo is capable of tracking the MPP efficiently and greater than IC-based ANN. Moreover, in the cuckoo search method, no further fluctuations exist in the system output. T.R. Premila had studied twenty-one techniques that use MPPT in PV systems [7]. The results show that the best technique in this search is hybrid perturb and observe (P&O) using a grey wolf optimizer (GWO) for achieving better and faster-tracking speed and convergence speed. Saied. A. Osman illustrates the comparison of some techniques to get the optimum gains by integral time square error (ITSE) [8]. The results show that the GWO provides good results, where the value of the average power has increased from 158.7 kW to 161.9 kW. Eid A. Gouda proposed two techniques: P&O and IC based on PSO [9]. The results of the proposed techniques are better in terms of power loss, high tracking speed, less time and minor oscillations than the other conventional techniques. Yihao Wan proposed combining the salp swarm algorithm (SSA) and GWO (namely, SSA-GWO) [10]. The results showed that the technique had succeeded in achieving accurate performance with a reduction in energy consumption. Abed el-Raouf, M. Osama, et al. presented an MPPT of PV - wind - fuel cell (PV – wind - FC) of an off-grid hybrid system for a new community [11]. The results show that the proposed system succeeded in feeding the AC community loads with maximum power from three-generation sources (PV-wind-FC). Mosaad, Mohamed I., et al. studied an optimal PI controller of dynamic voltage restorer (DVR) to enhance the performance of a hybrid renewable power system feeding a remote area in Egypt [12]. The integration of the three controlled DVR proposed into the off-grid hybrid power system keeps the continuous operation of the three renewable power sources even at faulty conditions. Han Huang, Noel Bristow studied of a single-diode based computational PV model for organic photovoltaic cells. The results through the Matlab program showed accurately, with a maximum error of 3.9%. The experiment on two different days on larger module including 512 cells a maximum error of 5.9% [28]. Animesh Masih, H K Verma, proposed optimization and reliability analysis of renewable energy system for farm house electricity and irrigation load demand located at remote area. The authors propose a three different optimization techniques used for selecting the best configuration The results the optimal system is PV-Wind-battery energy system in terms of economic and reliability in remote areas [29]. I. Tegani and A., M. Becherif, M.Y. Ayad studied sizing optimization of a stand-alone hybrid wind/PV/diesel energy system with battery storage. The system is optimized using genetic algorithms and the formulation of the problem is detailed. The results verify that hybrid PV-wind generator-Diesel systems result in lower system cost compared to cases where either only wind generator-PV sources are used [30]. Mahmoud Saleh, Yusef Esa studied a new approach to find the optimal location for Microgrids in the electric distribution systems using complex network analysis. Results show an optimal location in this paper refers to a location that would result in increased grid resilience, reduced power losses, less line loading, higher voltage stability and secured supply to critical loads during power outage [31]. Jaber A. Abu Qahouq, Yuncong Jiang studied the results of a series-output-connection MPPT (SOC-MPPT) controller for sub- module integrated converters architecture using a single sensor at the output and a single digital MPPT controller (sub-MIC SOC MPPT controller and architecture). Results show decrease in the cost of the controller technology and power converter technology will naturally reduce the cost difference further [32]. In this context, the major contributions of the presented article can be summarized in the following main points: a) Experimental measurements of real seawater desalination plant for both water and energy consumption over one year had been performed, b) Different alternative scenarios had been proposed for the use of renewable energy to select the best techno-economic proposal based on the min. cost through HOMER c) Three optimization methods were conducted to improve the efficacy of MPPTCs for the PV system. The research work in this paper is divided into three-manifolds: firstly, the power data for the real SWDP through daily readings of the measuring meters and their analysis to obtain the energy (kWh/year), peak load (kW), average load (kW) and the average (kWh/day) are obtained. Secondly, HOMER software is employed to get the optimal sizing of the system based on minimum NPC. Thirdly, new versions of MPPT techniques based on modern optimization techniques are developed and tested to select the best technique to get the optimal performance for PV array. This research work is authored into the following sections: system described in in section (2). Section (3) shows the modeling of the PV array. Section (4) presents the incremental conductance techniques. In section (5), applicable of Artificial Intelligence Optimization Techniques are studied. In section (6), a real case study is investigated. In section (7), the system is constructed using MATLAB/SIMULINK. In section (8), results and discussion are presented and section (9) presents the conclusion.

