TuEngr Group

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

PAPER ID: 11A16H

OPTIMAL SIZING OF ISOLATED HYBRID PV/WT/FC SYSTEM USING MANTA RAY FORAGING OPTIMIZATION ALGORITHM

Hamdy M. Sultan [1], **Ahmed S. Menesy** [1], **Salah Kamel** [2], **Ali S. Alghamdi** [3*], **Mohamed Zohdy** [4]

[1] *Department of Electrical Engineering, Minia University, Minia, EGYPT*
[2] *Department of Electrical Engineering, Aswan University, Aswan 81542, EGYPT*
[3] *Department of Electrical Engineering, College of Engineering, Majmaah University, Almajmaah 11952, SAUDI ARABIA.*
[4] *Electrical and Computer Engineering Department, School of Engineering and Computer Science, Oakland University, Rochester, Rochester, MI 48309, USA.*

ARTICLEINFO

Article history:
Received 22 June 2020
Received in revised form 08 September 2020
Accepted 19 September 2020
Available online 24 September 2020

Keywords:
Hybrid energy generating system; Photovoltaic; Wind turbine; MRFO; Statistical analysis; Optimal energy system; COE; LPSP.

ABSTRACT

This work seeks to optimize the size components of a proposed stand-alone photovoltaic (PV)/ wind turbine (WT)/ fuel cell (FC) hybrid renewable generating system. A new efficient optimization algorithm called Manta-Ray Foraging Optimization (MRFO) is adapted to design the size components of the hybrid system under multi-objective functions, minimizing the cost of energy (COE) and minimizing the loss of power supply probability (LPSP). The real case study is applied in Ataka city, located on the Suez Gulf (latitude 30.0, longitude 32.5) of Egypt. To ensure the high performance and stability of the developed algorithm, this study testes three different system configurations (PV + WT + FC, WT + FC, and PV + FC). Furthermore, statistical measures for the different configurations have been presented to affirm the robustness and reliability of the developed MRFO technique. The simulation results proved the high capability of the MRFO in solving the studied optimization problem with fast convergence and reliable results, to supply loads with the minimum COE.

Disciplinary: Electrical Engineering (Electric Power Management), Sustainable Energy (Solar Energy, Wind Energy).

1 INTRODUCTION

Renewable resources of the electrical energy like solar PV, wind turbine, and fuel cell have an effective role in improving the diversity process in power supply markets, ensuring continuous feeding of energy in the long run as well as decreasing the atmospheric emissions (Farghally et al.,

---

*Corresponding author (Ali S. Alghamdi). Tel: +966 16 404-2568. Email: aalghamdi@mu.edu.sa

2014, Kamankesh et al., 2016). Generally, the PV and wind turbines are widely utilized for supplying the residential, industrial, commercial consumers with electrical energy in the rural and remote areas (Baghaee et al., 2016). The continuous fluctuations of these renewable sources along its operating time lead to the problems of grid stability and reliability. Therefore, the hybrid system is proposed to solve these problems (Wu et al., 2015, Diab et al., 2019). Different strategies of electrical energy storage systems such as FCs, batteries, super-capacitors, and hydroelectric pumped storage (HPS) are suggested to solve the continuous fluctuations problem of PV and WT systems (Bernal-Agustín and Dufo-Lopez, 2009).

In recent years, several optimization algorithms are used for optimizing the size components of different configurations of hybrid generating systems, namely, particle swarm optimization (PSO) (Abedi et al., 2011), Hybrid Particle Swarm-Gravitational Search Algorithm (PSOGSA), Moth-Flame Optimizer (MFO), Whale Optimization Algorithm (WOA), Water Cycle Algorithm (WCA) (Diab et al., 2019), Genetic Algorithm (GA) (Ashari et al., 2010), Multi-Objective Evolutionary Algorithm (MOEA) and GA (Dufo-Lopez and Bernal-Agustín, 2008), and Multi-Objective Particle Swarm Optimization Algorithm (MOPSO) (Baghaee et al., 2016).

This research paper introduces and applies a novel metaheuristic optimization algorithm called MRFO for optimizing the size components of isolated PV/ WT/ FC hybrid power systems. MRFO is inspired by the behavior of fancy creatures called Manta rays, which survive on eating the small organisms (plankton) in water without the need for teeth. Manta rays follow three different intelligent foraging strategies to find abundant plankton, namely, Chain foraging, Cyclone foraging, and Somersault foraging. The main target of this work is to optimally design the hybrid system components with minimum COE, minimum LPSP, and fewer fluctuations level in power exchange with the national grid. Moreover, several metrics of statistical analysis has been performed to confirm the viability and stability of the developed optimization algorithm in solving the studied problem. As well, the developed MRFO algorithm is tested on two additional configurations of the proposed system to check its reliability and efficiency.

2 HYBRID SYSTEM MODELLING

The description of the proposed isolated hybrid generating system including PV, WT, and FC is provided in the schematic diagram shown in Figure 1.

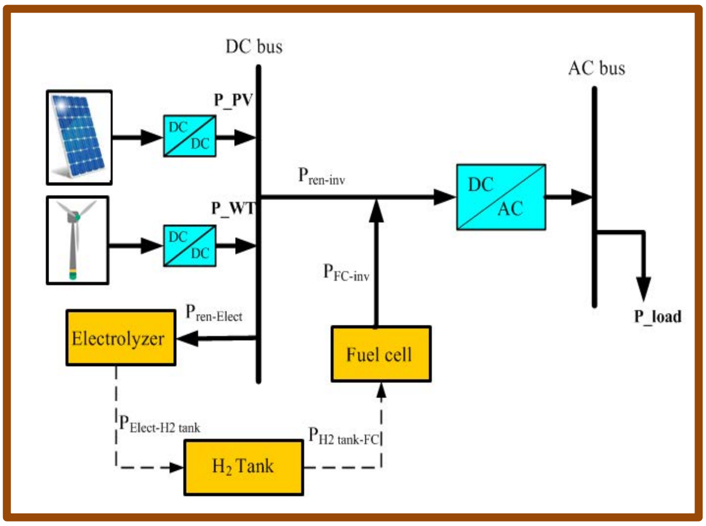


Figure 1: Schematic diagram of the studied isolated system.

