# Economic Design and Simulation of a Building Integrated Stand-alone Hybrid PV-wind-battery System at Badr University, Egypt

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## ABSTRACT

*A thorough technical and financial analysis of the Hybrid Renewable Energy System (HRES) at the University of Badr is presented in this study. This paper seeks to determine whether it is possible to meet load demand using the system that has the lowest net present cost (NPC).*

*In order to achieve the best minimum objective value modified whale optimizer is used to choose the number of units among photovoltaic, wind, and battery banks. The widely used HOMER software, other optimizers are applied, and their results are compared with those obtained by the modified whale to confirm the system's dependability, an annual energy balance analysis and simulation performance are completed.*

*Wind energy, battery cost, and load have a greater impact on NPC than other factors, according to sensitivity analysis.*

*To evaluate the performance and dynamics of the system, modelling and simulation are performed using MATLAB-Simulink at different scenarios with MPPT and without MPPT and changing weather conditions speed and shown performance of state of charge of battery with change of weather.*

**Keyword : -***Optimization Techniques, Renewable energy, Hybrid system, simulation, Homer, Simulation.*

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## 1. Introduction

In the modern era, energy is regarded as an indicator of economic growth and the improvement of individuals' standard of living. The global demand for energy has been increasing at an unprecedented rate due to rising population, the introduction of new technologies, and rising energy consumption, resulting in a massive gap between supply and demand. Fossil fuels provide approximately 75% of the world's total energy requirement [1,2].

However, using diesel generators as a substitute has some disadvantages, including a lack of fossil fuels, environmental pollution, and high transportation costs [3]. For supplying electricity to such areas, renewable energy sources (RESs) have garnered a lot of attention globally.

Many studies have concentrated on using single renewable energy sources, such as solar or wind power-based systems. However, due to RESs' intermittent nature, this decision results in oversizing [4]. Hybrid RESs systems have the ability to address the oversizing issue and improve reliability in order to overcome the aforementioned difficulties [5,6]. Egypt, for example, has a distinct geographical location, and the government intends to diversify electric energy production in favor of RESs. Egypt receives 2900-3200 hours of sunlight per year [7].

Egypt has an average global horizontal radiation of 7 kWh/m$^2$, which is sufficient to generate enough solar power. Furthermore, some areas have average wind speeds of 10 m/s. Renewable energy technologies are gaining traction, with a total installed capacity of 2799 GW worldwide by the end of 2020 [8]. The shares of hydropower appear to be 1211 GW, 733 GW of solar power, 714 GW of wind power, and the remainder for other technologies.

There are few literature studies in Egypt for the feasibility analysis of implementing renewable resources in university buildings at Badr University. Optimised hybrid-grid design and performance for a university educational building. According to the simulation results, the developed hybrid renewable energy system could meet the load demand with the best optimization results by combining solar energy, wind energy, and a battery system.

The study investigates the HRES from a technological and economic standpoint, employing well-known software HOMER or developed mathematical models for optimization. The unpredictability of renewable resources is a barrier to the development of renewable projects. Renewable energy systems that are more reliable, effective, and economically viable can be established by combining various renewable energy sources such as wind and solar into a hybrid system that uses batteries or backup units similar to conventional energy generators or grids. These systems' precise design is a critical step towards their effective deployment [9].

Various methods for stand-alone RESs planning can be found in the literature; they rely on either commercial software such as HOMER or mathematical models for optimization that have been developed. The authors presented a methodology for optimizing PV/wind/battery system configuration, and hybrid system scenarios were analyzed [10]. teaching-learning-based used optimizations to minimize NPC of a grid-connected PV/battery. During peak periods of electricity demand, it is heavily reliant on the grid [11]. Another PV/wind/battery cell backup system was designed to address the problem of power outages in remote districts [12].

It was optimized to reduce the levelized COE in a micro-grid that uses PV and batteries [13]. Battery bank depth of discharge and PV tilt angle were taken into consideration in addition to the number of PV and batteries. The results of improved harmony search and simulated annealing algorithm comparisons for PV/battery system optimization are presented in [14].

In this paper, two goals are taken into consideration. These include the achievement of system reliability and the minimization of costs. In order to supply electricity to the university, the goal of this paper is to optimize hybrid renewable energy system in terms of total NPC and LPSP (loss of power supply probability). In this study, Modified particle swarm optimization (MPSO) & Multi objective Evolutionary Algorithm (Ev-moga) & Non-dominated Sorting Genetic Algorithm (Nsaga II) and modified whale Optimization Algorithm (MWOA) is used to determine the best values for three decision variables, including the number of batteries, the total area occupied by PV panels, and the total area swept by rotating turbine blades.

In this research, two objective functions are minimized, the project's NPC is its primary goal, and LPSP minimization is its secondary goal.

A mathematical model and operating theory for a hybrid PV/wind system are developed by research at BADR University in Cairo (BUC), which also shows that HRES is fully capable of supplying electricity on its own [15]. However, no study has created a mathematical model for the stand-alone HRES designing that considers the saturation of each available RE resource at the design stage to mitigate RE's inherent intermittency and reliability problem. Instead, the literature has used a variety of software, algorithms, numerical methods, and intuitive methods to compare autonomous HRES [16,17,18,19].

The main goal of this research is to implement a well-defined control strategy for standalone Hybrid Renewable Energy Systems (HRES) that has a low level of complexity in terms of Maximum Power Point Tracking (MPPT) with a small number of components in order to lower costs and produce high-quality, reliable output.

The simulation is carried out using MATLAB-Simulink to evaluate the performance and dynamics of the system, considering four scenarios: (1) Maximum Power Point Tracking (MPPT) with a limited number of components. (2) comparison between MPPT and without MPPT with a limited number of components. (3) System’s dynamics and performance with change PV radiation scenario. (4) System’s dynamics and performance with change wind speed scenario. The simulation results show that the proposed system can use an efficient battery charging control configuration, eliminating the need for a specific battery converter, providing high output power quality with THD below 1% in steady-state, and sustaining output voltage magnitude and frequency under changing system dynamics [20].

## 2. Load Specification of Proposed Site and Load Demand

BADR university selected as case study and as a sample in this paper which is located at Egypt via Ismailia Agriculture Rd.

HRES systems are built using historical University electricity consumption data. This medium-sized institution is located at 30° 7′ 41.83″ N, 31° 42′ 11.96″ E, Long-term hourly solar radiation, wind speed, and air temperature data for a nearby station. The simulations were carried out using meteorological data from the NASA website and a load profile over the course of one year (2021), as shown in table1.

**Table 1**

*average and peak load of study area.*

| Particulars | Details |
|---|---|
| Average (kwh/d) | 31,137 |
| Average (kw) | 1297.4 |
| Peak (kw) | 4911.9 |
| Load factor | 0.26 |

The goal of this approach is to conduct a feasibility analysis for various locations based on weather data and available resources. The BADR university chose a test on the feasibility of HRES, Data was obtained from the Canal Company for Electricity Distribution's control department. Fig.1 depicts the daily profile load, while Fig.2 depicts the monthly profile.

