Journal of Advanced Research in Applied Sciences and Engineering Technology 30, Issue 3 (2023) 302-314

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Micro-Grid Hybrid Renewable Energy Sources Optimal Sizing for Cost and Carbon Emission Reduction using Grey Wolf Algorithm

Kareem Hussien Hamouda[1,*], Noha Hany El-Amary[1], Rania Abdel Wahid Swief[2], Tarek Saad Abdel-Salam[2]

[1] Department of Electrical and Control Engineering., Arab Academy for Science, Technology and Maritime Transport (AASTMT), Cairo, Egypt
[2] Department of Electrical Power and Machines Engineering, Ain Shams University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 13 December 2022
Received in revised form 20 April 2023
Accepted 28 April 2023
Available online 17 May 2023

Keywords:
Carbon emissions reduction; hybrid renewable energy system; optimal sizing; micro-grid scheduling; Grey Wolf Algorithm

ABSTRACT

The rapid depletion of fossil fuel resources and the growing evidence of global warming have made the utilization of renewable energy sources more attractive, especially with the increase in global energy demand. Most of the renewable energy sources are dependent on climate conditions. Therefore, Hybrid Renewable Energy Sources (HRES) can be highly efficient systems. In this paper, the Grey Wolf Algorithm (GWO) is proposed to find the optimal operation of PV/Wind HRES for a typical industrial load system with the objective of minimizing carbon emissions and life cycle cost (LCC). The algorithm is utilized to study two scenarios (PV/Wind and PV/Wind/Diesel generator) in comparison with conventional energy systems. The analysis of the results shows that both scenarios are more appealing than the conventional system. The first scenario can be considered the most attractive scenario for LCC and carbon emissions reduction. 60% and 90 % reductions are achieved, respectively. The second scenario can be considered the most attractive scenario for dump energy reduction. A 33% reduction is achieved compared to the first scenario.

1. Introduction

IRENA-2021 reports estimated that the number of people without access to electricity is 759 million, which represents around 10% of the world population. 45% of global greenhouse gas emissions from 2010 levels must be reduced by 2030 [2].

Carbon emissions and their direct effect on global warming have a clear impact on the climate change crisis, especially in 2022, with deadly floods, heat waves, and droughts wreaking havoc on crops in many countries, especially in Africa. This crisis shows the importance of taking action to implement the energy transformation plan from fossil based energy to renewable clean energy reaching the ambitious target of the 2015 Paris climate agreement, which is to limit global warming to 1.5 °C by decreasing greenhouse-gas emissions by 45 per cent by 2030 [1,2], also the economic crisis which is affecting all the countries worldwide due to current war between Russia and Ukraine

* *Corresponding author.*
E-mail address: Kareemhussien@live.com

https://doi.org/10.37934/araset.30.3.302314

and its direct impact on increasing fuel costs to unprecedented levels, encourage the approach of clean energy. For the past seven years, more renewable power was added to the grid annually than fossil fuels and nuclear combined with the target of reducing carbon emissions and life cycle costs for power generation projects, renewable power technologies now dominate the global market for new electricity generation capacity, as they have become the cheapest sources of electricity in many markets [19]. This is a promising attraction for rapid decarbonisation of the power sector. By 2030, renewable power should reach 10,700 GW globally, almost quadrupling the current capacity.

Micro-grids are implemented with renewable energy sources (RES), current trends in optimization demonstrate that artificial intelligence (AI) provides worthwhile optimization for hybrid renewable energy sources (HRES) micro-grid operation without extensive long-term weather data, especially for the systems which require features that may not be achieved by traditional techniques [3, 4]. Solar and wind energy conversion systems are widely being integrated into hybrid systems as they efficiently complement each other [5]. In this paper, same hybrid type (SPV & WTG) is utilized.

AI includes many branches like Artificial Neural Network (ANN), Fuzzy Logic (FL), Genetic Algorithm (GA), Grey Wolf Algorithm (GWO) and hybrid techniques that contain two of these branches or more. In [20] the authors used GA and the elitist strategies for optimum sizing of stand-alone hybrid solar Panel Photovoltaics (SPV)/ Wind Turbine Generators (WTG) system per a year (8760 h), their major objectives were to decrease the total initial capital system costs with limited loss of power supply probability (LPSP).In [4] the authors shows various models of Fuzzy Logic, these models are highly used because it maps the exact situation to the best level, the models of FL are Fuzzy Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) which are utilized for finding a relative status of the variables, these approaches are used with related to a problem domain. For the forecast purposes, other models are used like fuzzy regression and fuzzy gray prediction. ANN is a structured group of AI neurons that practices the mathematical models for processing information dependent on the connectionist method for making the computation. In reference [21], the authors applied the ANN-based method for using preventive control approaches for big HRES. In reference [22], Authors proposed ANN control strategy for multi-energy common DC bus hybrid power supply by examining the distinctiveness of SPV, WTG. In reference [23], the author improved a hybrid model for an hourly forecast of the SPV-WTG RES and used the computational intelligence of Particle Swarm Optimization (PSO) for calculating different definitions of the forecast error. It has been clear that researchers were focusing on the sizing of the RES and forecast errors in previous researches.