2.1 PV SYSTEM MODELLING

For a PV power plant including NPV modules at a certain temperature T_C and solar radiation G, the generated power is calculated from (Sultan et al., 2018),

$$P_{PV}(\mathrm{t}) = N_{PV} P_{PV\_rated} \eta_{PV} \frac{G(t)}{1000} (1 - \beta_T (\mathrm{T}_C(t) - 25)) \quad (1),$$

where P_{PV_rated} presents the nominal generated power of the photovoltaic array working under standard atmospheric conditions ($G = 1000$ W/m^2 and $T_C = 25$°C), and η_{PV} is the output efficiency of the PV generating system including the efficiencies of the wiring system, maximum power point tracker, and inverter.

2.2 WIND ENERGY SYSTEM MODELLING

For a certain wind farm consist of a certain number of wind turbines, N_{WT}, operating under a wind speed v, the electrical power produced from the WT farm is controlled by the wind speed limits of the WT, i.e. the rated wind speed (v_{rated}), the cut-in speed ($v_{cut\text{-}in}$) from which the WT starts generating electric power, and the speed at which the turbine is stopped for preventing the mechanical damage ($v_{cut\text{-}off}$). Equation (2) provides the mathematical expression of the power generated from the wind farm (Sultan et al., 2018),

$$P_{WT}(t) = \begin{cases} 0 & v(t) < v_{cut-in} \\ \dfrac{N_{WT} \eta_{WT} P_{WT\_rated} (v^2(t) - v^2_{cut-in})}{(v^2_{rated} - v^2_{cut-in})} & v_{cut-in} < v(t) < v_{rated} \\ N_{WT} \eta_{WT} P_{WT\_rated} & v_{rated} < v(t) < v_{cut-off} \\ 0 & v(t) > v_{cut-off} \end{cases} \quad (2),$$

where P_{WT_rated} denotes the rated electrical power of the WT when operating under the rated speed, η_{WT} is the WT efficiency. In this study, 7.5 Kw/ 48 V DC WT has been used (Khan and Iqbal, 2005). The WT specifications include the cost and efficiency of other components such as the converter and the control system.

2.3 FUEL CELL/ELECTROLYZER SYSTEM MODELLING

During excess produced electrical energy from the renewable PV and WT systems, the electrical power is supplied to the water electrolyzer, where the DC current is used to regenerate the original components of water molecules, i.e. oxygen and hydrogen. The hydrogen around the anode electrode is produced under a low pressure of 1.2 bar. The produced hydrogen is compressed until 30 bar and stored in special tanks (Garcia and Weisser, 2006). In this research study, to reduce the proposed system cost, it is proposed that the hydrogen is stored under low pressure as it is directly delivered to the tanks without the need for compressors. In this study, the water electrolyzer, hydrogen tank, and the fuel cell systems are mathematically modeled based on the power flow through these systems. The model of the electrolyzer utilizes the input power from the renewable sources ($P_{ren\text{-}Elect}$) and power output from the water electrolyzer ($P_{Elect\text{-}tank}$) (Khan and Iqbal, 2005; Kaviani et al., 2009),

$$P_{Elect-\tan k} = P_{ren-Elect} \times \eta_{Elect} \quad (3),$$

where η_{Elect} denotes the efficiency of the water electrolyzer which is taken constantly during the simulation time. The hydrogen gas tank is modeled based on the electrical energy stored inside it all time t, which is formulated as follow (Kaviani et al., 2009),

$$E_{\tan k}(t) = E_{\tan k}(t-1) + \left(P_{Elect-\tan k}(t) - \frac{P_{\tan k-FC}(t)}{\eta_{storage}} \right) \times \Delta t \quad (4),$$

where $P_{tank\text{-}FC}$ represents the electrical power produced from the tank of hydrogen and supplied to the FC, and $\eta_{storage}$ denotes the electrical hydrogen storage system efficiency which is taken as 95% (El-Sharkh et al., 2006). The time interval Δt is taken as one hour. The hydrogen mass (M_{tank}) stored in the hydrogen tank is taken as a representation of the energy stored in the tank as a function of the higher heating value of the hydrogen gas (HHV_{H2}) which equal 39.7kWh/m^2 (Kaviani et al., 2009; Strunz and Brock, 2006).

$$M_{\tan k}(t) = \frac{E_{\tan k}(t)}{HHV_{H_2}} \quad (5).$$

The FC model is depended on the output power supplied to the DC/AC converter, the power transferred from the tank of hydrogen gas to the FC, and the FC efficiency. This model can be expressed as

$$P_{FC-inv} = P_{\tan k-FC} \times \eta_{FC} \quad (6),$$

where η_{FC} denotes the energy conversion efficiency of FC, which is taken as 50% in this study.

2.4 DC/AC CONVERTER MODELLING

For supplying the load with AC current, the DC/AC is the main device that is included in such a renewable hybrid system. Based on the power fed to the load from the renewable sources ($P_{ren\text{-}inv}$) and output power from the FC ($P_{FC\text{-}inv}$) as well as the efficiency of the inverter (η_{inv}) which is taken as 90% (Khan and Iqbal, 2005),

$$P_{inv-AC} = \left(P_{FC-inv} + P_{ren-inv} \right) \times \eta_{inv} \quad (7)$$

3 OPERATING STRATEGY

The studied isolated hybrid generating system is working according to the following modes:

- when the energy generated from PV and WT systems is greater than the needs of the load, then the extra energy is transferred to the water electrolyzer and the obtained hydrogen gas is stored in special tanks.

- If the hydrogen gas tank is full and/ or the excess energy is higher than the capacity of the electrolyzer then the electrical power is consumed in a dummy load and this part has to be minimized.

$$P_{dummy}(t) = P_{ren-inv}(t) \times \eta_{inv} - P_{load}(t) \quad (8),$$

- If the electrical power produced from WT and PV generating systems is less than the consumption of load, then the differences are covered by the FC.