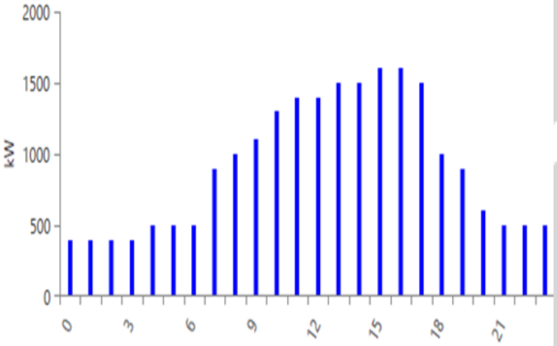


**Fig. 1**- Daily profile

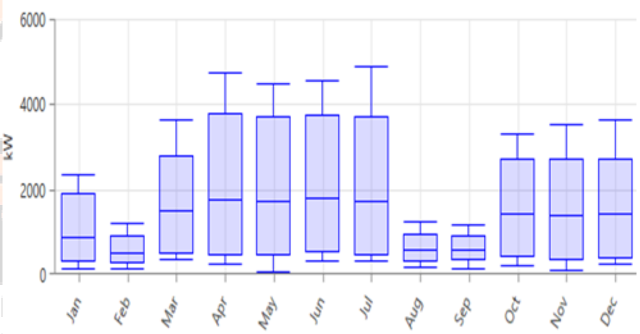


**Fig. 2**- Monthly average electrical load demand

From Fig. 2 Colum's presents max kw, average day max kw, average kw, average day min kw and min kw.

## 3. Climate And Environmental Specification of Proposed Site.

HOMER programmer uses The NASA website to obtain the monthly average wind speed, global horizontal irradiation (GHI), and ambient temperature as input parameters.

It shows that solar radiation is at its highest in the summer and at its lowest in the winter. It is evident that Badr University experiences a monthly solar radiation peak of almost 7.79 kWh/m$^2$. According to Fig. 3, Badr University has the lowest solar irradiation at almost 3.9 kWh/m$^2$. University receives 6.02 kWh/m$^2$ of solar radiation on a monthly average.

the variation in monthly average wind energy for the university location. Monthly peak wind speed at Badr University is close to 6.45 m/s. According to Fig. 4, Badr University has the lowest wind speed which is almost 4.9 m/s and 5.71 m/s is average monthly wind speed at university with Hight 50 m.

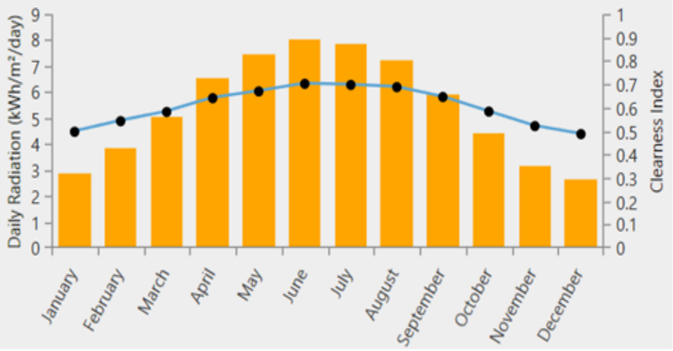
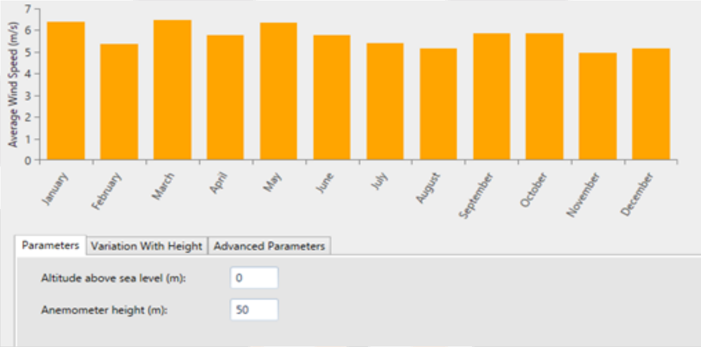


**Fig. 3**- Monthly average global horizontal irradiation with clearance index



Altitude above sea level (m): 0

Anemometer height (m): 50

**Fig. 4**- Monthly average wind speed

## 4. System Component Specification Of Proposed Configurations.

The HOMER software optimizer determines the best size for each component in terms of capacity. The suggested configurations with various schemes include a wind turbine, PV, and batteries.

There are several configurations available through the HOMER software to reduce COE and NPC, operation, and maintenance (O&M) costs while still meeting demand loads.

Each component's economic and technical details are as follows:

**Table 2**

*displays the economic and technical specifications of wind turbine.*

| Description | Specification | Unit |
|---|---|---|
| wind turbine | Generic 10kw | ---- |
| Rated power | 10 | kW |
| rated wind speed | 5.71 | m/s |
| Capital cost | 2.0<br>505.6 | \$/W<br>$\$/m^2$ |
| Replacement cost | 0 | \$/unit |
| O&M cost | 5.1<br>(0.01 capital cost) | $\$/m^2$ |
| Lifetime | 20 | year |
| Interest rate | 0.16 | |
| Annual rate | 0.075 | |

**Table 3**

*displays the economic and technical specifications of PV model.*

| **Description** | **Specification** | **Unit** |
|---|---|---|
| PV model | Longi solar panel | ---- |
| Rated power | 350 | W |
| Temp. coefficient | -0.410 | %/℃ |
| Operating temp. | 45 | ℃ |
| Capital cost | 2.0<br>328.3 | $\$/W$<br>$\$/m^2$ |
| Replacement cost | 0 | $\$/module$ |
| O&M cost | 10<br>(1.64) | $\$/kW/year$<br>$\$/m^2$ /year |
| Lifetime | 20 | year |
| Interest rate | 0.16 | |
| Annual rate | 0.075 | |

**Table 4**

*displays the economic and technical specifications of battery.*

| **Description** | **Specification** | **Unit** |
|---|---|---|
| Type of battery | Generic 100kw/h | --- |
| Nominal voltage | 600 | V |
| Nominal capacity | 100 | kWh |
| Capital cost | 350 | $\$/unit$ |
| Replacement cost | 350 | $\$/unit$ |
| O&M cost | 0 | $\$/unit$ |
| Lifetime | 5 | year |
| Battery charge efficiency | 82% | |
| efficiency<br>Maximum depth of discharge | 0.5 | |

**Table5**

*displays the economic and technical specifications of Converter model.*

| **Description** | **Specification** | **Unit** |
|---|---|---|
| Converter model | PRETTL REFUsol24K | -- |
| Inverter efficiency | 90 | % |
| Rectifier efficiency | 85 | % |
| Capital cost | 110 | $\$/kW$ |
| Replacement cost | 110 | $\$/kW$ |
| O&M cost | 0 | $\$/year$ |
| Lifetime | 20 | year |

## 5. Mathematical Model of Proposed Configurations

In this study, technical and financial modelling of each system component are the two goals needed to identify the objectives. The modelling of the components is described in the ensuing subsections:

## A. Technical modelling

### 1. PV Array Output Power

The equation for the power supplied by a set of PV panels at hour t:

$$P_{PV}(t) = \eta_{PV}.A_{PV}.S(t) \tag{1}$$

where, $\eta_{PV}$ denotes PV panels efficiency.
$A_{PV}$ is the total area occupied by PV panels in $m^2$ and
S(t) is the hourly solar insolation in $kW/m^2$.