In this paper, GWO is used to optimize an off-grid PV/wind hybrid system at a distinctive industrial site located in Egypt with the objective of minimizing life cycle cost (LCC) and CO_2 emissions in comparison with conventional (grid) energy systems. GWO is one of the leading algorithms in the optimization problems. Since it has a low number of variables, it can achieve optimization with very low execution. Moreover, GWO has high efficiency. Using GWO will significantly increase the convergence rate, accuracy of the final answer, non-localization, low standard deviation, and robustness.

The paper is organized as follows. The off-grid system construction and modelling are in Section 2. Mathematical models and formulas are given in Section 3. Section 4 describes the Grey Wolf optimization technique, as well as the system boundaries and flow chart. Then the tested system simulation and results are shown in section 5. A statistical analysis of GWO is done in section 6. Finally, the conclusion is given in section 7.

2. System Construction and Modelling

2.1 System Description

The proposed system is a PV/wind independent micro-grid for 14 mWh/day typical load. The DC bus combines the output of PV panels, while the AC bus combines the output of wind turbines, diesel generators, and the input to the AC load. The system block diagram is shown in Figure 1. The system depends on operating during the available time of operation for RES. The hourly energy demand is obtained in Eq. (1) [6–8].

$$E_l = P_l \times t \tag{1}$$

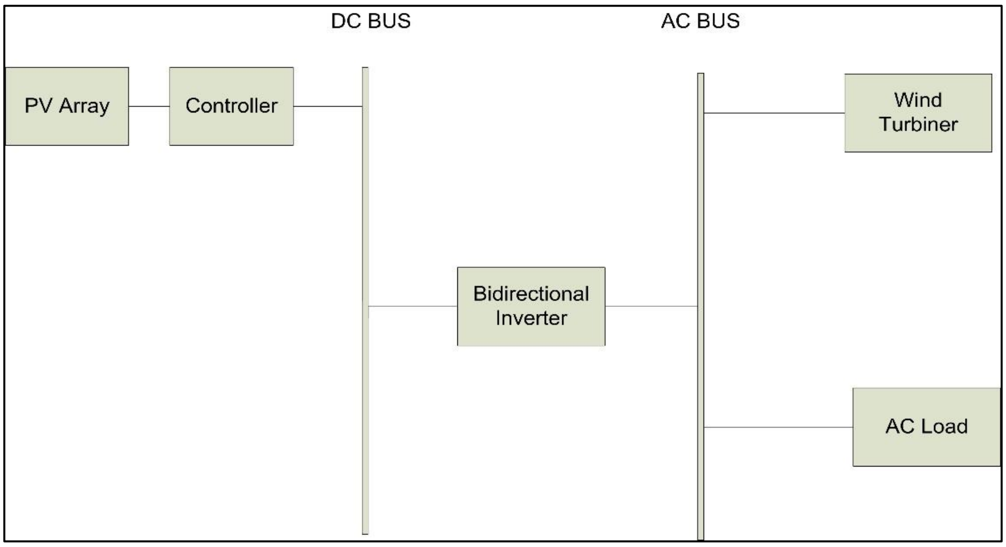

Fig. 1. System block diagram

2.2 PV System

Photovoltaic converters are semiconductor devices that convert part of the incident solar radiation directly into electrical energy. In recent years, cell laboratories have reported cells with efficiencies of over 30%. Modules are groups of cells which are manufactured with an area of many square meters and have a large aggregate peak value of over 70 GW [9], with a cumulative installed capacity of 716 GW in 2021 [10].

The PV module output energy is given by the following equations [9].

$$E_{PV} = P_{PV} \times t \tag{2}$$

$$P_{pv} = A_{pv} \times Ir \times \eta_{pv} \tag{3}$$

where A_{PV} is the area of the PV cell, I_r is the irradiance in W/m2, η_{pv} is the cell efficiency, and t is the time in hrs., Table 1. Shows the selected PV cell data sheet.

Table 1
PV data sheet

PV Module	Max. Power	Voc	Efficiency	Dimension (mm)	NOCT (C^O)
HiKu7- CS7N-665MS	665 W	43 V	21.4 %	2384*1303*35	42±3

2.3 Wind System

Wind turbines convert part of the kinetic energy of moving air to mechanical energy and then to electrical energy. Wind turbines are installed onshore and offshore. Wind turbine capacities have increased dramatically since the 1980s, from roughly 75 kW to 10 MW and larger in 2018. Wind turbines are typically grouped into wind power plants with larger total capacities. In terms of total installed capacity, wind power is the leading renewable energy technology after hydropower, with more than half a terawatt installed globally as of 2018 [18].

The wind turbine's output energy is given by the following equation.

$$E_{wind} = 0.5 \times \rho \times \pi \times r^2 \times C_p \times V^3 \times t \quad (4)$$

where ρ is the air density, r is the rotor radius, C_p is the power coefficient, and t is the time in hrs. and V is the wind speed. Table 2 shows the selected wind turbine data sheet.