- If the hydrogen mass inside the hydrogen tank reached the minimum allowable limit and/or the power shortage exceeds the FC rated, then the LPSP will be increased.

4 PROBLEM FORMULATION

In this work, the MRFO algorithm has been adopted and developed to optimizing the size components of the studied isolated hybrid renewable generating system and addressing all possible configurations of the system. Obtaining the optimal configuration of the studied system is the goal of this research work so that the COE generated by the studied hybrid generating system is minimized and ensuring high reliability and stability of the power supply. The LPSP is denoted as the reliability index that is supposed to be below the predefined value of 5%. The optimization problem and the MRFO algorithm are introduced in the following subsections.

4.1 THE OBJECTIVE FUNCTION

The *COE* of the generating kWh units supplied by the hybrid generating system can be calculated from this expression (Xu et al., 2013),

$$COE = \frac{NPC}{\sum_{1}^{8760} P_{load}} \times CRF \tag{9}$$

where *NPC* denotes the net resent system cost i.e.

$$NPC = \frac{C_{tot\_ann}}{CRF} \tag{10}$$

where C_{tot_ann} denotes the system annual cost. The annual cost of individual components in the presented hybrid generating system is represented as the summation of the capital cost interest, operating and maintenance cost, O&M, and replacement cost of this component. CRF denotes the capital recovery factor of the proposed system. In this work, the rate of interest is selected as 0.06 where the lifetime is selected as 25 years. The specifications of each component in the studied standalone hybrid system are introduced in Table 1 (Khan and Iqbal, 2005).

For minimizing the COE of the system, ensuring high reliability of the studied generating system by minimizing the LPSP and minimizing the power consumed in the dummy load (P_{dummy}), the following objective function has been utilized,

$$\min_x f = \min_x(\gamma_1 \times COE + \gamma_2 \times LPSP + \gamma_3 \times D_{load} + \gamma_4 \times D_{gs}) \tag{11}$$

where x denotes the optimization parameters (N_{PV}, N_{WT}, P_{Elect_rated}, $M_{tank,\ max}$, P_{FC_rated}), γ_1, γ_2, and γ_3 are obtained through trial and error principle until the optimal results are obtained. In this study, $\gamma_1 = 0.5$, $\gamma_2 = 0.45$, and $\gamma_3 = 0.05$.

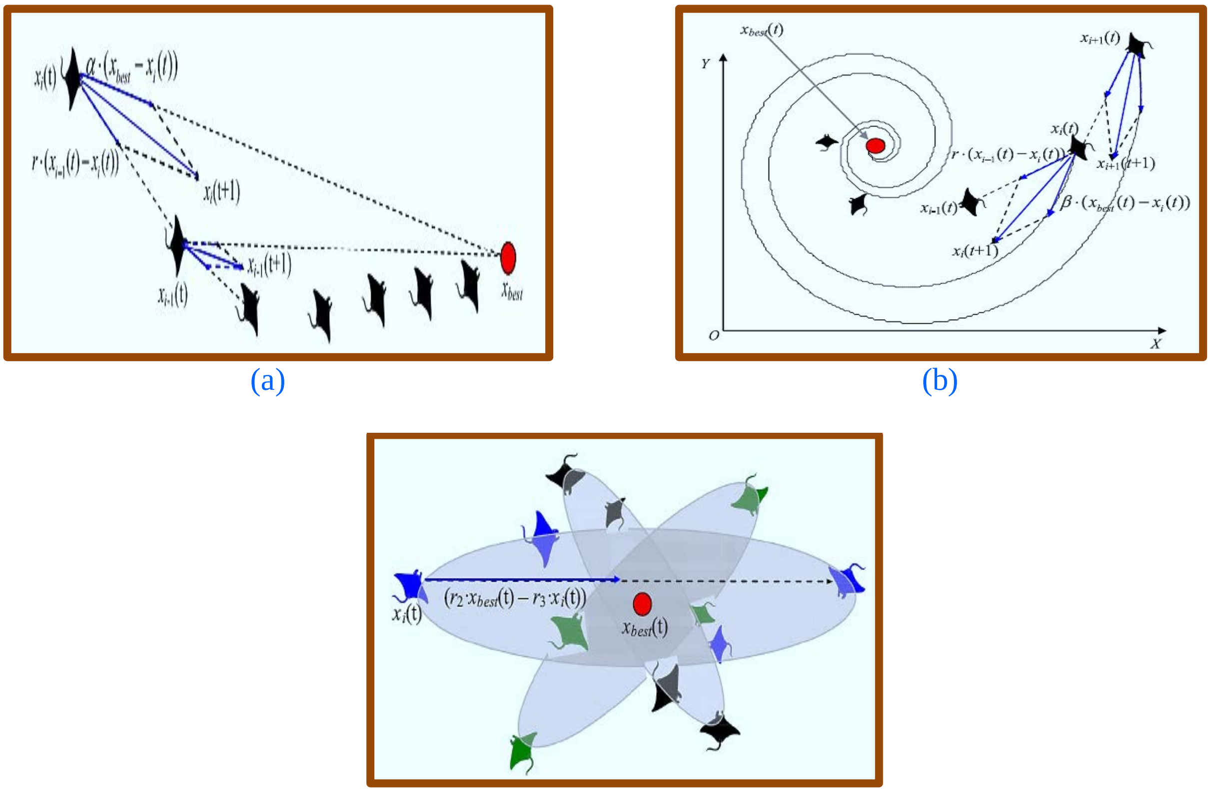
Table 1: Characteristics of different components in the proposed renewable energy system.

