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# Sizing Optimization Algorithm for Vehicle-to-Grid System Considering Cost and Reliability Based on Rule-Based Scheme

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**Abstract:** The most widely two Renewable Energy Sources (RESs) used are solar and wind as naturally found sources due to the provided merits as clean, free of charge, and environmentally friendly. However, they are facing limitations in intermittency. This article aims to utilize natural resources integrated with the utility grid and Electric Vehicle (EV) to provide a hybrid system with a minimum of two objectives namely Cost of Electricity (COE) and reliability using the Losses Power Supply Probability (LPSP) method. The two mentioned objectives are considered to satisfy the residential load demand with EV in terms of Vehicle-to-Grid (V2G) as this article considered. The mentioned objective has been addressed by the Improved Antlion Optimization Algorithm (IALO) and coupled with a high supervisory control method called Rule-Based Energy Management Strategy (RB-EMS) to guarantee to spread the power among the system component. Optimization results show the hybrid integration of the utilized RESs with the Battery (BT) gives the most economic and reliable system for the study area integrated with the EV battery. The gained result was validated with a natural-inspired metaheuristic algorithm called Particle Swarm Optimization (PSO). This article assesses the effect on the RESs generators to achieve an economic and reliable system.

**Keywords:** COE, EMS, IALO, LPSP, V2G.



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## 1. INTRODUCTION

Hybrid systems are considered the most cost-effective systems for providing energy. Energy has been used by human beings to improve their living conditions by running electric appliances and charging the Electric Vehicle (EV) when using Renewable Energy Sources (RESs). Generally, there are two types of energy sources that can be coupled, renewable energy sources (RESs) and Non-renewable energy sources (N-RESs) [1]. The former is become globally utilizing such as Photovoltaic (PV) and Wind Turbine (WT) due to the green energy provided. While the latter is widely used to supply appliances, however, it is producing a lot of power and environmental problems. Utilizing RESs can provide job opportunities, lower environmental impacts, and increase the security of the suppliers. Additionally, sustainable, environmentally friendly, cost-effective, and satisfying load demand and can be an intervention for power problems. At the same time RESs facing intermittency due to the changeable weather conditions during the year seasons for running the appliances and charging the EV. The EVs considering as a basic device to reduce emission, work as an alternative energy source to reduce the burden on the grid, and are promising options to overcome power and environmental problems. The V2G technology is one of the smart grid technologies that was firstly introduced in 1997 by Lovins and used to enhance energy systems operation and allow the bidirectional exchange between the vehicle and grid. Due to the provided advantages such as excessive battery degradation, integration with the grid, and use as battery and load [2]. Besides, reducing Greenhouse Gas (GHG) emissions, improving power quality, and maximizing revenue have been considered in the scholar's studies [3].

The Libyan authorities made a plan for utilizing the RESs in the country, however, some of the proposed plans facing some challenges due to political changes and security issues [4]. As the aforesaid RESs (PV and WT) as dual sources can overcome the losses and costs caused by the grid [5]. Moreover, the wind speed and solar irradiance are the main sources of the utilized RESs as highly sporadic in nature. Related studies presented in the state-of-the-art considering different hybrid RESs optimized by different metaheuristic optimization algorithms. Because of the accelerated developments of metaheuristic algorithms in solving various engineering problems, different techniques have been used in various fields to size and optimize hybrid systems. It is an issue with the respect to reach the computational simplicity and global optimum from the provided resources. Some of the very well-known methods such as Genetic Algorithm (GA), Cuckoo Search Algorithm (CSA), Ant Lion Optimization (ALO) algorithm, Improved ALO (IALO), Grasshopper Optimization Algorithm (GOA), and Particle Swarm Optimization (PSO) were mostly utilized for V2G system.

The contribution of the article is to size the system configurations using IALO and address the proposed objective function by the IALO coupled with supervisory control called Rule-Based EMS. The utilized load demand type for the residential area is 220 V and 50 Hz integrated with battery ($LiFePO_4$) and 5 EVs as system size. The remaining article is organized as follows, the proposed system, the research method included a mathematical model for the utilized RESs, the collected data, the proposed objective functions are denoted in Section 2, Section 3 discusses the acquired result from the system. In addition, the concluded summary of the article is presented in Section 4. Eventually, the acknowledgments followed by the references are located at the end of this article.