Table 2
Wind turbine data sheet

Wind Turbine	Rated Power (KW)	Rotor Diameter (m)	Cut in Speed (m/s)	Rated Speed (m/s)	Cutout Speed. (m/s)
RYES-E5	18	9.8	2	11	30

2.4 Diesel Generator

Diesel generators are now mostly employed in HRES exclusively as backup sources in an effort to promote green energy. Diesel generators are used when battery systems and renewable energy sources are unable to meet the demand [3]. A diesel generator is solely taken into consideration in this paper as an energy source for reducing dump energy in the second scenario. The diesel generator's output energy is given by the following equation.

$$E_d = P_d \times h \times d \quad (5)$$

where P_D is the diesel power, h is the generation hours per day, and d is the number of days, Table 3 Shows the selected diesel generator data sheet.

Table 3
Diesel generator data sheet

Diesel Gen.	Power Capacity (Kva)	Power Capacity (Kw)	Voltage	P.F	Fuel Consumption
MTU – 500 KVA	500	400	380	0.8	100 Liter/Hr. at 100% Loading

3. System Mathematical Modelling

This section presents mathematical modelling, meteorological information, load curves, and energy source output curves. The energy resources data consists of hourly average wind speed and sun irradiation measurements made over a one-year period. Data in Microsoft Excel format was acquired. The data comes from IRENA EGYPT, and the chosen location in Egypt is at latitude 30.007274° and longitude 31.723022° (30°00'26", 031°43'23"). Given that the studied load is industrial and nearly constant throughout the day, the simulation of the mathematical model takes the worst-case scenarios for wind speed and sun irradiation into account.

3.1 System Output Curves

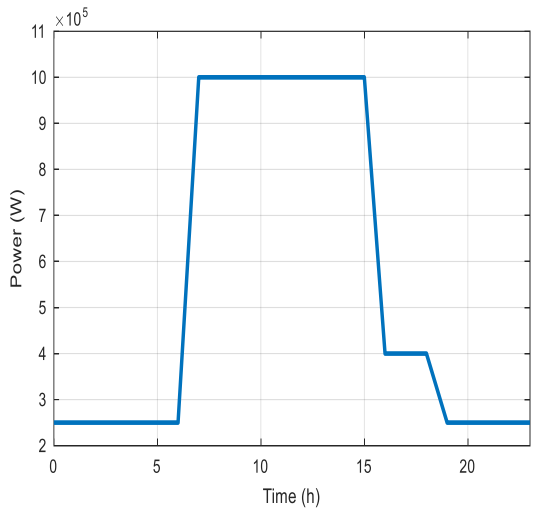

Fig. 2. Daily average load curve

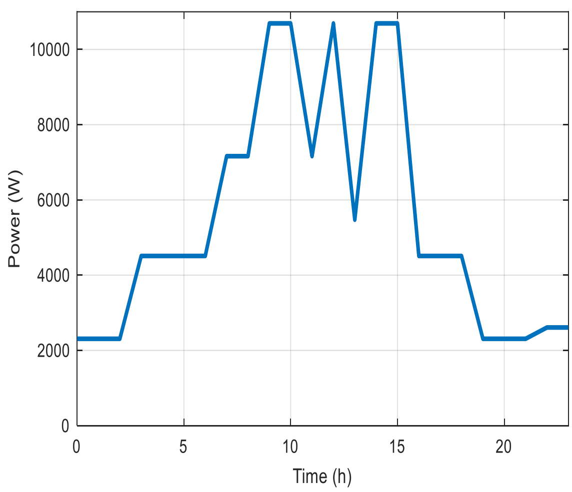

Fig. 3. Daily average wind turbine output power

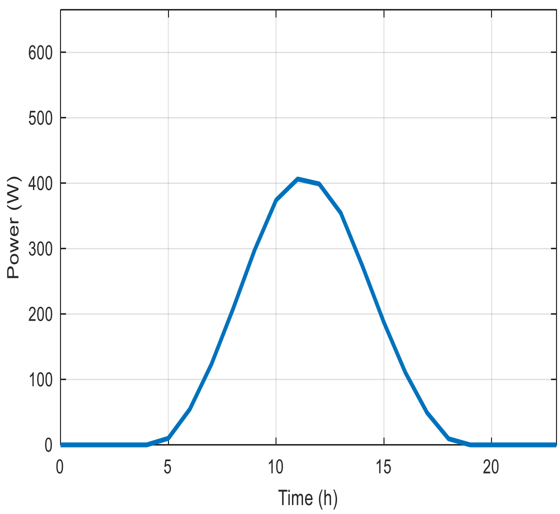

Fig. 4. Daily average PV module output power

3.2 System Cost Function

The total cost of the system will be calculated using the following equation

$$C_K = (E_K \times X_K ((C_{I,K} + (T_P \times C_{O,K} \times (1/W_O) + (C_{R,K} \times W_R) + C_{EM,K} \quad (6)$$

where E_K is the energy source component output energy, X_K is the number of energy source components, $C_{I,K}$ is the initial cost, $C_{O,K}$ is the operation cost, $C_{R,K}$ is the replacement cost, and $C_{EM,K}$ is the carbon dioxide emission cost. W_O is the capital recovery factor and W_R is single payment present worth, which are calculated respectively using the following equations [6-8].

$$Wo=\frac{(i+1)^{Tp}-1}{i(i+1)^{Tp}} \tag{7}$$

$$Wr=\frac{1}{(1+i)^{L\times n}} \tag{8}$$

where i is the real interest rate, which is 8.75 % according to the central bank of Egypt rate, T_P is the project lifetime (25 years), L is the lifetime of the energy source component, and n is the number of replacements.