Component	Capital cost (US$/unit)	Cost of replacement (US$/unit)	Cost of O&M (US$/ unit-year)	Lifetime (year)	Efficiency percentage	Unit
WT	19400	15000	75	20	-	7.5kW
PV module	7000	6000	20	20	-	1kW
Water electrolyzer	2000	1500	25	20	75	1kW
Tank of hydrogen	1300	1200	15	20	95	1kg
FC	3000	2500	175	5	50	1kW
DC/AC inverter	800	750	8	15	90	1kW

4.2 MRFO ALGORITHM

MRFO is a recent bio-inspired optimization technique, which was inspired by the behavior of fancy creatures called Manta rays, which was firstly developed by Zhao et al. (2020). Manta rays survive on eating the small organisms (plankton) in water without the need for teeth, then using modified gill rakers the prey is filtered from the water. Manta rays are divided into two groups according to the surrounding environment, where they live. Reef manta rays and giant manta rays; the first species reaches 5.5m width and usually found in the Indian Ocean, while the second species reaches 7m width and lives in high temperatures in tropical and high-temperature oceans. Manta rays always eat 5 kg of plankton every day. These unique creatures may travel alone or in groups, but in foraging, they are observed always in groups of up to 50 individuals. Manta rays can find abundant plankton and they have three different intelligent foraging techniques.

The first technique is called the chain foraging, where the manta rays act in foraging their prey. In this technique, roughly fifty manta rays formed in a line, one behind the other, and the females carry the small male manta rays on their backs. In this way, the plankton, which escaped from the first one will be caught by the one behind. This technique helps them to improve their foraging by collecting most prey in their gills. When manta rays see the planktons, they swim in their direction. The best position in MRFO is defined as the position of the most concentration on planktons. When a group of manta rays observes a concentration of planktons, they arranged in a line head-to-tail forming a foraging chain. The chain foraging technique is described in Figure 2(a). In this algorithm, except the first individual, others move towards the source of food and at the same time towards the individual in front of it, consequently, the solution for each individual is updated based on the optimal solution so far (most concentration of planktons) and the solution of the front individual.



(a)

(b)

(c)

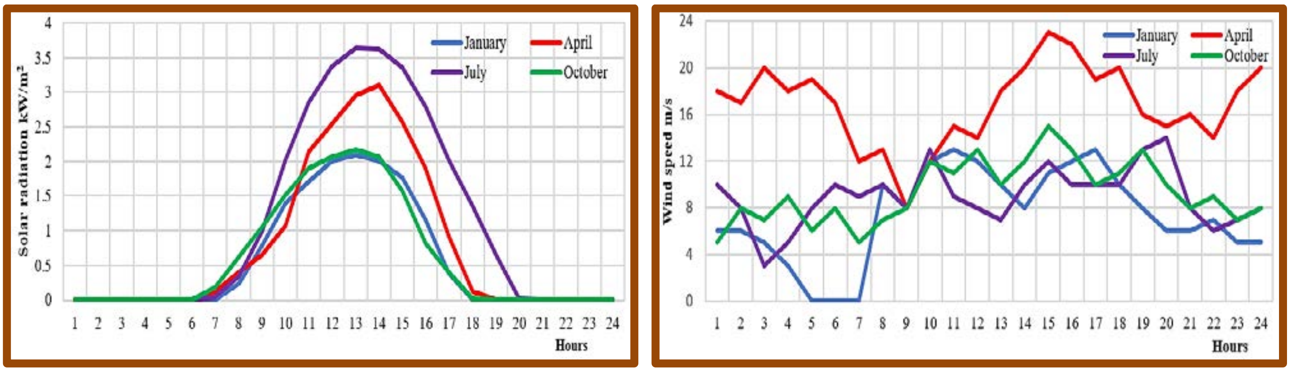
Figure 2: Foraging manta ray: (a) chain foraging, (b) cyclone foraging, (c) somersault foraging (after Zhao et al. (2020)).

The second technique is the cyclone foraging. Manta rays act this technique in scooping up their prey. When the planktons in the way of the manta rays are in large amounts, a group of manta rays are shared together the head at the end of the tail and surround their prey. During the foraging process, the gathered group forms a spiral around the planktons towards the surface of the water and catches the planktons in their mouths. When a group of manta rays meets a stream of planktons in their way in deep water, they go towards them in a spiral movement. In the cyclone foraging mechanism (Figure 2(b)), manta rays do not only perform a spiral surrounding the concentration of the planktons but also each of them moves towards the one in front of him.

The third technique is somersault foraging. Manta rays follow this technique in scooping up planktons. When manta rays in their way in the water meat a stream of planktons, they will perform backward to let prey to swim towards the manta rays. Somersault is a unique, random, cyclical motion that optimizes the chance of catching planktons, Figure 2(c). In this mechanism, manta rays observe the food source as a pivot and each of them swims and somersaults to his new position around that pivot. Manta rays in this technique updated their positions around the most plankton concentration (best position so far). For MRFO algorithm, the reader can refer to Zhao et al. (2020).

5 RESULTS AND DISCUSSIONS

The MRFO technique is proposed for addressing the optimization problem of the optimal arrangement of the suggested renewable isolated hybrid system. A case study of the proposed system comprising PV, wind turbine, and fuel cell generating units has been applied in the Ataka region, on the Red Sea shore in Egypt, which is rich in renewable energy resources characterized by a continuous wind flow whole year and high intensity of solar radiation (Figure 3). The annual load demand on intervals of an hour of the region under study presented in Figure 4 is used in this study.



(a) (b)

Figure 3: Meteorological parameters at the proposed location; (a) solar radiation, (b) wind speed.

The MRFO algorithm is utilized for generating the optimal size components of the three possible configurations of the proposed renewable hybrid generating system. For obtaining the optimal design of the system, in each of the three cases, the optimization program is executed 50 times and the results corresponding to the minimum objective function has been realized. For validating the accuracy and stability of the proposed algorithm itself, statistical measurements have been accomplished. The results of the statistical study based on different metrics for the three configurations are provided in Table 2, the reader can notice the insignificant values of the main, median, and relative error (RE) which ensure the accuracy of the proposed technique. The high values of the efficiency and small values of root mean square error (RMSE), and standard deviation (SD), proved the stability of the MRFO algorithm. The convergence curves of the 50 individual run for the three different configurations are shown in Figure 5. The end values of the objective function over 50 executions for the proposed configurations are presented in the graphical form as shown in Figure 6.