## 2. PROPOSED SYSTEM PARAMETERS AND THE OBJECTIVES

The RESs integrated with the utility grid and EV to form the hybrid system using Vehicle-to-Grid (V2G) technology as demonstrated in Figure 1 that is controlled by Rule-Based Energy Management Strategy (RB-EMS) [6]. Generally, algorithms can be defined as a sequence process of instructions to achieve a goal through defined steps. The considered method for sizing the system is one of the enhanced recent nature-inspired metaheuristic algorithms called Improved Ant Lion Optimization (IALO) algorithm that will be presented in this section. It uses to solve constraints engineering problems steps of antlion for hunting the prey considering six steps which are a random walk of ants, trapping in antlions traps, building traps, sliding ants toward antlion, catching the prey (ant) and rebuilding the traps, and elitism (best solution) as illustrated in Figure 4 [7]. The attained result from the proposed method will be benchmarked with Particle Swarm Optimization (PSO) as a very well-known algorithm. In terms of components, the same RES used as WT that extracting the energy from the collected wind speed data through the blads of the WT as illustrated in Figure 2 (a). While solar panels are utilized to convert collected solar radiation to energy with the ambient temperature as shown in Figures 2 (b) and (c), respectively.

The implemented data has been sourced from PVWATT as reported in the manual [8]. Whereas the process of the PV cells is like the PN junction which is formed by semiconductor materials. Additionally, the residential load demand of Tripoli-Libya has been collected from the General Company of Libya (GECOL) considering 220 V and 50 Hz is shown the annual residential load demand in Figure 3, the peak load as shown in the medal of the year specifically in July as (7 kW) during the nighttime.

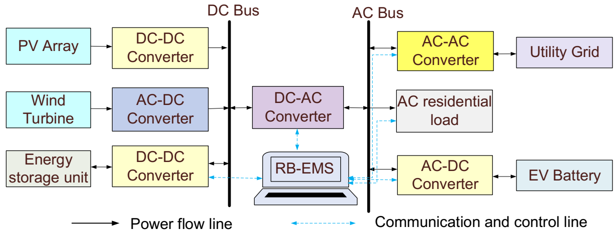


Figure 1. The proposed hybrid grid-connected system integrated with Electric Vehicle.

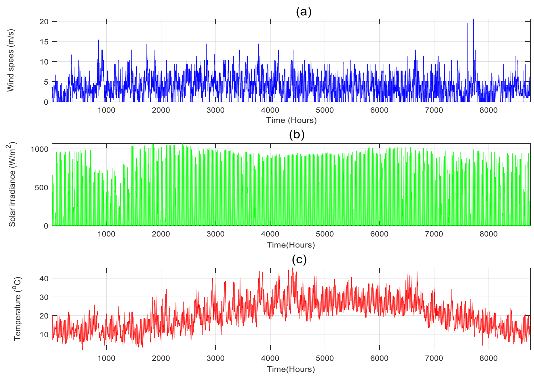


Figure 2. Climatology collected data (a) Wind speed, (b) Solar irradiance, (c) ambient temperature [9].

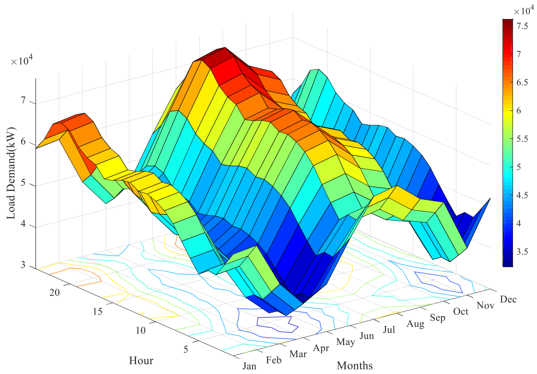


Figure 3. Contour plot of the load demand for the considered location.

The acquired output power from the RESs (PV and WT) with the help of collected data is determined by the presented Equations (1) and (2), respectively [1].

$$P_{pv_{out}}(t) = P_{(PV_{rated})} * \frac{G_{(t)}}{1000} * [1 + \alpha_t((T_{amb} + ((0.03125 * G_t)) - T_{C_{STC}} \quad (1)$$

$$P_{WT}(t) = \{0\ P_r \frac{v(t) - v_{cut-in}}{v_r - v_{cut-out}} P_r \quad v(t) \leq v_{cut-in}\ v_{cut-in} < v_r\ v_r < v(t) < v_{cut-out} \quad (2)$$

when the power is delivered from the battery mathematically can be calculated as Equation. (3). In addition to the utilized components, the energy storage battery is used to store the generated energy from the RESs as the responsible device for the charge and discharge process when the grid is not able to power the system [1].

$$P_{BT}(t) = P_{pv_{out}}(t) + P_{WT}(t) - \frac{P_l(t)}{\eta_{inv}} \quad (3)$$

In terms of components, the solar panels are utilized to convert collected solar radiation to energy and the considered type is the Canadian solar CS6U-320 [10]. While the WT system is providing clean energy that is beneficial in many applications such as residential, commercial, agriculture. The utilized WT type in this study is Eocycle E025.