### 2. Wind Generator Output

The power curve shown in Fig. 5 depicts a model for output power calculation.

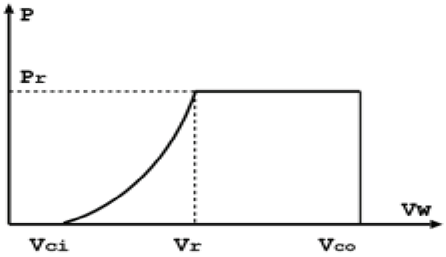


**Fig. 5**- typical wind generator power curve

There is no power production from wind turbines under cut-in speed $V_{ci}$, As wind speed rises above cut-in speed, the power produced by the turbines increases as the cube of wind speed, till reaching a maximum point at rated speed ($V_r$ ).This is the power the wind turbine is proposed for rated power ($p_r$) in kW As it is seen, at some point the wind speed is very strong so there is danger to the wind turbine. This is called cut-off speed ($V_{co}$). and the machine should be stopped. The mathematical model of this behaviour is as follows:

$$P_w(t) = \begin{cases} 0 & v(t) \leqslant v_{ci} \text{ or } v(t) \geqslant v_{co} \\ P_r \dfrac{v^3(t) - v_{ci}{}^3}{v_r{}^3 - v_{ci}{}^3} & v_{ci} < v(t) < v_r \\ p_r & v_r < v(t) < v_{co} \end{cases} \tag{2}$$

where, v(t) is the wind speed in time t in m/s.
The rated power of wind turbine generator at hour t is calculated by the following equation.

$$P_r = \frac{1}{2}.C_p.P_\sigma.\eta_g.A_w.v_r{}^3 \tag{3}$$

where, $C_p$ is power coefficient and it is the ratio of the power output of a wind generator divided by maximum power. $P_\sigma$ is the air density in $kg/m^3$. $\eta_g$ is the efficiency of wind turbine, and $A_w$ is the total swept area by the rotating turbines' blades in $m^2$.
As can be seen, wind power is inversely proportional to wind speed cube, so even a slight increase in wind speed can have an effect. Putting the turbine on a taller tower is one way to get more wind output. High irregularities, such as forests and buildings, slow surface winds. The impact of the earth's surface's roughness on wind speed is represented by the following equation:

$$\frac{v}{v_o} = \left(\frac{h}{h_o}\right)^\alpha \tag{4}$$

where, $v$ and $v_o$ are the wind speeds at height $h$ and $h_o$ respectively, and α is the roughness factor. The α value is less than 0.1 for flat land, water, or ice and more than 0.25 for forested landscapes.

### 3. Battery

The amount of energy generated by the grid, PV panel array and wind turbine at hour t is:

$$P_g(t) = P_{pv}(t) + P_w(t) + P_{grid} \qquad (5)$$

Depending on the load demand $P_l$ the amount of $P_g$ at a specific time can be enough or not to meet the power demand. As a result, state of charge of the battery (SOC) at any time t can be found as follows:

If $P_g(t) \geqslant \frac{P_l(t)}{\eta_{inv}}$, then there exists surplus energy by which the battery can be charged. During charging, the SOC is calculated as follows:

$$SOC(t) = SOC(t-1).(1-\sigma) + \left(P_g(t) - \frac{P_l(t)}{\eta_{inv}}\right).\eta_{bc} \qquad (6)$$

where, SOC (t) and SOC (t-1) are states of charge of the battery in time t and t-1 respectively. σ is hourly self-discharge rate, $\eta_{inv}$is efficiency of the inverter and $\eta_{bc}$is the battery charging efficiency. Since state of charge of the battery cannot exceed the maximum state of charge, so during optimization the following constraint should be considered.

$$\text{SOC (t)} \leqslant SOC_{max} \qquad (7)$$

where, maximum state of charge of the battery is the nominal capacity of the battery bank ($C_b$).

If $P_g(t) \leqslant \frac{P_l(t)}{\eta_{inv}}$, then there exists deficit of energy fromand the load is supplied by the storage systems. $P_g$ During discharging, the state of charge can be obtained as follows:

$$SOC(t) = SOC(t-1).(1-\sigma) + \left(\frac{P_l(t)}{\eta_{inv}} - P_g(t)\right)/\eta_{bd} \qquad (8)$$

where, $\eta_{bd}$is discharge efficiency of the battery.

To extend the battery's lifespan, the state of charge should not drop below the minimum state of charge, so during optimization, the following restriction should be applied to the battery's discharge time:

$$\text{SOC (t)} \geqslant SOC_{max} \qquad (9)$$

The minimum state of charge can be obtained as follows:

$$SOC_{min} = (1 - DOD).C_b \qquad (10)$$

Where DOD is the maximum depth of discharge.

### 4. Power converter modelling

The generated power from PV is DC and that from the wind turbine is AC. To supply AC load, a power converter is used to link DC and AC buses. The converter size ($P_{conv}$) is selected based on load maximum demand ($P_{peak}$) and inverter efficiency ($\eta_{inv}$).

$$P_{conv}(t) = \frac{P_{peak}(t)}{\eta_{inv}} \qquad (11)$$

## <u>B. Economic analysis.</u>

The economic model is used for assessing the total cost of the developed systems. The NPC is the difference between the total cost of installation and operation of the system and the total earned revenues over the project lifetime NPC and capital recovery are calculated based on the following equations (12,13,14):

The cost of the developed systems is determined using the economic model. NPC is the Sum of the present value of all costs over the period of interest, including residual values such as negative costs during the project's lifespan. Based on the following equations, NPC and capital recovery are computed:

$$NPC(\$) = \frac{TAC}{CRF\ (i, R_{prj})} \qquad (12)$$

$$CRF\ (\$) = \frac{i \times (1+i)^N}{(1+i)^N - 1} \qquad (13)$$

$$i = \frac{i` - f}{1 + f} \qquad (14)$$

where, TAC is the total annualized cost ($); CRF is the capital recovery factor; $R_{prj}$is the annual project lifetime; N is the number of years; i is the annual real interest rate (%); i` is the nominal interest rate which equals 6% in the proposed system; f is the annual inflation rate which equals 3%.

**1. PV Array NPC**

The capital cost of the investment for PV array is equal to the initial cost $/m$^2$ of PV array multiplied by the total area m$^2$ occupied by PV array:

$$C_{PV} = \alpha_{PV} . A_{PV} \qquad (15)$$

The total operation and maintenance cost of PV array per year is.

$$OM_{pv} = \beta_{pv} . A_{pv} \qquad (16)$$

Where $\beta_{pv}$ is the annual operation and maintenance cost in $/m$^2$ /year. Now, if the cost grows at an annual rate of $\mu_{pv}$ the sum of the net present value of operating and maintenance cost for PV array is:

$$OM_{npv,pv} = \beta_{pv} . A_{pv} . \sum_{j=1}^{N} \left(\frac{1+\mu_{pv}}{1+j}\right)^{j} \qquad (17)$$

**2. wind turbine**

The capital cost of the investment for wind turbine is equal to the initial cost $/m$^2$ of WT multiplied by the total area m$^2$ occupied by WT:

$$C_{wt} = \alpha_{wt} . A_{wt} \qquad (18)$$

The total operation and maintenance cost of WT per year is.

$$OM_{wt} = \beta_{wt} . A_{wt} \qquad (19)$$

Where $\beta_{wt}$ is the annual operation and maintenance cost in $/m$^2$ /year. Now, if the cost grows at an annual rate of $\mu_{wt}$ the sum of the net present value of operating and maintenance cost for WT array is:

$$OM_{nwt,wt} = \beta_{wt} . A_{wt} . \sum_{j=1}^{N} \left(\frac{1+\mu_{wt}}{1+j}\right)^{j} \qquad (20)$$

Where, $i$ is the interest rate anddenotes the project lifetime. By assuming the lifetime span of WT panels $N$ equal to the project lifetime, the total replacement cost for WT panels is zero ( $R_{WT} = 0$).