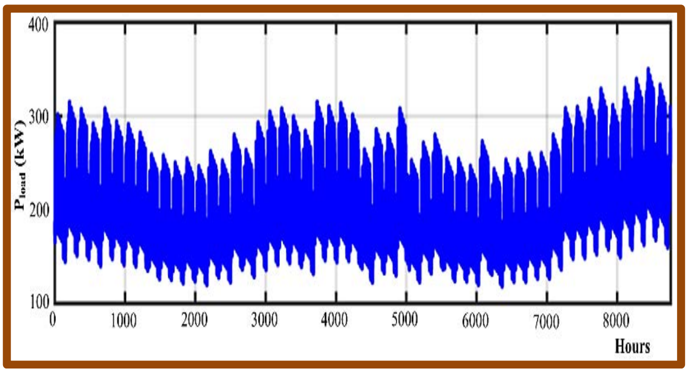


Figure 4: Annual load demand of the site.

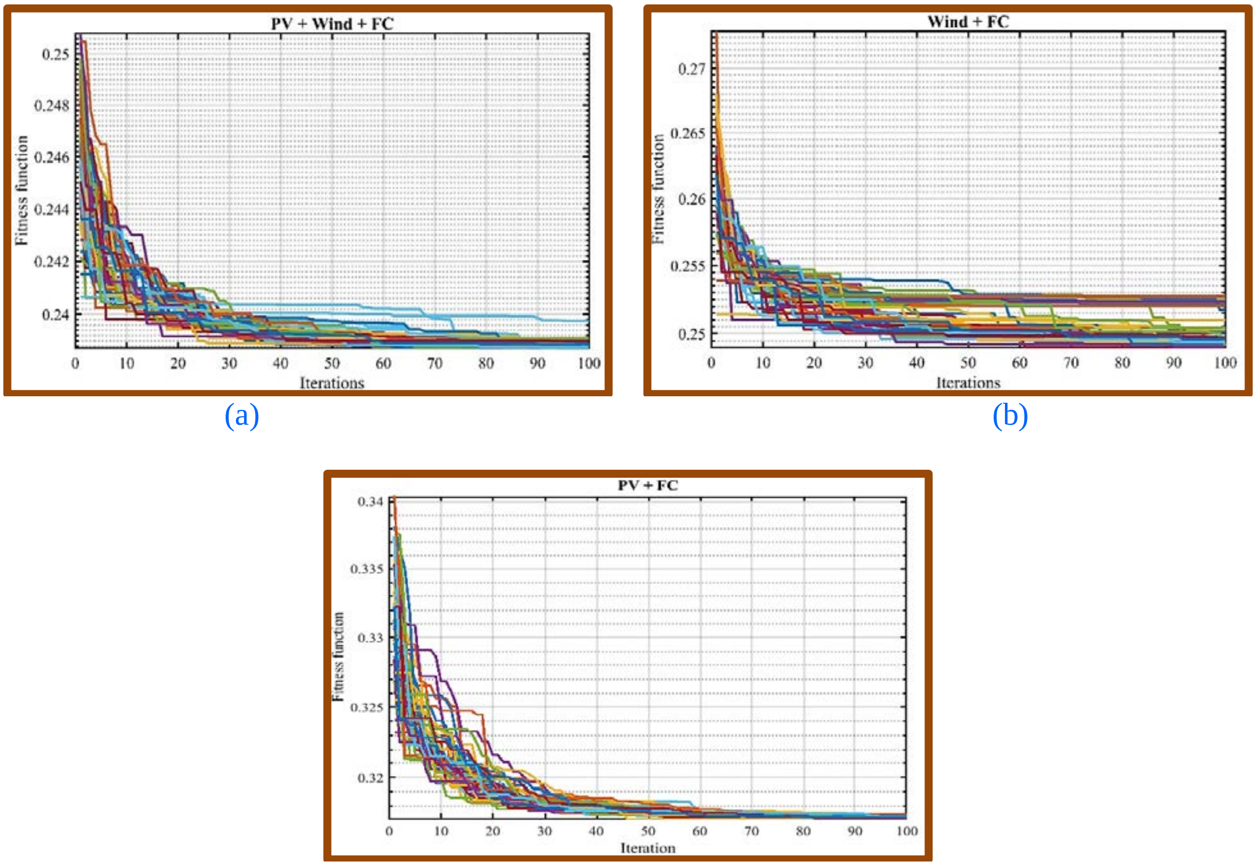
The objective function convergence curves corresponding to the implement that gives the minimum fitness function value are presented in Figure 7 for the three different configurations. Table 3 provides the optimal values results obtained from the MRFO method. The MRFO successes to generate the optimal size of each subsystem in all cases that result in the minimum cost of energy while ensuring high stability of the studied standalone hybrid generating system. The best optimal results of the complete PV/wind/FC hybrid system (Table 3) are applied and the specific operation of the overall proposed system is visualized. Figure 5 provides the operation for a certain summer day (24-hour simulation). Figure 5(a) presents the load demand, renewable generation, and the resultant difference between them while Figure 5(b) emphasizes the operation of the electrolyzer, FC, and the DC/AC converter. The optimized results of the studied hybrid isolated system in Table 3 are applied to the proposed system model and the operation of the hybrid system on a certain summer day is emphasized in Figure 8.

Table 2: Results of the statistical study for the three proposed hybrid systems.

Case	PV + Wind + FC	Wind + FC	PV + FC
Best	0.23873	0.24900	0.31713
Worst	0.23974	0.25272	0.31743
Mean	0.23886	0.25024	0.31728
Median	0.23883	0.24975	0.31727
RE	0.01498	0.11377	0.00722
MAE	0.02635	0.24905	0.02366
SD	0.00013	0.00124	0.00015
RMSE	0.00019	0.00168	0.00017
Eff.	99.947	99.506	99.953

Table 3: Simulation results of the designed system.