3.3 System Parameters

Table 3 shows the system parameter.

Table 3
System parameters

Parameter	PV panels	Wind turbine	Diesel Generator	Reference
Initial Cost ($/KWh)	$ 0.057	$ 0.039	$0.11	[17]
O&M Cost ($/KW per year)	$ 0.02 – 0.04	$ 0.017-0.030	$0.02	Homer, [17]
Replacement cost ($/KW)	No replacement	80 % of initial	80 % of initial	[7]
Lifetime (yrs.)	25	20	26280 h	[6,8]
E_M (g CO_2 per KWh)	40KgCO_2 Per Mwh	8.21 g Per KWh	2.4 - 2.8 Kg CO_2 Per Liter	[7,14,15]
C_{CO2}: ($/kg CO_2)	$ 17 – 80 Per ton of CO_2			[16]

3.4 System Objective Function and Constraints

The proposed Grey Wolf Algorithm (GWO) aims to optimize the configuration of the number of each energy source (PV, wind turbines and diesel generator) for the industrial load profile, where CO_2 emissions and Lifecycle cost (LCC) are minimized. A lifecycle of 25-years is considered.

The objective function of the GWO is expressed using the following equation

$$Min\ \begin{Bmatrix} f(LCC(X) \\ f\ (Em\ (X) \end{Bmatrix} \tag{9}$$

where X is a positive integer vector. The row consists of three elements (X_1, X_2 and X_3) and typically represents the system configuration. The first value is the number of PV arrays, the second value is the number of wind turbines and the third value is for the diesel generator required for the system. Vector X is depicted as follows

$$X=[\,X_1\,X_2\,X_3] \tag{10}$$

Subject to

$$E_{total} \geq E_{load} \tag{11}$$

where E_{total} is the total energy supplied by the PV and Wind systems and E_{Load} is the average daily load needed. E_{total} can be formulated as Follows.

$$E_{total} = X_1 \times E_{PV} + X_2 \times E_{wind} + X_2 \times E_{Diesel} \tag{12}$$

4. Grey Wolf Algorithm

In this paper Grey Wolf Algorithm is used, GWO is one of the leading algorithms in the optimization problems imitates the hierarchy of leadership and the mechanism of hunting of gray wolves in nature. Since it has a low number of variables, it can achieve optimization with very low execution. In this algorithm, four types of gray wolves, including alpha, beta, delta and omega, have been used to simulate the hierarchy of leadership. In addition, three main stages of hunting include prey search, prey siege, and attack are simulated.

The computation of the energy is done on an average daily basis, and then optimization is done to achieve the minimum cost and emission cost of the system for a maximum daily average energy. The GWO algorithm and flowchart are shown in Figures 5 and 6, respectively.

GWO is a hierarchal algorithm and it is based on the hunting behaviour of wolfs. When searching for quarry, wolves are classified into three main types

i. Alpha (α)
ii. Beta (β)
iii. Delta (δ)

Based on their position to the prey, α possesses the nearest position and δ the farthest position, three main steps in the hunting behaviour of the wolves are illustrated as: example

i. Searching for the prey
ii. Pursuing and encircling
iii. Attacking

An essential step in these procedures is the encircling. And for that GWO is scientifically represented as

$$\vec{Dg} = \left| \vec{C} \cdot \vec{K}_p(N) - \vec{K}_p(N) \right| \tag{13}$$

where N is the current iteration, Dg, A, and C is coefficient vectors, Kp is the position vector of the prey, and K indicates the position vector of the wolf. The vectors A and C are formulated as

$$\vec{A} = 2\,\vec{a} \cdot \vec{r_1} - \vec{a} \tag{14}$$

$$\vec{C} = 2\,\vec{r_2} \tag{15}$$

where r_1 & r_2 are random numbers in [0, 1].

4.1 GWO Algorithm Process & Flow Chart

The GWO algorithm and flowchart are shown in Figure 5 and 6, respectively.