2. System Description

The overall system can be described, as shown in Figure 1. According to SWDP electrical loads, it consists of four high-pressure pumps, four deep-water pumps, four chemical treatment pumps and water tanks. This plant is operating in two stages, as demonstrated in Figure 1.

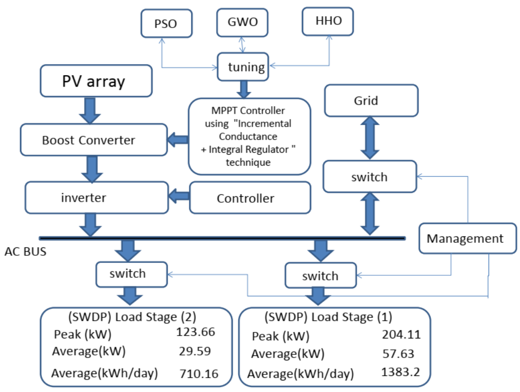

Fig. 1. Block diagram of the system under study

3. Modelling for the PV Array Description

The commonly adopted equivalent circuit diagram that fits to measured current-voltage characteristics of a crystalline-silicon PV module is the so-called one-diode model is shown in Figure 2.

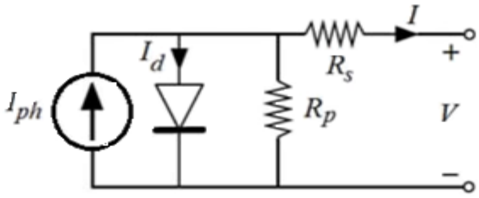

Fig. 2. Photovoltaic equivalent circuit

The output current of the module can be described as the following equations:

$$I = [I_{ph} - I_d - I_{sh}] \quad (1)$$

where, I is the load current, I_{ph} is the current generated by the irradiances, I_d is the diode current, I_{sh} is the shunt current.

$$I = (I_L N_P) - (I_d N_P) - (I_{sh} N_P) \quad (2)$$

$$V = (AV_t N_s) \ln \left[\left(\frac{(I_L N_P) - I - (I_{sh} N_P)}{(I_S N_P) + 1} \right] - (IR_s) \quad (3)$$

where, I_s is reverse saturation current, V is the load voltage, V_t is the thermal voltage of the PV module having N_s, N_p cells connected in series and parallel, A is the ideality factor and R_S, R_{sh} are series and parallel resistances, respectively [13, 14, 15].

4. Incremental Conductance Technique

This method is based on the fact that the slope of the power-voltage (P-V) curve of the generated source is positive on the left of the MPP and is negative on the right of the MPP and equal zero at the MPP [16,17,18]. Figure 3 shows the current-voltage (I-V) and P-V characteristics of a PV module.

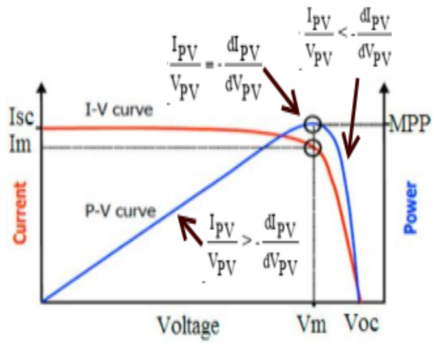

Fig. 3. I-V and P-V characteristics of a PV module

Maximum power point tracking by the incremental conductance method is to increase contrast the ratio of the derivative of conductance with the instantaneous conductance as the following equations. A maximum power point (MPP) is obtained when:

$$\frac{dP_{pv}}{dV_{pv}} = 0 \quad \text{where,} \ P = V \times I \quad (4)$$

where: dI_{pv}, dV_{pv} are the fundamental components of I and V ripples measured, I_{pv}, V_{pv} are the mean values of voltage and current. The integral regulator minimizes the error.

$$\text{error} = \frac{dI_{pv}}{dV_{pv}} + \frac{I_{pv}}{V_{pv}} \quad (5)$$

Regulator output = Duty cycle correction

where dI_{pv}, dV_{pv} and dP_{pv} are the change in PV current, voltage and power, respectively [19]. The driven error of the equation (5) is minimized by employing the PI controller tuned by the following optimization techniques PSO, GWO and HHO.

5. Artificial Intelligence Optimization Techniques

To improve MPPT for PV system control, three methods of optimization techniques were used for the assessment of the dynamic performance of the presented SWDP.

a. Particle Swarm Optimization.