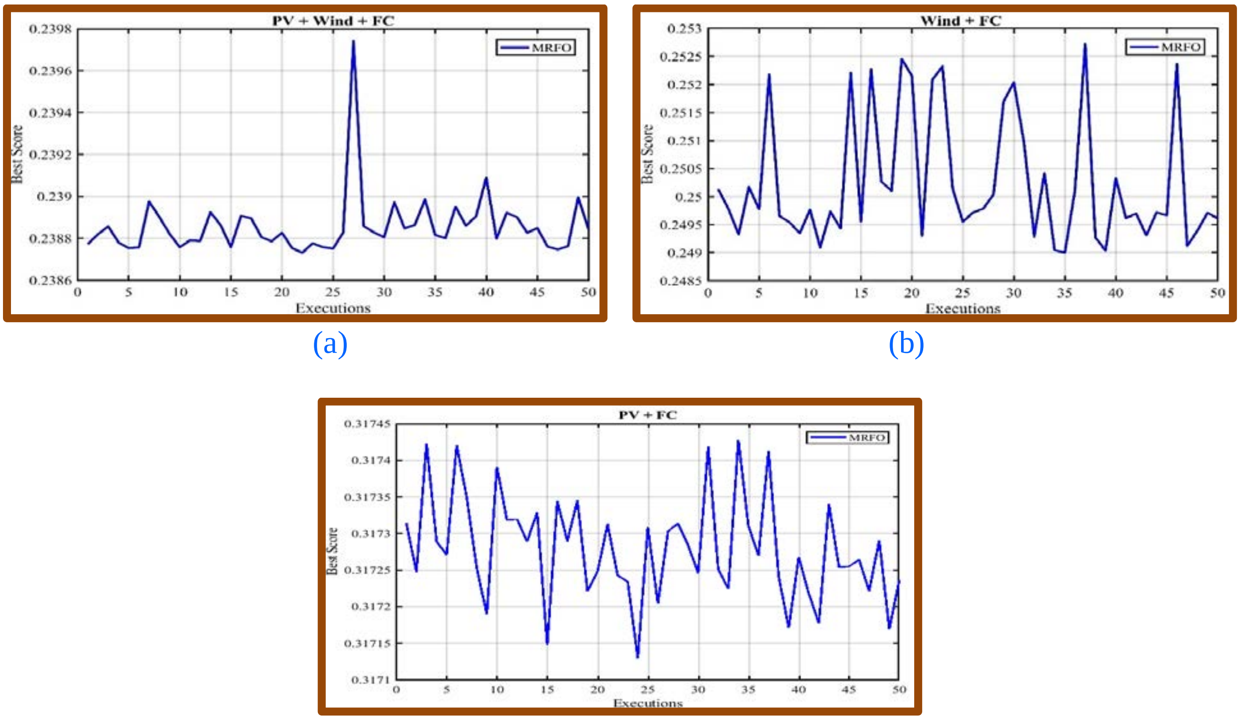
Case		PV + wind + FC	Wind + FC	PV + FC
Best objective function		0.239	0.249	0.317
Best solution	PV (units)	268.028	-	600.832
	Wind (units)	66.430	218.109	-
	Electrolyzer (kW)	710.021	886.843	702.422
	Hydrogen tank (kg)	103.405	158.905	165.103
	Fuel cell (kW)	200.010	300.601	300.033
Iteration number for the best solution		93	61	46
COE		0.429	0.656	0.519
NPC		10367628.181	15839687.400	12541058.453
LPSP		0.028	0.050	0.063
P_dummy		430297.483	746938.217	1093893.797



(a) (b)

(c)

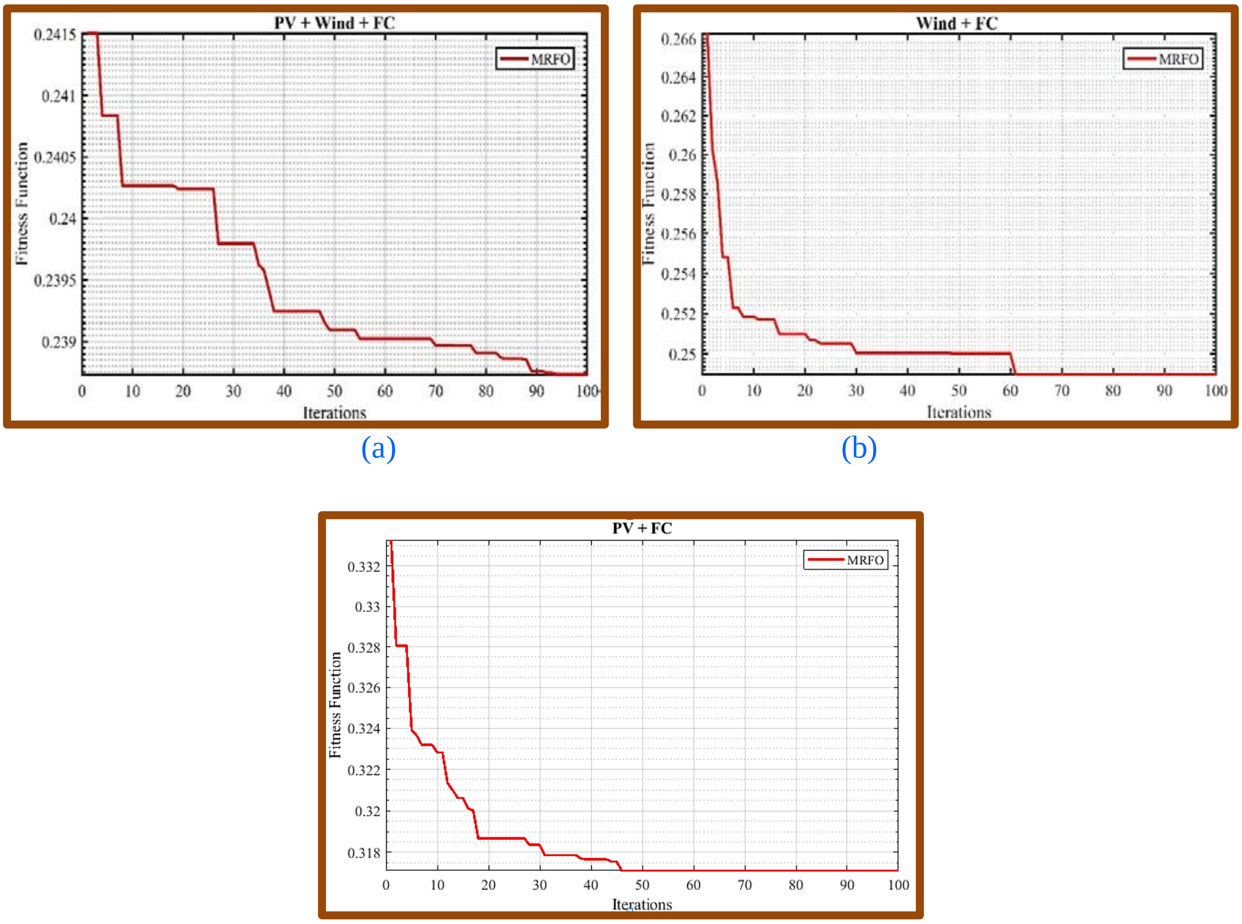
Figure 5: Convergence curves for the 50 runs: (a) PV/wind/FC system, (b) Wind/FC system, (c) PV/FC system.