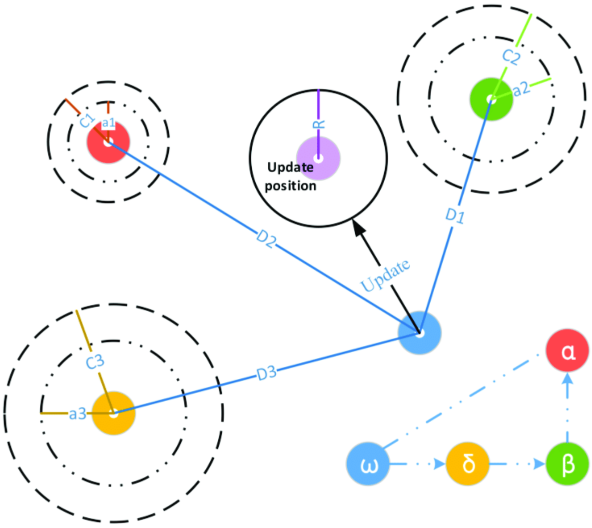

Fig. 5. GWO algorithm

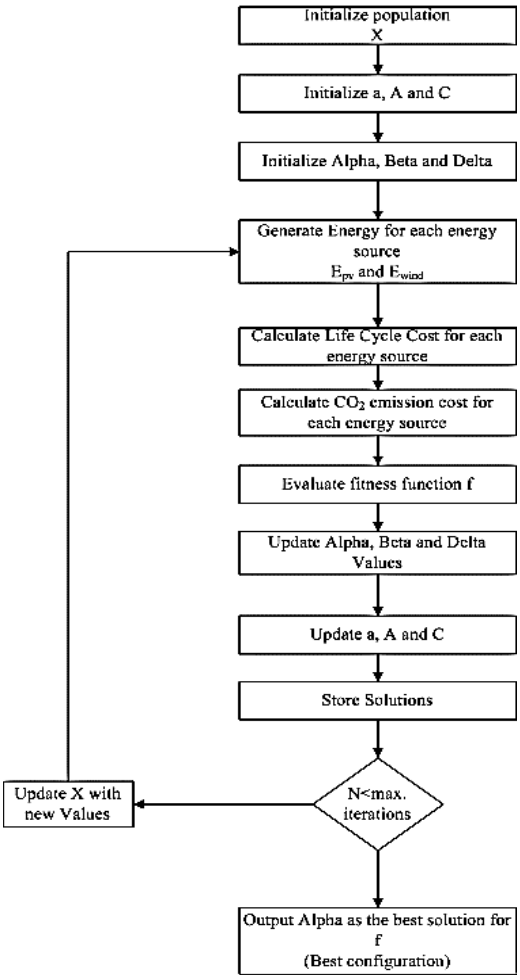

Fig. 6. GWO flow chart

5. Tested System Simulation

The GWO is used to determine the number of PV modules and the number of Wind stations to be used to supply the average daily load of the site. The site uses an average daily load of 14 MWh/day and the load is distributed as shown in Figure 2.

Simulation is done by MATLAB using the PV module and wind turbine data sheets provided in Section 2. The lower and upper boundaries are suggested to be 10 and 700 (modules or turbines) respectively, the suggestion is according to minimum and maximum load, related energy output, and available area consideration.

5.1 Case 1

In case 1 the simulation is done using only PV and Wind power generation with considering two factors, covering the model load during the operating hours of the utilized sources according to allocated weather data. The optimization is done to determine the best configuration between PV modules and Wind turbines number to provide low cost and low emission whilst maintain the maximum power needed. The results shown in Figure 7 represents the daily average generated power of the PV modules and the Wind turbines (combined) in addition to the daily average load power.

The results in Figure 7 shows that the total generated power is higher than that of the load, so there is a dumped energy that is not used which is shown in Figure 8. The Cost and CO_2 emission cost are shown in the following Figure 9 and Figure 10. The optimization process is clear that the cost and emission cost is lowered while maintaining the highest available power.