PSO is a stochastic, population-based evolutionary algorithm (EA), modeled after the behaviors of bird flocks. [20,21,22].

b. Grey Wolf Optimization.

Grey wolves are considered predators; they often prefer to live in herds, where the group size is around 5 to 12 herds, which has a hierarchy. The mathematical model is in [23,24].

c. Harris Hawks Optimization.

Harris hawks suddenly fly in different directions to chase prey. Prey is tracked based on movement with different dynamic patterns and behaviors that can be simulated using algorithms and artificial intelligence. The position vector of hawks is proportional to iterations, the position of rabbit, current position vector of hawks and the energy of a rabbit. Symbolic equations and more details are illustrated, as shown in [25, 26].

6. Real Case Study

This research presents a proposal to study the construction and implementation of a renewable solar power plant to feed a seawater desalination plant to produce 700 m3/day at Mirette Touristic village allocated in the Red Sea in Hurghada - Egypt (Latitude: 27° 14.6’ N, Longitude: 33°, 50.3’ E). The existing SWDP was installed in the mid of 2016. This plant consists of two stages of potable water production and work together at full load. Currently, this plant is fed from the utility network.

a. Daily measurements

Mirette company made measurements of water production and electricity consumption to know the efficiency of the SWDP plant. Installed meters for measuring water production and measuring the energy consumption for each phase separately to know the efficiency of the plant and the energy consumed to produce each cubic meter of water. Reading was recorded daily at fixed times and selected reading schedules for the whole year from January to December for 2017.

b. Electrical Load Analysis

Electrical loads are referred to as a desalination plant producing 700 m3/day. This plant consists of two stages to produce potable water. Each stage consists of several load pumps with high pressure to pass the saltwater through the filters to get potable water and several pumps that raise salt water from the deep hole near the beach. From the previous and current meter readings, the daily energy consumption and the amount of water produced every day were calculated. A table was obtained for each month during 2017. Measurement schedules for daily energy consumption and monthly water production have been simplified, as shown in Tables 1.

Table 1. Measurements of energy in the desalination plant

	Energy consumption (kWh)		
	Stage (1)	Stage (2)	Total
January	42560	22384	64944
February	36640	19960	56600
March	39680	15880	55560
April	46400	19520	65920
May	46068	23995	70062
June	30752	31365	62117
July	51840	24552	76392
August	38720	22936	61656
September	44000	20696	64696
October	46400	19520	65920
November	39680	15880	55560
December	40640	21568	62208
Total	503380	258255	761635

According to the daily measurement tables, annual Energy consumption (kWh/year), Peak value of load (kW), Average load (kW) through the year, Average Energy consumption per day (kWh/day) and load factor for each stage can be concluded as shown in Table 2.

Table 2. Measuring loads data

	Stage (1)	Stage (2)
Energy (kWh/ year)	503379.9	258255.1
Peak load (kW)	208.1	124
Average load (kW)	57.58	29.59
Average load (kWh/day)	1382	710.3
load factor	0.277	0.239

To obtain the daily load curve, the power consumption during the day was distributed 24 hours a day. The maximum value and the minimum load are deduced from the daily activities of the hotel. 30 May was selected as the maximum load value during the year for the first stage equals 208 kW, as shown in Figure 4.

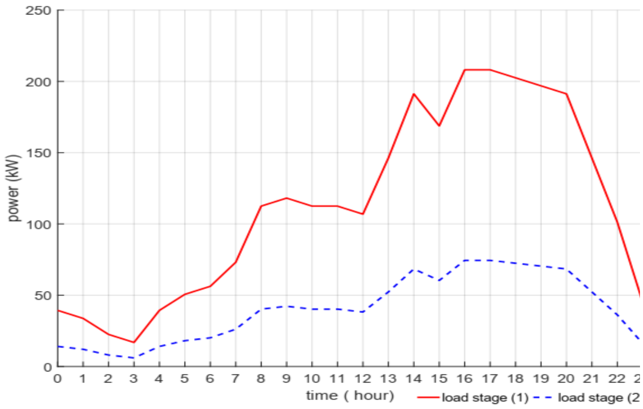

Fig. 4. Hourly load profile date: 30-5-2017.

However, the peak value of the load for the second stage equal to 124 kW on the 27th of November 2017, shown in Figure. 5.