## 2.1 Ant Lion Optimization

The Ant Lion Optimization (ALO) is a metaheuristic algorithm introduced in 2015 by Seydali Mirjalili for solving optimization problems and makes use of exploitation and exploration because it uses random walks [11]. The ALO algorithm mimics or emulates the hunting behavior of antlions searching for food using random walk form that causes premature convergence and stagnation as ALO challenges that leads to improving it [7]. The mechanism steps of the algorithm from (a-c) are illustrated in Figure 4 and present the steps of making traps and entrapment of ants in pits. While Figure 4 (d-f) presents the steps of catching the prey and rebuilding as will be further elaborated in terms of mathematical equations. The abovementioned actions illustrated in Figure 4 are mathematically presented from Equation. (4) to Equation. (12).

(a) Random walk and building trap (b) Trapping (c) Entrap in the pits (d) Sliding ants (e) Catching the prey (f) Elitism

Figure 4. Hunting Mechanism of Antlion.

$$X(t) = [0, cumsu(2r(t_1) - 1, cumsu(2r(t_2) - 1, \ldots\ldots, cumsu(2r(t_n) - 1] \quad (4)$$

where $n$ is the maximum number of iterations, $t$ refers to the step of random walk (iterations), $cumsu$ denoted for computing the cumulative sum, $r(t)$ defined as the stochastic function and can be mathematically expressed in Equation. (5). The $rand$ is the random number generated with uniform distribution in the interval of [0,1]. Moreover, the aforementioned hunting steps have been further pointed with more elaboration from points 1 to 5.

$$r(t) = \{1\ if\ \ rand > 0.5\ 0\ if\ rand < 0.5\ \} \quad (5)$$

1. Random walk of ants

The random walk is based on an Equation. (4) to update the position of each ant while Equation. (5) is used to update the position of each ant and Equation. (6) is used for keeping the random walk ($X_i^t$).

$$X_i^t = \frac{\left(X_i^t - a_{i)}\right) * (d_i^t - C_i^t)}{(d_i^t - a_i)} + c_i \quad (6)$$

where $a_i$ and $b_i$ are the minimum and maximum of random walk and $C_i^t$ is the minimum of $i^{th}$ variable at $t^{th}$ iteration which can calculate by Equation. (7).

2. Trapping antlions pits

The random walks of ants are affected by antlions' traps which can be mathematically expressed as presented in Equation. (7) and Equation. (8), respectively. Where $C_i^t$ and $d_i^t$ are the minimum and maximum of all variables at the iteration of $t^{th}$ while the $Antlion_j^t$ is the position of the selected $j\ ^{th}$ antlion at $t^{th}$ iteration.

$$C_i^t = Antlion_j^t + C^t \quad (7)$$

$$d_i^t = Antlion_j^t + d^t \quad (8)$$

3. Building traps

The ability of Antlion can build traps. Additionally, Antlion has a high possibility to catch ants due to the selected function exploited which is Roulette Wheel Selection.

4. Sliding ants against toward antlion

Equations (9) and (10) run for the behavior of the escaping ants from the antlions' trap and sliding ants down. The I is denoted as the sliding ratio. While the $C^t$ and $d^t$ are the minimum and maximum of all variables at $t^{th}$ iteration.

$$C^t = \frac{C^t}{I} \quad (9)$$

$$d^t = \frac{d^t}{I} \quad (10)$$

5. Catching preys and rebuilding the traps

As the stages of hunting by antlion, catching prey, and rebuilding the traps are the last step. It is mathematically calculated by Equation. (11). Where $Antlion_j^t$ present the position of selected $j^{th}$ at $t^{th}$ iteration while the $Ant_i^t$ is the position of $i^{th}$ of ants at $t^{th}$ iteration and $t$ is the previous iteration.

$$Antlion_j^t = Ant_i^t, \quad if\ f(Ant_i^t) > f\left(Antlion_j^t\right) \quad (11)$$

6. Elitism

Elitism refers to the best-obtained result and can be mathematically obtained by Equation. (12) which shows the saved iteration from each step. Where the $Ant_i^t$ is the position of $i^{th}$ ant at $t^{th}$ iteration, while $R_A^t\ and\ R_E^t$ are the random walk around antlion selected by roulette wheel and random walk around the elite, respectively.

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (12)$$

## 2.2 Improved Antlion Optimization Algorithm

In addition to the provided details for ALO and facing some challenges such as the fast convergence speed and easily acquiring local optima, near-global optima. Also, the random walk that causes a long-running time. Using levy flight method to improve the search of antlion algorithm, solve microgrid optimization systems, and gain the best number of configurations (elite). The computational stages of the IALO method are tabulated in Table 1. Equation. (13) was utilized to update all ants and antlions' positions by levy flight algorithm instead of using Roulette Wheel Selection.