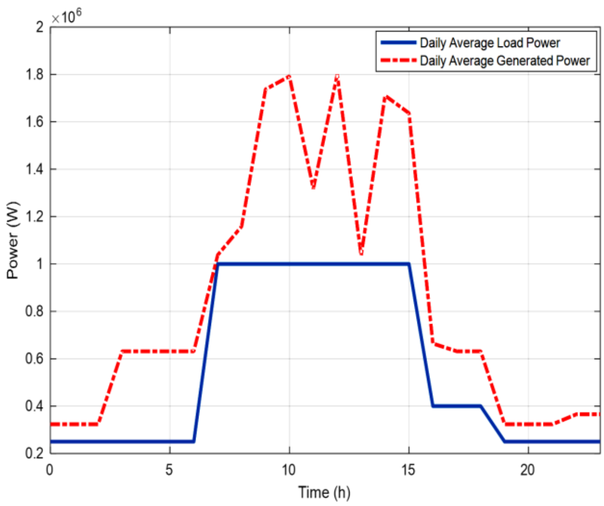

Fig. 7. Daily average generated power (PV and wind) vs daily average

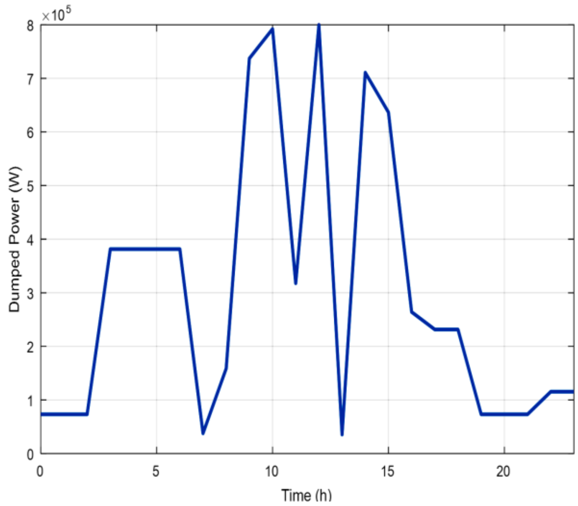

Fig. 8. Average daily dumped energy

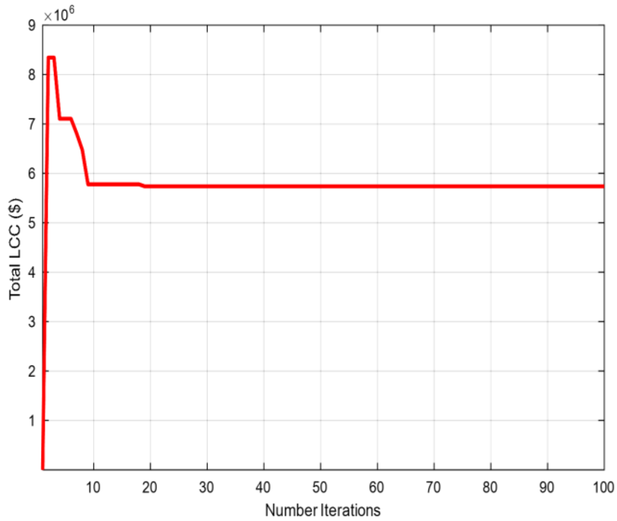

Fig. 9. LCC of the system

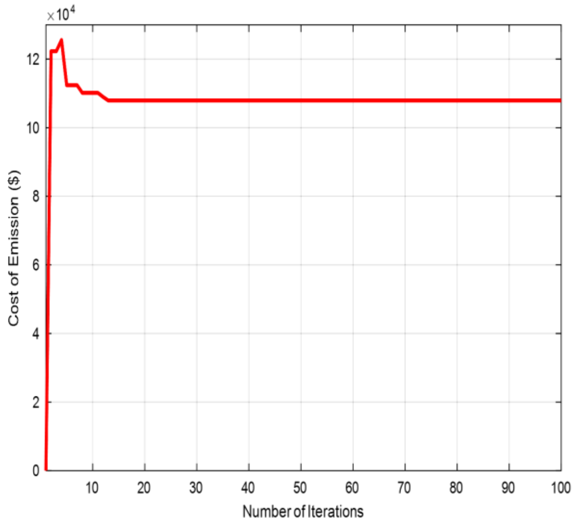

Fig. 10. CO_2 emission cost of the system

5.2 Case 2

In case 2 the simulation is done by combining PV, Wind and diesel generator. The diesel generator is used to make the system more reliable and in case of any fault in any of the other sources (PV or wind) it can be used to supply power to the load. The generator used is 400 KW. The 400 KW generator is almost 40% of the maximum load power needed which is 1 MW.

The results shown in Figure 11 represents the daily average generated power of the PV modules, Wind turbines and diesel generator (combined) in addition to the daily average load power. The diesel generator optimum schedule is shown in Figure 12. The optimum schedule is used to maintain a minimum dump energy as possible. As show in Figure 13 the total generated power is higher than that of the load, but there is also a dumped energy that is not used.

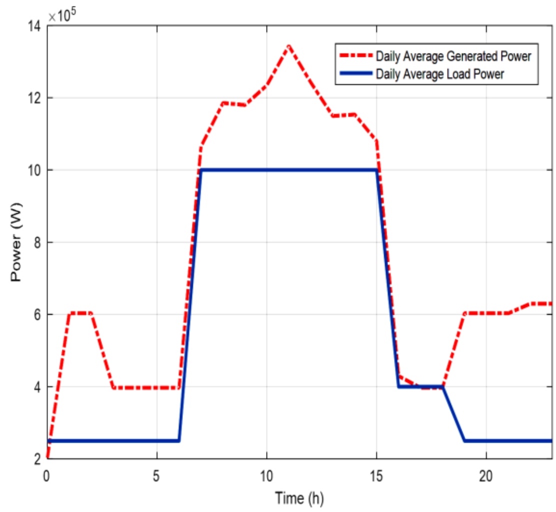

Fig. 11. Daily average generated power (PV & wind & diesel) vs daily average load power