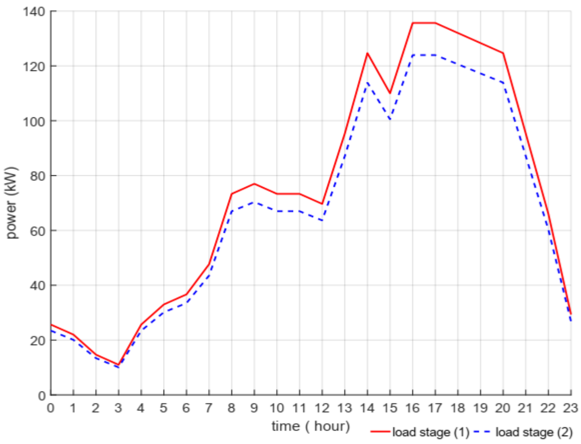

Fig. 5. Hourly load profile date: 27-11-2017.

7. System Model in MATLAB Simulink

a. System Model

The system model implemented using MATLAB Simulink for the PV system with the buck-boost converter and MPPT controller Model. The size of the components has been determined through the HOMER program. The system consists of a network, PV Array, load divided into two stages Peak load (1) = 204 kW and Peak-load (2) = 123 kW / 380 volt / 50 Hz, inverter, controller, grid and management as shown in the block diagram of the system under study.

b. PV array Characteristics

The system model implemented using 320.5-kW PV Array SunPower X21-335-BLK (Nser=5 Npar=191). Parameters of the PV module are shown in Table 3.

Table 3. The Parameters of the PV module (SunPower X21-335-BLK)

Symbol	Name	unit
Pmax	Maximum power	335.205 W
V_{oc}	open-circuit voltage	67.5 V
V_{mp}	voltage at maximum power	57.3 V
T	temperature coefficient of V_{oc}	-0.25 ^{O}C
N_{cell}	cells per module	96 cells
I_{sc}	short-circuit current	6.23 A
A	Diode ideality factor	0.96065
R_{sh}	shunt resistance	431.0177 Ω
R_{se}	Series resistance	0.51919 Ω

The output of the PV array is affected by the change in temperature degrees. The Figure shows the effects of voltage, current and power with a change in the temperature at (0, 25, 50 oC) at irradiance = 1000 W/m2 as shown in Figure 6.

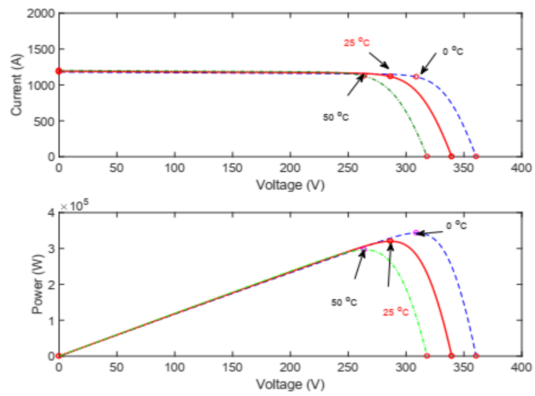

Fig. 6. Effects of changing the temperature at irradiance1000 W/m

The output of the PV array is also affected by the change in the irradiances and the Figure shows the power of the effect with the change of irradiances at (500, 1000 W / m2) at a temperature = 25 oC as shown in Figure.7

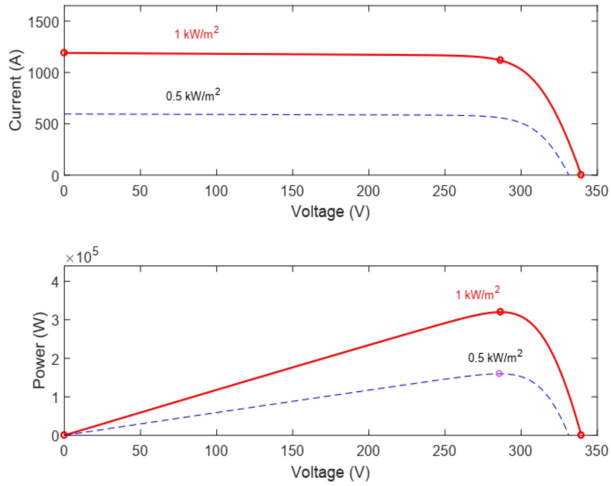

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Fig. 7. Effects of changing the irradiance at t = 25 oC.

After selecting the elements of the model system, and through the MATLAB–Simulink, the Figure shows the change in the output of the PV array with the change in irradiance (500-1000 W / m2) at a temperature of 25 degrees as shown in Figure 8.