**3. Battery Storage**

The capital cost of the investment for the storage system is:

$$C_{bat} = N_{bat} . \alpha_{bat} \qquad (21)$$

where, $N_{bat}$ is the number of batteries and $\alpha_{bat}$ denotes the unit cost of battery in $. The lifetime of battery ($L_{bat}$) is less than that of the PV array and WTs. Therefore, additional investments are required before the end of the project. The number of times during lifetime of a project that a battery is required to be replaced is.

$$X_r = \frac{N}{L_{bat}} - 1 \qquad (22)$$

In this research, the lifetime of the project is selected 20 years, and the lifetime of each battery is 5 years, so each battery must be replaced 3 times during the lifetime of the project. Finally, the net present value of the replacement cost is:

$$R_{npv,bat} = N_{bat} . \alpha_{bat} . \sum_{j=5,10,15} \left(\frac{1+\mu_{bat}}{1+i}\right)^{j} \qquad (23)$$

In this study, the operation and maintenance cost and salvage value of the battery are neglected.

## 6. Discussion Homer Results.

The simulation process serves two purposes. First, it determines whether the system is feasible or not. HOMER considers the system to be feasible if it can adequately serve the electric load and satisfy other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. To be equitable, such comparisons must account for both capital and operating costs. Life-cycle cost analysis includes all costs that occur within the life span of the system. HOMER uses NPC to represent the life-cycle cost of a system.

The simulation process accomplishes two objectives. It starts by assessing the system's viability. If the system can serve the electric load adequately and adhere to any additional user-imposed requirements, HOMER deems it to be feasible. Second, it calculates the system's life-cycle cost, or the total cost of setting up and running the system over the course of its lifetime. Such comparisons must consider both capital and operating costs to be fair. The costs that arise over the course of a system's lifetime are all considered in the life-cycle cost analysis. The life-cycle costs of a system are represented by HOMER using NPC.

The decided configuration of the hybrid PV\WT\battery system is illustrated in Fig. 6

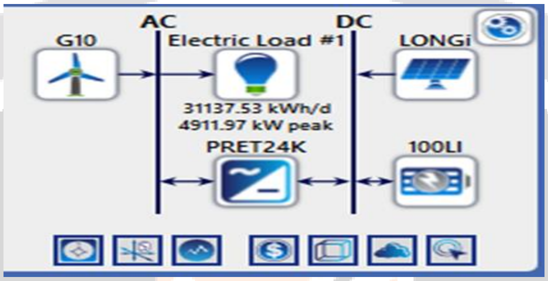
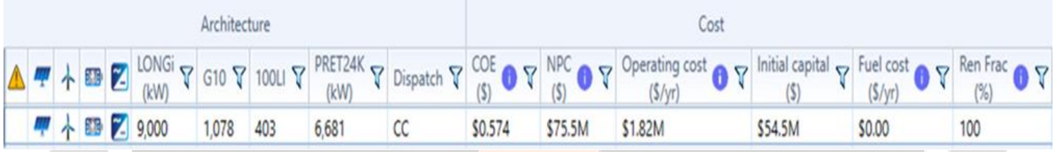


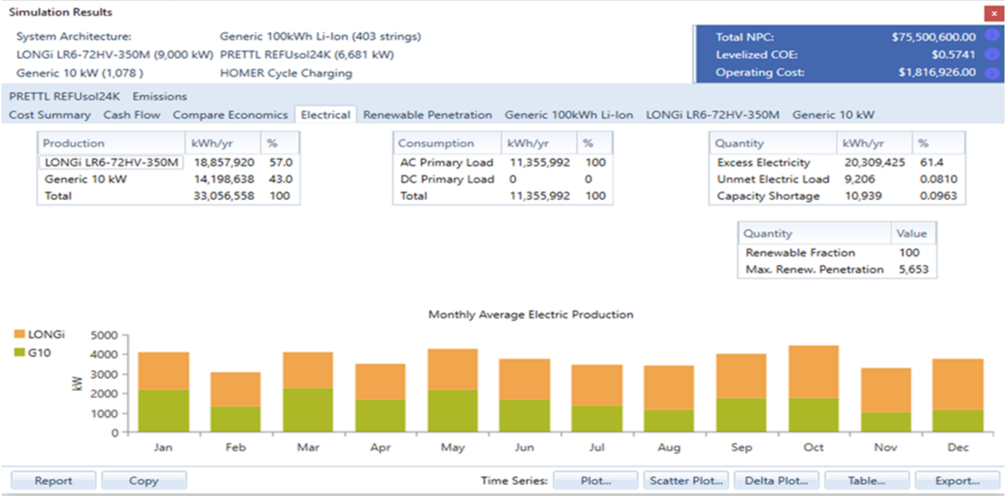
**Fig. 6**- Schematic model of the hybrid system



| | | | | | Architecture | | | | | Cost | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⚠ | | | | | LONGi (kW) | G10 | 100LI | PRET24K (kW) | Dispatch | COE ($) | NPC ($) | Operating cost ($/yr) | Initial capital ($) | Fuel cost ($/yr) | Ren Frac (%) |
| | | | | | 9,000 | 1,078 | 403 | 6,681 | CC | $0.574 | $75.5M | $1.82M | $54.5M | $0.00 | 100 |

**Fig. 7**- Simulation results for isolated hybrid micro-grid EVCS composed of PV module / wind with storage battery.

Fig. 7 presents the categorized results required to achieve average and peak load of study area as illustrated in Table 1. The optimal system is composed of 9000 kW PV (25714 units × 0.350 kW), 1078 wt. units (Generic 10kw),403 batteries (100 kwh) and 6681 kW converter (PRETTL REFUsol24K). The COE is 0.574 $/kWh. The obtained system has NPC of $75.5M. The operating cost per year is $1.82M. PV panel production 57% kwh/y and wind power produced 43% kwh/y as shown in Fig. 8.



Simulation Results

System Architecture: Generic 100kWh Li-Ion (403 strings)
LONGi LR6-72HV-350M (9,000 kW) PRETTL REFUsol24K (6,681 kW)
Generic 10 kW (1,078 ) HOMER Cycle Charging

Total NPC: $75,500,600.00
Levelized COE: $0.5741
Operating Cost: $1,816,926.00

| Production | kWh/yr | % |
|---|---|---|
| LONGi LR6-72HV-350M | 18,857,920 | 57.0 |
| Generic 10 kW | 14,198,638 | 43.0 |
| Total | 33,056,558 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 11,355,992 | 100 |
| DC Primary Load | 0 | 0 |
| Total | 11,355,992 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 20,309,425 | 61.4 |
| Unmet Electric Load | 9,206 | 0.0810 |
| Capacity Shortage | 10,939 | 0.0963 |

| Quantity | Value |
|---|---|
| Renewable Fraction | 100 |
| Max. Renew. Penetration | 5,653 |

**Fig. 8**- Average electric production for isolated hybrid composed of PV module / wind with storage battery.

## 7. Objective Functions Result (Meta-heuristic algorithms outputs):

Results of simulation the total NPC of the project and the LPSP are two fitness functions that are suggested to be minimized. The two objective functions have been minimized by using MPSO & EVMOGA &NSAGA II and modified whale optimizers to determine the best values for the decision variables.