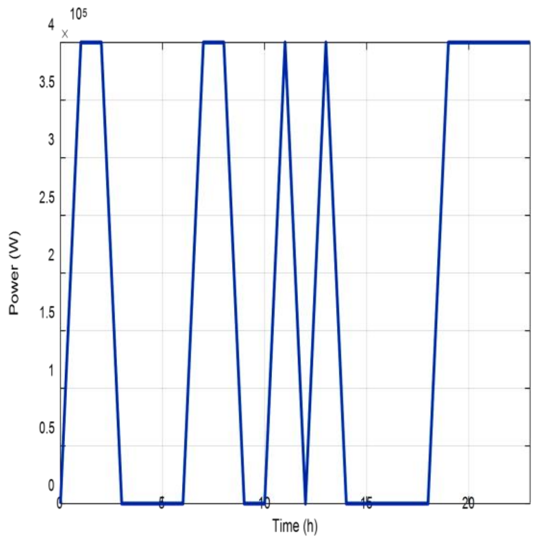

Fig. 12. Diesel generator operation schedule

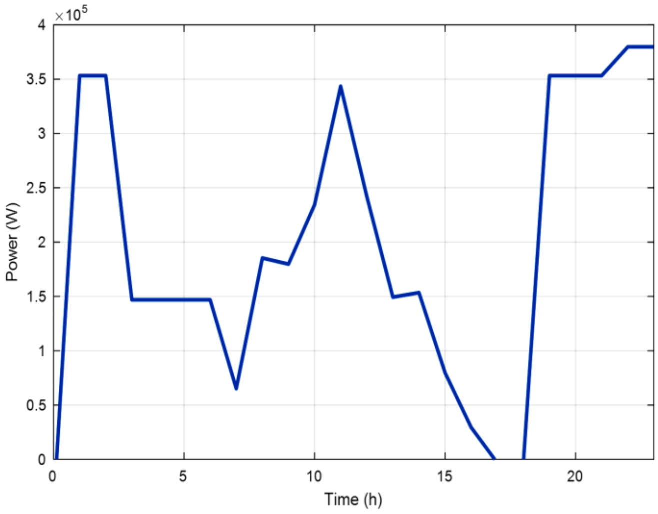

Fig. 13. Average daily dumped energy

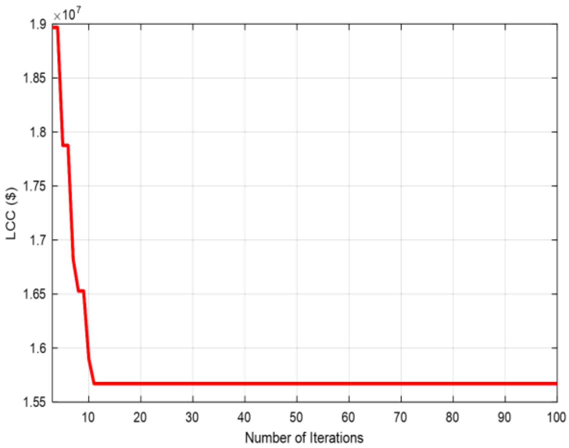

Fig. 14. LCC of the system

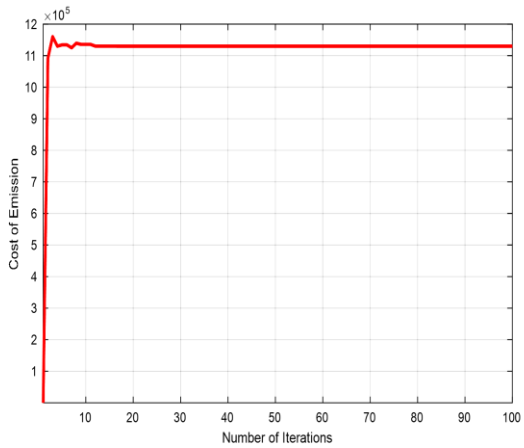

Fig. 15. CO_2 emission of the system

5.3 Case 3

In case 3 the results for case 1 and 2 is compared with grid power which is calculated using the following equation

$$C_{grid} = (E_{grid}(C_i + (Tp \times C_i \times (\frac{1}{Wo})) \tag{16}$$

where Egrid is the power supplied from the grid in KWh for the project life cycle, C_i is the cost of the Energy $/KWh which is 0.08$/KWh. T_P is the project life time (25 years), W_O is the growth rate and it's taken on average of 4% per year. These rates are given in the IRENA EGYPT report 2021, comparing three cases are shown in Table 4.

6. Conclusion

The results shows how the optimization process works in different scenarios, in the first scenario, 700 PV modules and 135 wind turbines are utilized to achieve the load coverage during the available time of these sources with minimum LCC and carbon emissions, but in the second scenario, 696 PV modules, 88 wind turbines and one diesel generator are utilized. In the third scenario, the first and the second scenarios are compared to a conventional power source operation. The results shows in the first scenario a lower LCC and carbon emission but with higher dump energy, the second scenario shows a lower dump energy but with higher LCC and carbon emission comparing to the first, the third scenario shows a very high LCC when compared with two previous scenarios respectively. From the results it can be concluded that both the RES scenarios are more appealing than the conventional model which support the aim of the paper to encourage the transformation of energy generation from fossil based to renewable sources. The comparison analysis is shown in Table 4.

For the robustness of the algorithm, among a 100 trials GWO have only a divergence of 2 PV modules and 2 wind turbines, statistical analysis of the algorithm is shown in Table 5.

Table 4
Comparing results for the three scenarios

Case	PV Module	Wind Turbine	Diesel Generator	Average Daily Energy	LCC	Co_2 Emission Cost	Total Cost ($LCC+Co_2$)	Dumped Energy
Case 1	700	135	0	14.02 MWh/day	$ 5.8 M	$ 108000	$ 5.908 M	7.15 MWh/day
Case 2	696	88	1	17.92 MWh/day	$ 15.5 M	$ 1150000	$ 16.65 M	4.723 MWh/day
Grid	-	-	-	14 MWh/day	-	-	$ 21.8 M	-

Table 5
Statistical analysis for GWO

Case	Mean Power Value	Standard Deviation	Optimum Number of PV panels/ Wind Turbines/Diesel Generator	Minimum Number of PV panels/ Wind Turbines	Maximum Number of PV panels/ Wind Turbines	Max. Energy/day
Case 1	1 MW	20 KW	700/135/0	698/133/0	700/136	14.02 MWh/day
Case 2	1 MW	20 KW	696/88/1	690/80/1	700/90/1	17.92 MWh/day

6.1 Future Work Approach

Comparing these paper results with new or other artificial intelligence techniques can be considered in future work, also adding a battery storage to the model can be considered as a comparing scenario with other RES models.