(a) (b)

(c)

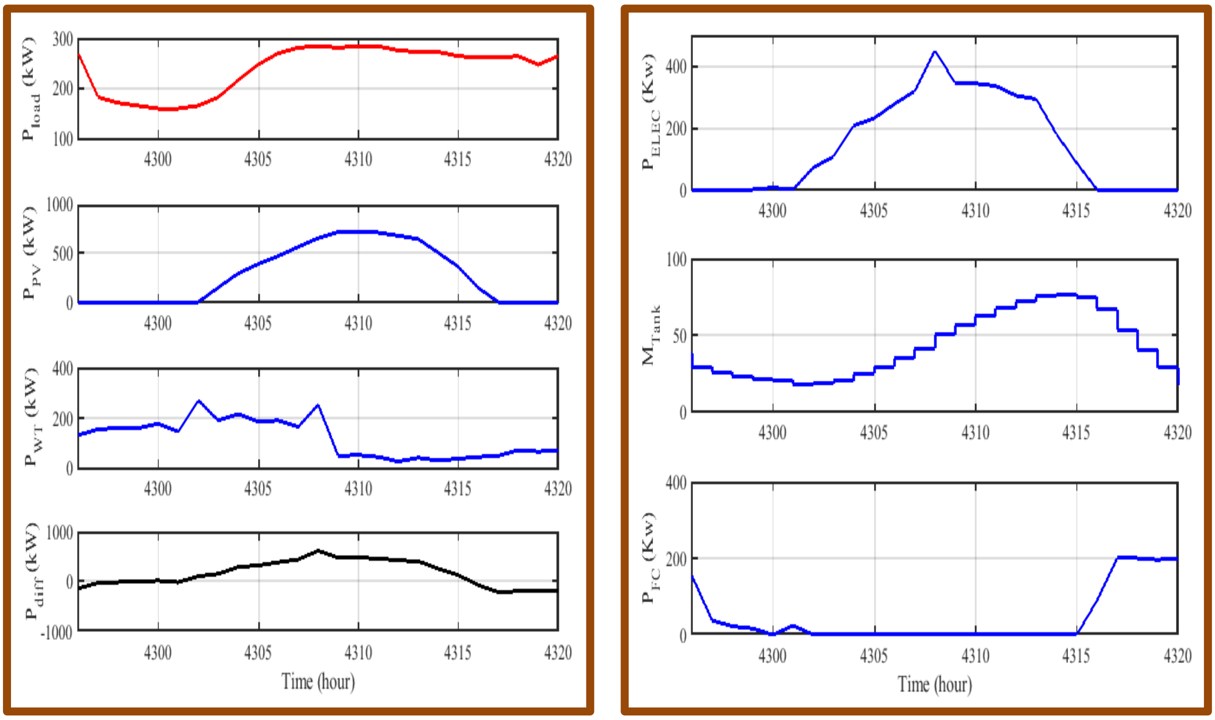
Figure 6: End values of the objective function over the 50 runs: (a) PV/wind/FC system, (b) Wind/FC system, (c) PV/FC system.



(a) (b)

(c)

Figure 7: The convergence curves of MRFO: (a) PV/wind/FC system, (b) Wind/FC system, (c) PV/FC system.



(a) (b)

Figure 8: 24-hour operation of the proposed PV/wind/FC hybrid system.

6 CONCLUSION

The main objective of the optimal design of a hybrid energy system is to feed consumers with electrical energy with high reliability with minimum energy cost. In this research work, the lifespan of the suggested hybrid power system is 25 years and the tank of hydrogen has been utilized as an energy storage system. The MRFO metaheuristic technique has been applied to achieve the optimal design of the size components of the proposed system. Three different configurations of the hybrid system have been studied and compared. From the obtained results, it was found that the studied hybrid generating system is capable to supply the load with the minimum COE of USD0.43/kWh. Furthermore, the simulation results showed that the developed algorithm has proven its efficiency in solving the studied optimization problem with fast convergence and reliable results.

7 AVAILABILITY OF DATA AND MATERIAL

Information can be made available by contacting the corresponding author.

8 REFERENCES

Abedi, S., H. G. Ahangar, M. Nick, and S. H. Hosseinian. (2011). Economic and reliable design of a hybrid PV-wind-fuel cell energy system using a differential evolutionary algorithm. *19th Iranian Conference on Electrical Engineering,* IEEE.

Ashari, M., H. Suryoatmojo, I. Robandi, and T. Hiyama. (2010). Optimal Design of Hydrogen Based Stand-Alone Wind/Microhydro System Using Genetic Algorithm. *ICSIIT 2010, 71.*

Baghaee, H., M. Mirsalim, G. Gharehpetian, and H. Talebi. (2016). Reliability/cost-based multi-objective Pareto optimal design of stand-alone wind/PV/FC generation microgrid system. *Energy, 115*, 1022-1041.