MATLAB is used to simulate the suggested methodology. The simulations were carried out using meteorological data from the NASA website [7,8] and a load profile over the course of one year (2021) with the average one day of 12 months (288 hour).

A hybrid renewable energy system (PV/WT/battery) constraints two objective functions are thought to be minimized in this study. The project's NPC should be kept to a minimum, and LPSP (Loss of power supply probability mean the difference between p generation and p load) should be minimized, the fitness functions are therefore defined as follows:

Besides, the constraints are mentioned in the part of the state of charge of the battery. The restrictions in the objective functions are.

$$F1= \quad NPC(\$) = \frac{TAC}{CRF\ (i, R_{prj})} \tag{24}$$

$$F2=LPSP \quad = \quad SUM\ (error) \ = P_L - P_{gu} \tag{25}$$

Where $P_{gu}$ is power of hybrid renewable energy system (PV/WT/battery) $P_L$ load power.

Meta-heuristic algorithms outputs (Comparison among algorithms).

With trial-and-error methodology, the best system performance is got with inputs search space of The NSAGA п, MPSO, EVMOGA and Modified WHALE Meta-heuristic algorithms outputs (Comparison among algorithms) runs with 200 population size and maximum iterations of 100 and the best results are. cropped. The statistical measures of the obtained results by these optimizers are shown in **Table 6**.

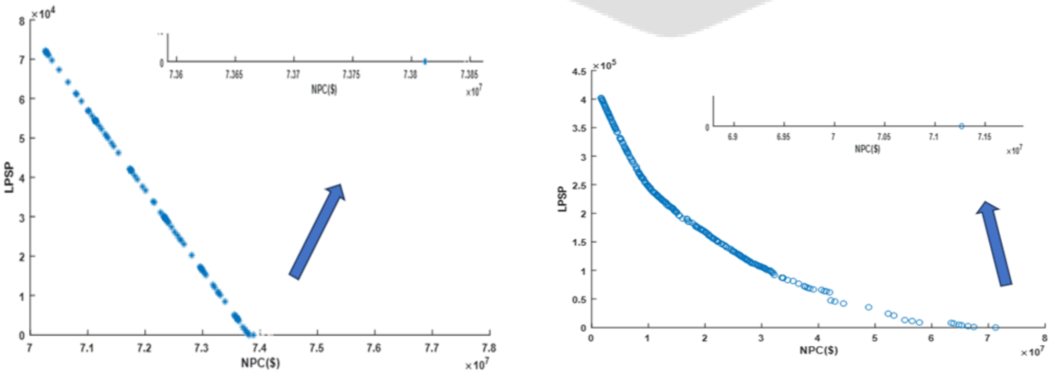
**Table 6**

*The statistical measures of the obtained results.*

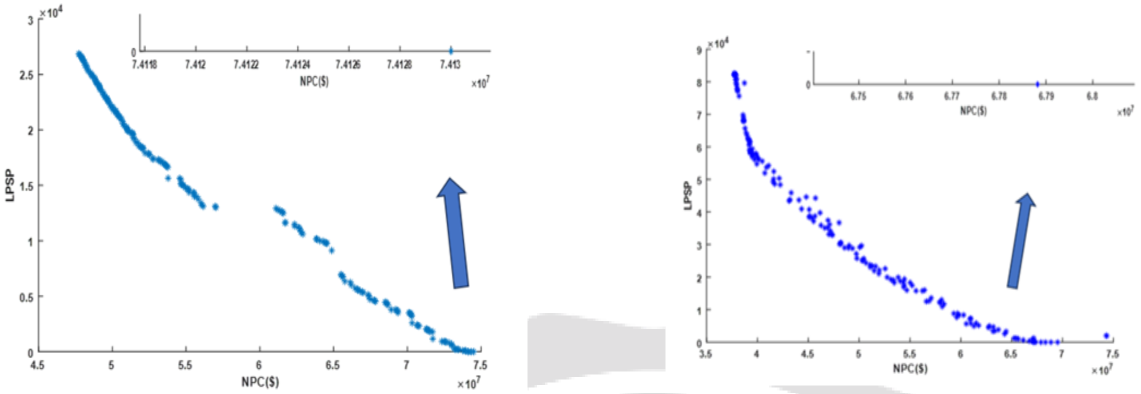
| Index | Value |
|---|---|
| Population size | 200 |
| Number of generations | 100 |
| Lower Bound of Variables | [0 0 0] |
| upper Bound of Variables | [100000 100000 100000] |

Fig. 9 explain Pareto fronts with different algorithm, As shown modified whale has better rate of convergence and statistical measures compared with other optimizers explains the optimal results of all algorithms with their lowest NPC and generate power equal to demand. Table 7 explains the optimal results of all algorithms with their NPC and power generation equal with demand.

the LCC decreases when LPSP increases and rises when LPSP gets down. The optimal size and the minimized values of the two objectives are shown in table 7.



(a) (b)



(c) (d)

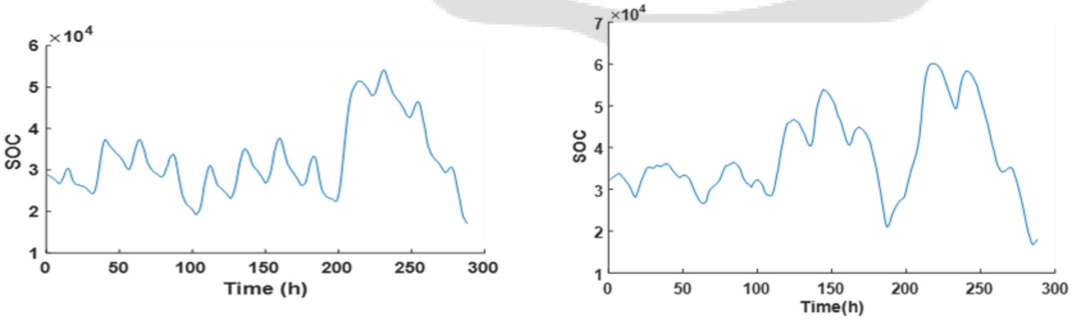
**Fig.9**- different algorithms pareto front (a)MPSO (b) Ev-moga (c)Nsaga-II (d) Modified whale