References

[1] IRENA, J. "World energy transitions outlook: 1.5° C pathway." *International Renewable Energy Agency* (2021).
[2] SDG, TRACKING. "The Energy Progress Report." *IEA: Paris, France* (2021).
[3] Fathima, A. Hina, and K. Palanisamy. "Optimization in microgrids with hybrid energy systems–A review." *Renewable and Sustainable Energy Reviews* 45 (2015): 431-446. https://doi.org/10.1016/j.rser.2015.01.059
[4] Dawoud, Samir M., Xiangning Lin, and Merfat I. Okba. "Hybrid renewable microgrid optimization techniques: A review." *Renewable and Sustainable Energy Reviews* 82 (2018): 2039-2052. https://doi.org/10.1016/j.rser.2017.08.007
[5] Iqbal, M., M. Azam, M. Naeem, A. S. Khwaja, and A. Anpalagan. "Optimization classification, algorithms and tools for renewable energy: A review." *Renewable and sustainable energy reviews* 39 (2014): 640-654. https://doi.org/10.1016/j.rser.2014.07.120

[6] Nadjemi, O., T. Nacer, A. Hamidat, and H. Salhi. "Optimal hybrid PV/wind energy system sizing: Application of cuckoo search algorithm for Algerian dairy farms." *Renewable and Sustainable Energy Reviews* 70 (2017): 1352-1365. https://doi.org/10.1016/j.rser.2016.12.038
[7] El-Amary, Noha H., Alsnosy Balbaa, R. A. Swief, and T. S. Abdel-Salam. "A reconfigured whale optimization technique (RWOT) for renewable electrical energy optimal scheduling impact on sustainable development applied to Damietta seaport, Egypt." *Energies* 11, no. 3 (2018): 535. https://doi.org/10.3390/en11030535
[8] Ogunjuyigbe, A. S. O., T. R. Ayodele, and O. A. Akinola. "Optimal allocation and sizing of PV/Wind/Split-diesel/Battery hybrid energy system for minimizing life cycle cost, carbon emission and dump energy of remote residential building." *Applied Energy* 171 (2016): 153-171. https://doi.org/10.1016/j.apenergy.2016.03.051
[9] Duffie, John A., and William A. Beckman. "Solar engineering of thermal processes." *John Wiley & Sons*, (2013). https://doi.org/10.1002/9781118671603
[10] "Renewable energy statistics 2021." https://www.irena.org/publications/2021/Aug/Renewable-energy-statistics-2021.
[11] "NREL - Solar Industry Update 2021." https://search4.nrel.gov/texis/search/?pr=metanrel&query=PR-7A40-81325.
[12] "Egypt Solar Atlas 2018." https://globalsolaratlas.info/download/egypt.
[13] "DieselO&Mcosts."https://homerenergy.force.com/supportcenter/s/article/diesel-om-costs..
[14] Jufri, Fauzan Hanif, Dwi Riana Aryani, Iwa Garniwa, and Budi Sudiarto. "Optimal battery energy storage dispatch strategy for small-scale isolated hybrid renewable energy system with different load profile patterns." *Energies* 14, no. 11 (2021): 3139. https://doi.org/10.3390/en14113139
[15] Wu, Peishi, Xiaoming Ma, Junping Ji, and Yunrong Ma. "Review on life cycle assessment of greenhouse gas emission profit of solar photovoltaic systems." *Energy Procedia* 105 (2017): 1289-1294. https://doi.org/10.1016/j.egypro.2017.03.460
[16] IRENA, IR. "Renewable energy outlook: Egypt." *International Renewable Energy Agency Abu Dhabi* (2018).
[17] "Renewable Power Generation Costs in 2020," https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.
[18] Prakash, Gayathri, Harold Anuta, N. Wagner, and G. Gallina. "Future of wind-deployment, investment, technology, grid integration and socio-economic aspects." *International Renewable Energy Agency (IRENA)* (2019).
[19] Gielen, Dolf, Ricardo Gorini, Rodrigo Leme, Gayathri Prakash, Nicholas Wagner, Luis Janeiro, Sean Collins et al. "World energy transitions outlook: 1.5° C pathway." (2021).
[20] Xu, Daming, Longyun Kang, Liuchen Chang, and Binggang Cao. "Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithms." In *Canadian Conference on Electrical and Computer Engineering,* (2005): 1722-1725. https://doi.org/10.1109/CCECE.2005.1557315
[21] Fidalgo, J. N., JA Peças Lopes, and Vladimiro Miranda. "Neural networks applied to preventive control measures for the dynamic security of isolated power systems with renewables." *IEEE Transactions on Power Systems* 11, no. 4 (1996): 1811-1816. https://doi.org/10.1109/59.544647
[22] Jifang, A. Li, B. Tang Tianhao, and C. Han Jingang. "A neural network control strategy for multi-energy common dc bus hybrid power supply." In *SPEEDAM 2010*, (2010): 1827-1831. https://doi.org/10.1109/SPEEDAM.2010.5542240
[23] Quan, Duong Minh, Emanuele Ogliari, Francesco Grimaccia, Sonia Leva, and Marco Mussetta. "Hybrid model for hourly forecast of photovoltaic and wind power." In *2013 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, (2013): 1-6. https://doi.org/10.1109/FUZZ-IEEE.2013.6622453
[24] Hrayshat, Eyad S. "Techno-economic analysis of autonomous hybrid photovoltaic-diesel-battery system." *Energy for Sustainable Development* 13, no. 3 (2009): 143-150. https://doi.org/10.1016/j.esd.2009.07.003