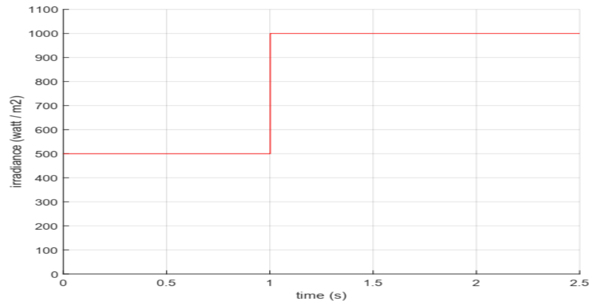

Fig. 8. Level irradiance implemented in MATLAB

c. *Optimization using MATLAB–Simulink*

Three AI techniques were employed as MPPT controllers, namely IC-PSO, IC-GWO and IC-HHO. The control algorithm is an IC-based PI regulator. The governing tuning criteria are Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE), Integral Time Square Error (ITSE) respectively. The overall methodology for minimizing error (i.e., objective function) can be depicted in the flow chart, as shown in Figure 9.

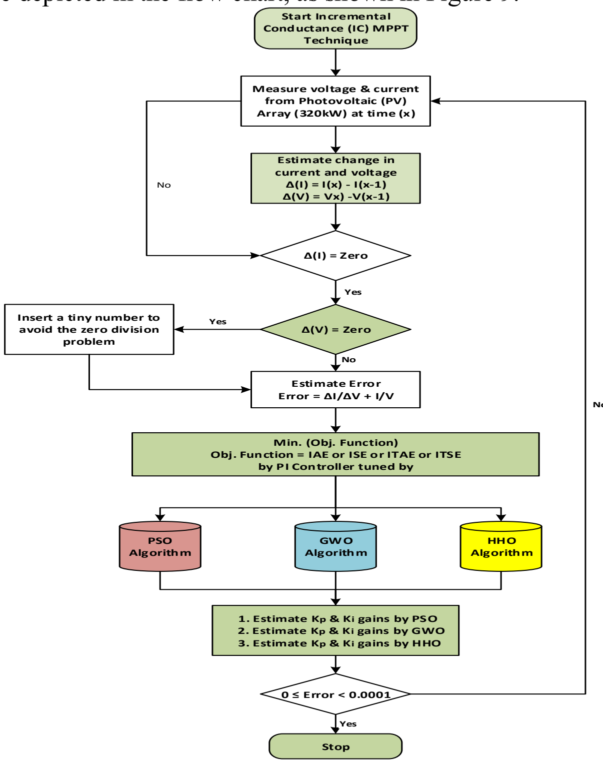

Fig. 9. Flow chart of IC-based PI tuned by AI techniques

The results were tabulated in Table 4 for each technique. From Table 4, it is obvious that ITAE performs best results as compared to other types of errors in terms of maximum power achieved for (PSO, GWO and HHO) and min error value occurred besides min. Overshoot, settling time and rise time. The summarized values for Kp and Ki in each technique can be clarified, as shown in Table 4.

Table 4. IC-Based PI controller gains different AI techniques

AI Type	iter no.	Error Type	P_{max}	Objective function	Overshoot	K_p	K_i
GWO	7	IAE	320.109	6.6E-06	4.291	0.2161	0.574
	6	ISE	320.107	2E-08	4.328	0.0933	0.8875
	5	ITAE	320.109	9.4E-08	4.38	0.1297	0.4389
	9	ITSE	320.107	1.3E-08	4.35	0.0808	0.8937
PSO	6	IAE	320.108	0.00321	4.388	0.4116	0.5836
	2	ISE	320.109	0.01539	4.397	0.1982	0.404
	3	ITAE	320.103	0.00107	4.381	0.729	0.3044
	4	ITSE	320.109	0.00802	4.284	0.2158	0.6649
HHO	9	IAE	320.101	0.00213	1.696	0.0016	0.0461
	3	ISE	320.109	0.00401	1.678	0.0033	0.0632
	1	ITAE	320.109	0.00277	4.42	0.0025	0.0526
	8	ITSE	320.109	0.00973	4.434	0.0119	0.0979

8. Results and Discussion

Controller gains (Kp and Ki) values from the previous table were tested and the best ones were selected for each technique, as shown in Table 5.