Baghaee, H. R., M. Mirsalim, and G. B. Gharehpetian. (2016). Power calculation using RBF neural networks to improve the power-sharing of the hierarchical control scheme in multi-DER microgrids. *IEEE Journal of Emerging and Selected Topics in Power Electronics, 4*(4), 1217-1225.

Bernal-Agustín, J. L., and R. Dufo-Lopez. (2009). Simulation and optimization of stand-alone hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews, 13*(8), 2111-2118.

Diab, A. A. Z., H. M. Sultan, I. S. Mohamed, O. N. Kuznetsov, and T. D. Do. (2019). Application of different optimization algorithms for optimal sizing of PV/wind/diesel/battery storage stand-alone hybrid microgrid. *IEEE Access, 7*, 119223-119245.

Dufo-Lopez, R. and J. L. Bernal-Agustín. (2008). Multi-objective design of PV-wind-diesel-hydrogen-battery systems. *Renewable energy, 33*(12), 2559-2572.

El-Sharkh, M., M. Tanrioven, A. Rahman, and M. Alam. (2006). Cost related sensitivity analysis for optimal operation of a grid-parallel PEM fuel cell power plant. *Journal of Power Sources, 161*(2), 1198-1207.

Farghally, H. M., F. H. Fahmy, and M. A. El-Sayed. (2014). Control and optimal sizing of PV-Wind powered rural zone in Egypt. *Online Journal on Power & Energy Engineering, 2*(2), 188-195.

Garcia, R. S., and D. Weisser. (2006). A wind-diesel system with hydrogen storage: Joint optimisation of design and dispatch. *Renewable energy, 31*(14), 2296-2320.

Kamankesh, H., V. G. Agelidis, and A. Kavousi-Fard. (2016). Optimal scheduling of renewable micro-grids considering plug-in hybrid electric vehicle charging demand. *Energy, 100*, 285-297.

Kaviani, A. K., G. Riahy, and S. M. Kouhsari. (2009). Optimal design of a reliable hydrogen-based stand-alone wind/PV generating system, considering component outages. *Renewable energy, 34*(11), 2380-2390.

Khan, M., and M. Iqbal. (2005). Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. *Renewable energy, 30*(6), 835-854.

Strunz, K., and E. K. Brock. (2006). Stochastic energy source access management: infrastructure-integrative modular plant for sustainable hydrogen-electric co-generation. *International Journal of Hydrogen Energy, 31*(9), 1129-1141.

Sultan, H. M., A. A. Z. Diab, N. K. Oleg, and S. Z. Irina. (2018). Design and evaluation of PV-wind hybrid system with hydroelectric pumped storage on the National Power System of Egypt. *Global Energy Interconnection, 1*(3), 301-311.

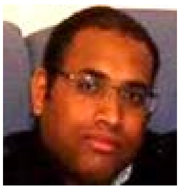
Wu, W., V. I. Christiana, S.-A. Chen and J.-J. Hwang. (2015). Design and techno-economic optimization of a stand-alone PV (photovoltaic)/FC (fuel cell)/battery hybrid power system connected to a wastewater-to-hydrogen processor. *Energy, 84*, 462-472.

Xu, L., X. Ruan, C. Mao, B. Zhang, and Y. Luo. (2013). An improved optimal sizing method for the wind-solar-battery hybrid power system. *IEEE transactions on Sustainable Energy, 4*(3), 774-785.

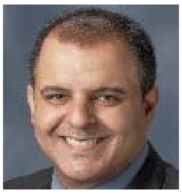
Zhao, W., Z. Zhang, L. Wang. (2020). Manta ray foraging optimization: An effective bio-inspired optimizer for engineering applications. *Engineering Applications of Artificial Intelligence, 87*, 103300. DOI: 10.1016/j.engappai.2019.103300

Hamdy M. Sultan is an Assistant Lecturer in the Electrical Engineering Department, Minia University, Minia, Egypt. He received a B.Sc. in Electrical Power Engineering from Minia University, and M.Sc. in Electrical Engineering from Minia University, Minia, Egypt. He works toward a Ph.D. degree at National Research University (Moscow Power Engineering Institute), Moscow, Russia. The key research area includes Power System Plan and Operation, Power System Transient Stability, and Renewable Energy.

Ahmed S. Menesy is an Assistant Lecturer in the Electrical Engineering Department, Minia University, Minia, Egypt. He received a B.Sc. degree in Electrical Engineering from Minia University, Minia, Egypt, and a Master's degree in Electrical Engineering from Chongqing University, Chongqing, China. His research interest includes optimization techniques, renewable energy, and smart grids.



Dr.Salah Kamel an Associate Professor at the Electrical Engineering Department, Aswan University. He received a Ph.D. degree from the University of Jaen, Spain (Main) and Aalborg University, Denmark (Host). Also, He is a Leader for the power systems research group in the Advanced Power Systems Research Laboratory (APSR Lab), Aswan, Egypt. He is currently a Postdoctoral Research Fellow in State Key Laboratory of Power Transmission Equipment and System Security and New Technology, School of Electrical Engineering, Chongqing University, Chongqing, China. His research activities include power system analysis and optimization, smart grid, and renewable energy systems.



Dr.Ali S. Alghamdi is an Assistant Professor and Acting Chair, the Department of Electrical Engineering, the College of Engineering, Majmaah University, Saudi Arabia. He received his dual B.S. degree (with high honors) in Computer and Electrical Engineering from Lawrence Technological University, Southfield, Michigan, USA, respectively, and an MSc in Electrical and Computer Engineering from Lawrence Technological University, Southfield, Michigan, USA. He received a Ph.D. in Electrical and Computer Engineering from Oakland University, Rochester, Michigan, USA. His research interests include Statistical Digital Signal Processing, Communication Systems, Adaptive Filter, Modern Control in Power System, Optoelectronics Nano-materials in Renewable Energy, and Wireless Sensor Network Innovation.

Professor Dr.Mohamed Zohdy works at Oakland University, Michigan, USA. He received his B.Sc. degree in Electrical Engineering, Cairo University, Egypt. He received his M.Sc. and Ph.D. degrees in Electrical Engineering, University of Waterloo, Canada. His interests are Control and Soft Computing.