**Table 7**

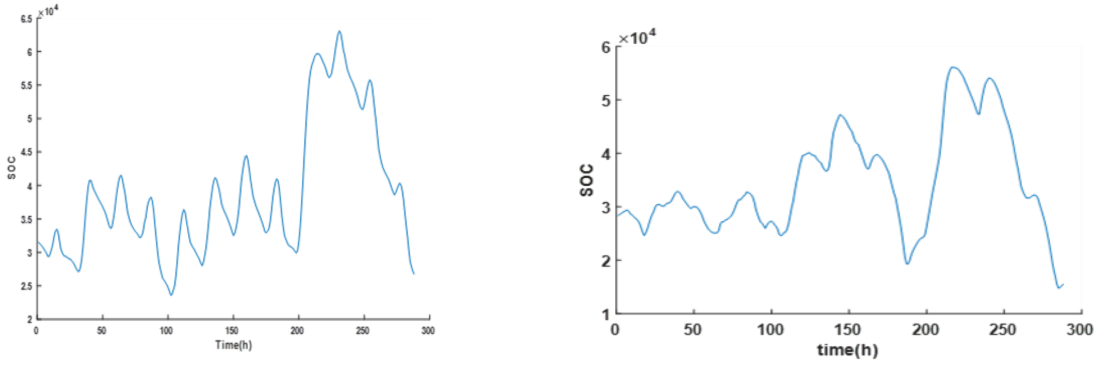
*The optimal results of all algorithms with their NPC and power generation equal demand.*

| | Pv longi 350w | Generic 10kw | No.Generic 100kwh | No. converter | Cost | LPSP (P generation- P load) |
|---|---|---|---|---|---|---|
| Homer | 25714 | 1078 | 403 | 6681 | 75M | 0.00 |
| MPSO | 19638 | 1066.20 | 800 | 6681 | 73M | 0.00 |
| Evmoga | 37903 | 792.94 | 758 | 6681 | 71M | 0.00 |
| nsga2 | 73945 | 300.63 | 793 | 6681 | 74M | 0.00 |
| Modified whale | 22797 | 1021.50 | 709 | 6681 | 67M | 0.00 |

To meet the demand, the battery is currently charged with the output power of WTs and PV. The state of charge of the battery bank is shown in Fig. 10 of each algorithm.



(a) (b)



(c) (d)

**Fig. 10**-SOC of battery (a)MPSO (b) Ev-moga (c)Nsaga-II (d) Modified whale

As it is seen in Fig. 11 total generated power and load demand are identical.

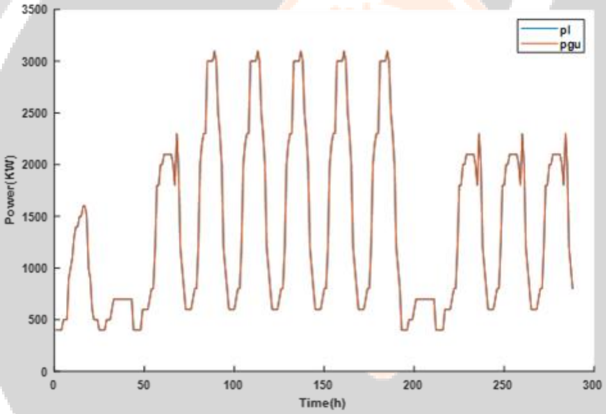


**Fig. 11**- Match power between total generated power and load demand.

It can be concluded from that the optimal results by modified whale have the lowest NPC as shown in table7 compared with other optimizer for the levels of LPSP. The optimum zero LPSP system configuration comprises of 22797 PV arrays (350 W), 1021 WT of (10 kW), 709 batteries (100 KWH) and 6681 converter units (24 kW) which is obtained by the modified whale and having NPC of 67M/$.

## 8. HRES Simulation MATLAB.

### Simulated Model Description

The load of the hybrid grid under study is made up of a combination of intermittent renewable energy sources. Using the outcome of modified whale optimization this assumed model is examined as an isolated power system. Photovoltaic (PV) technology is based on a fleet of solar panels that harness solar energy and a wind farm made up of wind turbines. The rated capacity of the PV farm is 7979 kW, while the capacity of the wind turbines is 10215 KW, and it uses 709 batteries by utilizing modified whale optimizer.

It is assumed that the complete hybrid system model will employ a load-following dispatch strategy. Only PV panels and wind turbines will be used in this strategy to recharge the battery storage component. The DC power generated by the PV modules needs to be converted into an AC source later using an inverter.

When there is extra energy after meeting the demand for the load, the PV and wind turbine will charge the battery storage component. According to the wind speed data, the afternoon tends to be windier than the morning. When the PV system is unable to supply enough energy to meet the entire load demand, wind turbines can always produce power for the system. In the worst case, the battery will discharge to meet the demand if PV and wind energy are insufficient to do so. If all available energy sources are insufficient to meet the load demand, which typically occurs at night, battery storage is activated.

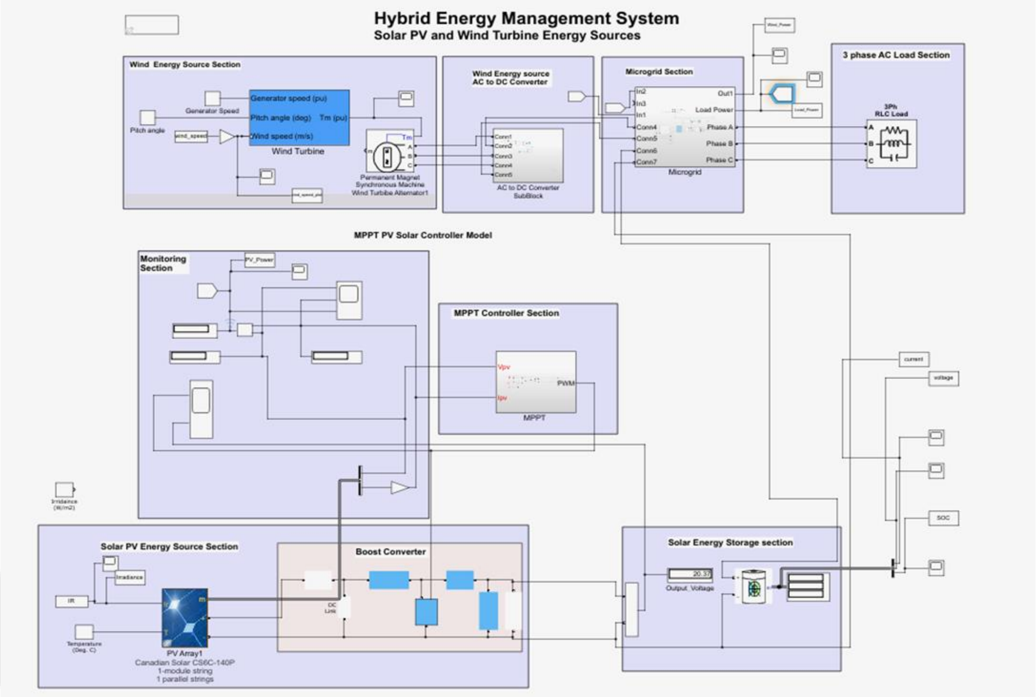


**Fig. 12**- Complete Hybrid System Model

The complete Hybrid system is divided in different sections as shown in Fig. 12 that included Wind energy section, solar PV energy sections, converters, MPPT Control and monitoring section etc.

This simulated model for 24 hours. The entire Hybrid system is divided into sections. There are sections for wind energy, solar PV energy, converters, MPPT control and monitoring, and so on. From result of modified whale optimizer as shown at the top topic the optimum zero LPSP system configuration comprises of 22797 PV arrays (350 W), 1021 WT of 10 kW, 709 batteries (100 KWH) and 6681 converter units (24 kW) which is obtained by the modified whale and having NPC of 67M/$.