Table 5. Best gain value (Kp and Ki)

Technique	Criterion	K_p	K_i
GWO	ITAE	0.1297	0.439
PSO	ITSE	0.2157	0.665
HHO	ITSE	0.012	0.098

The system is optimized using PSO, GWO and HHO to get the optimal gain values (Kp and Ki). The error profile first oscillates from 0.5 s to 1.5 s for the HHO technique and then settles for the remaining period, while the PSO technique has a much smaller value of the error at the same time, but the error of GWO technique is even less than PSO technique as shown in Figure10.

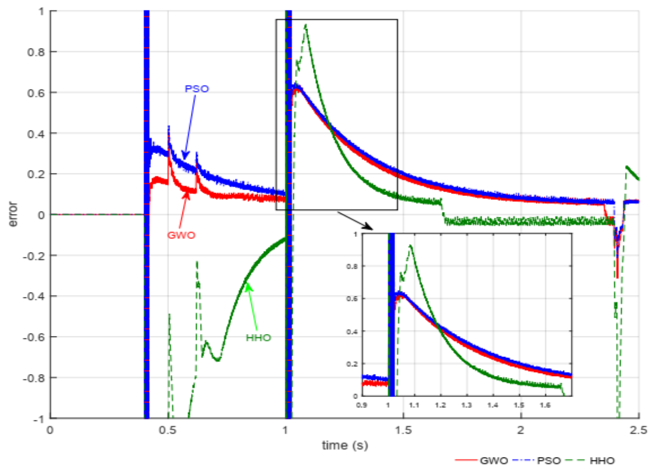

Fig 10. Error profile after using optimization techniques.

The power profile for HHO is a poor response, but still better than the base case. This drawback stems from that HHO is trapped into local optimum solutions during the tuning process. However, HHO has shorter calculation time for the same number of iterations. However, when using GWO and PSO techniques, the power waveforms are stable and better than the HHO technique, as shown in Figure 11.

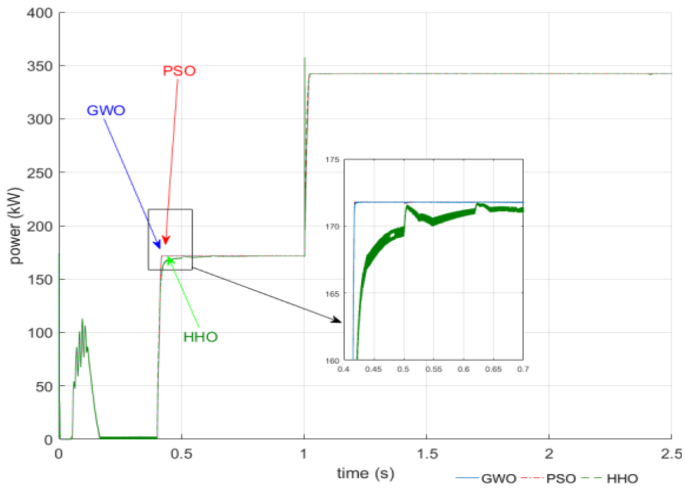

Fig 11. PV power profile after using (AI) optimization.

9. Conclusion

In this article, a solid electrical load analysis is presented to assess the optimal design of the seawater desalination plant fed by the PV system. Moreover, optimal maximum power point tracking controllers are developed to enhance the dynamic performance of SWDP fed by the PV system. To verify the efficacy of the proposed design approach, a real grid connected seawater desalination plant with a total producing capacity of 700 m3/day located in Egypt is constructed and implemented. The real experimental data of the plant were extracted through daily readings of electricity consumption and water production meters. The HOMER program is employed to suggest the optimal components of the PV system based on the minimum net present cost. Also, three MPPTCs are investigated to improve the dynamic performance of the proposed SWDP fed by the PV system. The system was constructed, modeled and simulated through MATLAB/SIMULINK. Three techniques of artificial intelligence were used to get the best performance of the PV Array. AI techniques, namely GWO, PSO, HHO. The techniques are compared before and after using the three techniques the result was unstable in the case of using the HHO technique. A moderated dynamic response is attained when using the PSO-based regulator. The best performance is achieved by applying the GWO technique. The GWO technique in this research work has the best performance in terms of the extracted power. The results that we obtained from this system are promising results that encourage. The proposed method can be applied to a large-scale than the system under study by increasing the size of the PV array Suitable for loads. This work is part of a PhD and is being worked on.

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