## 9. Run Simulation with Different Scenarios.

### 1. System's dynamics and performance with MPPT scenario:

To obtain solar energy power, we have to use canadian solar panel at radiation of badr university from NASA web [7] site for average one day (24h) Fig. 13 shown solar radiation & Fig. 14 shown Wind speed plot from NASA web site for average one day (24h) [8].

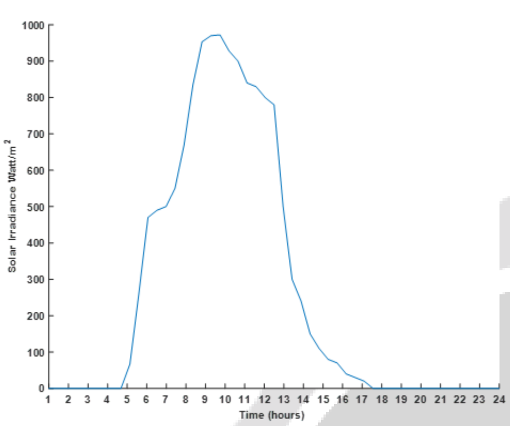


**Fig. 13**- solar radiation

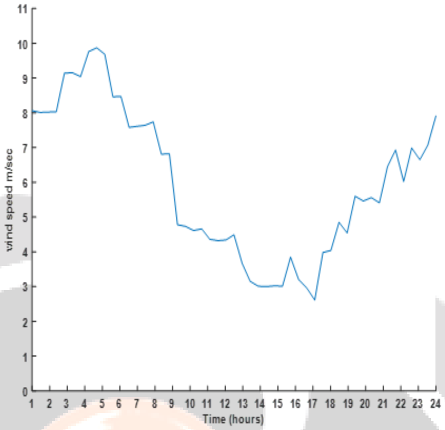


**Fig. 14**- Wind speed

This scenario demonstrated the validity of the model and control of the PV, wind, and battery systems, as well as the converters and inverter. The quantity of the PV array and wind turbine were according to their proposed values shown in section 6.

The results of power produced is shown in Fig. 15 according to their proposed values (load) shown in section 1 and Fig. 16 shown SOC battery.

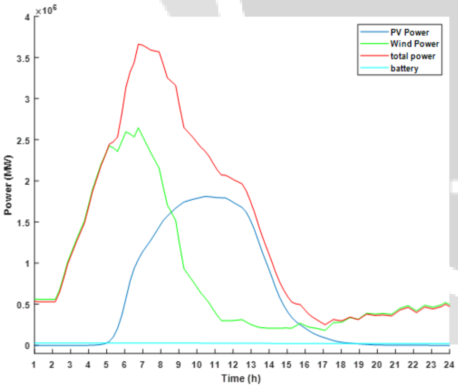


**Fig. 15**- total power

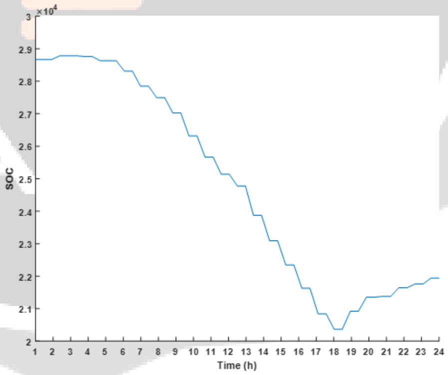


**Fig. 16**- SOC battery

### 2. Comparison System's dynamics and performance with MPPT and without MPPT scenario:

Figures 17&18 show the PV array outputs, the fluctuations in voltage due to the MPPT controller the PV power oscillates at the Maximum Power Point showing that the controller successfully tracked the MPPT. It can also be noticed that the increase in PV power is caused by an increase in the PV current output, where the PV voltage change remains under a smaller range.

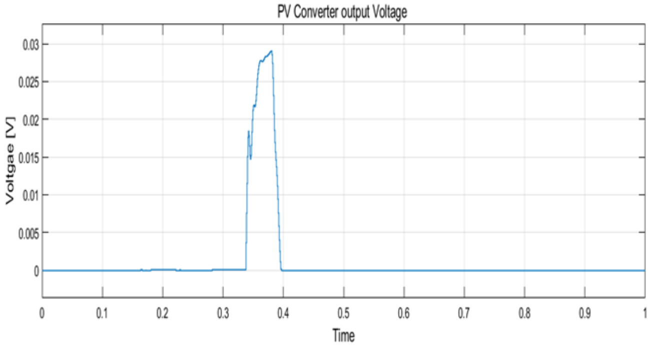


**Fig. 17**- PV converter output voltage without MPPT.

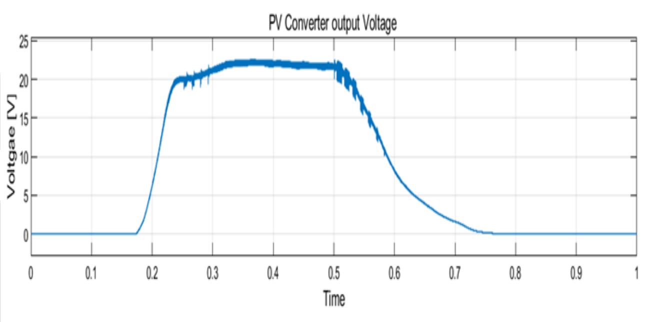
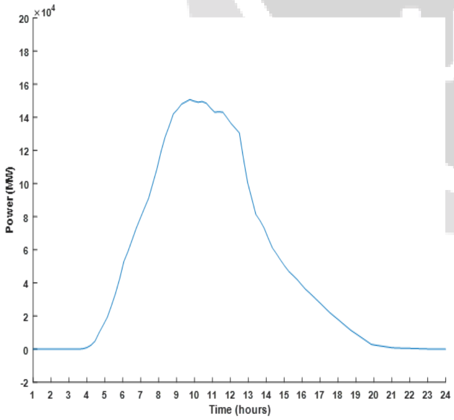


**Fig. 18**- PV converter output voltage with MPPT.

The results also demonstrated the performance of the MPPT for the PV system, where it was able to reach the maximum power point at different irradiances and temperatures; however, there were oscillations and energy loss.

PV without MPPT ($15*10^4$) & PV total power at MPPT is ($18 *10^5$) total power and the difference of total power shown in Fig. 19 & Fig. 20.



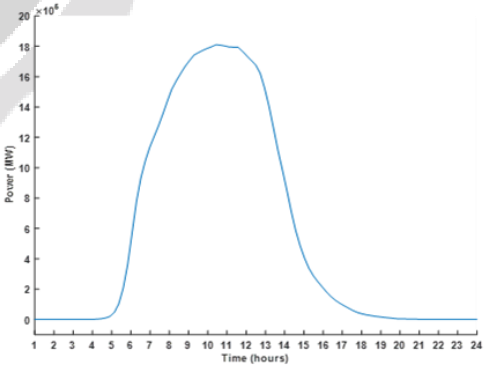


**Fig. 19**- PV without MPPT

**Fig. 20-** PV power with MPPT

## 3. System's dynamics and performance with change PV radiation scenario:

This scenario demonstrated the validity of the model and control of the PV, Battery systems and reduced solar radiation as well as the converters and inverter. The solar radiation reduced as shown in Fig. 21.

Numbers of wind turbines, PV panels, and batteries according to their proposed values shown in section 6.

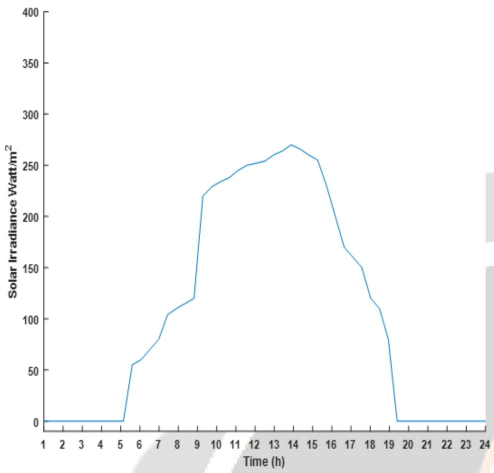


**Fig. 21**- Solar radiation

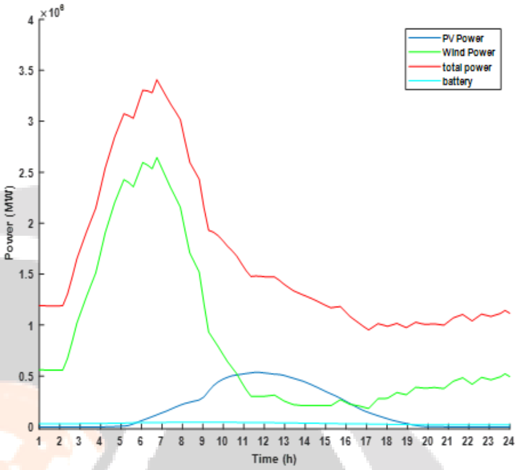
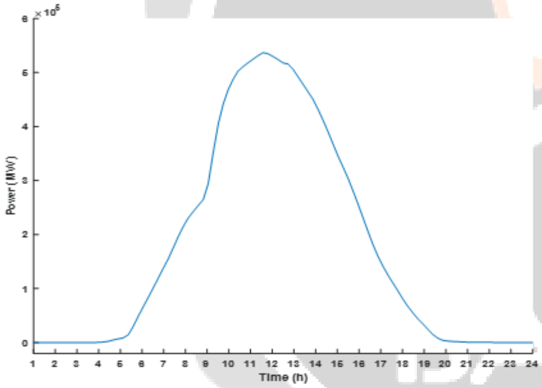


**Fig. 22**- Total power



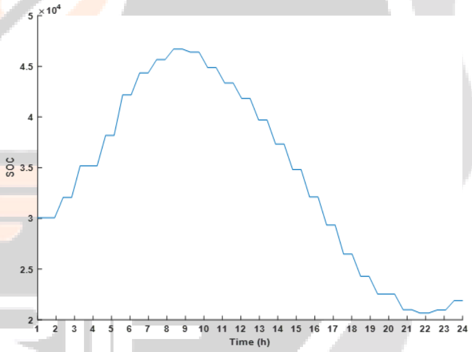


**Fig. 23**- PV power

**Fig. 24-** SOC battery

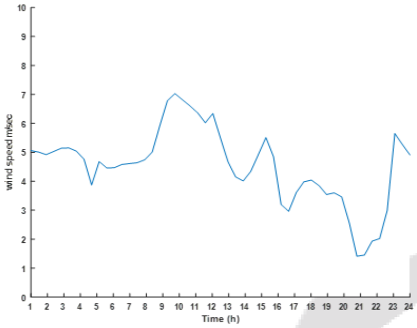
The result of power as shown in Fig. 22 total power according to load according to their proposed values shown in section 1.

It's noticed that total PV power decreased as shown in Fig. 23 But charging the battery offset the lack of power required as shown in Fig. 24.

### 4. System's dynamics and performance with change wind speed scenario:

That scenario demonstrated the validity of the model and control of the PV, battery systems and reduced wind speed as well as the converters and inverter. The wind speed is shown in Fig. 25.

Number of wind turbines, PV panels, and batteries according to their proposed values shown in section 6.



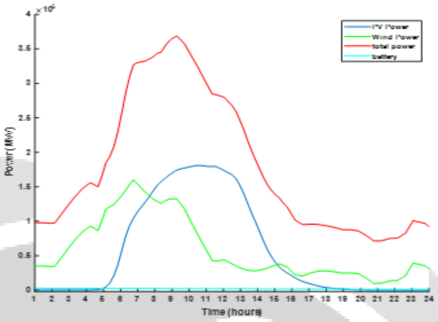
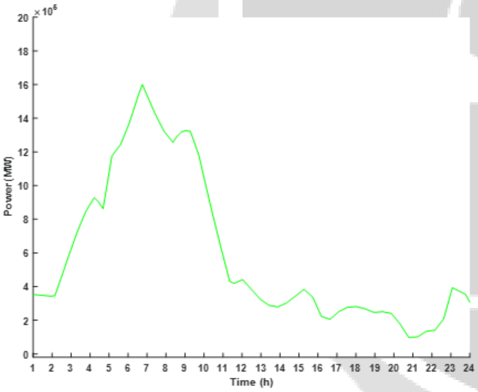


**Fig. 25**- Wind speed **Fig. 26**- Total power

The result of power shown in Fig. 26 total power according to load according to their proposed values.

It's noticed that total wind power decreased as shown in Fig. 27 but charging the battery offset the lack of power required as shown in Fig. 28.



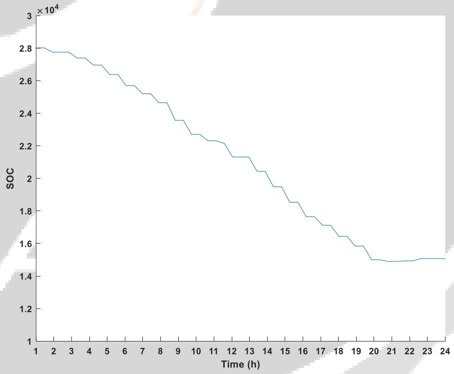


**Fig. 27**- Wind power **Fig. 28**- Charge of battery

## 10. Conclusion

An optimization model for designing a standalone hybrid renewable energy system is developed in this paper. The proposed power system comprises PV panels, WTs, and battery bank to cover power instead of gride at Badr university. Modified whale optimizer multi objective has been used to find the optimal values from other optimizer and homer of the three decision variables, namely the total area occupied by PV panels, total swept area by rotating WTs' blades and the amount of battery. The proposed methodology has been applied to minimize two objectives: NPC and the LPSP of the system. The simulation results reveal the ability of the proposed algorithm for producing optimum results.

The system was modeled and simulated with MATLAB-Simulink, and the detailed components simulation and control implementation were discussed and presented thoroughly. The simulation results demonstrated the adequate performance of the proposed MPPT and battery charging control. Effective tracking of the MPPT of the PV array was shown in the previous section.

Simulation of this paper shown the output of total power at different scenarios the fluctuations in the PV output were discussed at low radiation and shown the fluctuations in the wind output were discussed at low wind speed and shown performance of state of charge with change of weather.

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