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \otimes l'evy\ (s) \qquad (13)$$

where the $x_i^{(t)}$ is the current position of ant, $x_i^{(t+1)}$ denoted as the new position, $\alpha$ is considered as constant value and known as step size which is considered as greater than 0, and $s$ is step length that can be mathematically expressed as Equation. (14). Essentially, levy flight is providing a random walk, where the steps can be drawn by Equation. (15). Besides, the value of $\varphi$ is presented by Equation. (16) [7].

$$s = \frac{\varphi \times \mu}{|\alpha|^{\gamma}} \qquad (14)$$

$$l'evy\ (\gamma) \sim u = t^{-\gamma}, 1 < \gamma \leq 3 \qquad (15)$$

$$\varphi = \left[\frac{\Gamma(1+\gamma)\times sin\ (\pi\times\frac{\gamma}{2})}{\Gamma((\frac{1+\gamma}{2})\times\gamma\times 2^{\frac{\gamma-1}{2}})}\right]^{\frac{1}{\gamma}} \qquad (16)$$

where $\alpha$ and $\mu$ are denoted as the normal distribution, the value of $\varphi$ is presented by Equation. (16), and $\gamma$ is gamma that is greater than 1 and less or equal 3. Additionally, the uniform distribution random walk ($RaWa$) for both ant' and antlion' is performed in Equation. (17).

$$RaWa = Ant_i^t + \omega\times s\times r\times\left[Antlion_j^t - Ant_i^t\right] \qquad (17)$$

where $\omega$ is a controlling scale for the random walk considering the current iteration ($t$) that is can be mathematically expressed as in Equation. (18), and the number of allowable iteration (N).

$$\omega = 1 - \frac{t}{N} \qquad (18)$$

Table 1. The computational stages of improved ALO optimization.

| | |
|---|---|
| Step 1: Load input data | • Load weather database (solar irradiance, wind speed, Ambient temperature)<br>• Load demand database<br>• Load economic database for the microgrid components |
| Step 2: Initialization | • Set the ALO constants<br>- Population size=5, G=20, Max iteration=500, and Search agent=40<br>• Set constraint<br>- COE and LPSP.<br>• Set the research space:<br>- Lower and upper bounds for $P_{PV}$ [0,100]<br>- Lower and upper bounds for $P_{WT}$ [0,50]<br>- Lower and upper bounds for autonomy days [0,3]<br>• Update the fitness for each ant and antlion<br>• Select an antlion using levy flight |
| Step 3: Updating position | Updating the position between the antlion and elite |
| Step 4: Criterion | • Update the position of all ants.<br>• If updated calculate the fitness for each ant and antlion, if not go to step 2 |
| Step 5: Optimality | Search the optimal solution in the antlion group |
| Step 6: The best solution | If the best solution is obtained stop, if not repeat step 2 |

### 2.3 Objective functions

The main two objective functions considered in this article are to be minimized as applied in a Grid-Connected system are the Cost of Electricity (COE) and reliability using the Loss Power Supply Probability (LPSP) technique.

#### *2.3.1 The Cost of electricity*

The per capita of the electricity for the grid-connected is defined as the COE system to gain an economic system with minimum cost and can be calculated by Equation. (19) [12].

$$COE\left(\frac{\$}{kWh}\right) = \frac{TNPC(\$)}{\sum_{h=1}^{h=8760} P_l(kWh)} * CRF \qquad (19)$$

where the COE refers to the cost of electricity in (\$/kWh), TNPC is defined as total net present cost in (\$) that is expressed mathematically in Equation. (20) with help of Total Annualized System cost (TAC) in (\$) [1]. Besides, the $P_l$ is the load demand (kWh), and CRF is the Capital Recovacry Factor which calculated by Equation. (21) [12]. Where $n$ is system life period which equals the lifetime of the considered solar panels (25 years) and $i$ is the interest rate of the study area.

$$NPC(\$) = \frac{TAC}{CRF} \qquad (20)$$

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (21)$$

#### *2.3.2 The Reliability*

In general, reliability ranges between 0 and 1 and is defined as the failure of satisfying the load demand. Where 0 refers to satisfied load and 1 refers to unsatisfied. There are a lot of techniques that can be used to measure reliability in terms of losses in the power system [12]. The technique considering is (LPSP) technique to compute the power losses of the system that calculated by Equation. (22) [1].

$$LPSP = \frac{\sum_{i=1}^{N}[P_l(t_i) - (P_{PV}(t_i) + P_{WT}(t_i))]}{\sum_{i=1}^{N} P_l(t_i)} \qquad (22)$$

### 2.4 Energy Management Strategy

Generally, there are three main supervisory control algorithms used to control the flown power in the electric systems: Optimization-Based (OB), Learning-Based (LB), and Rule-Based (RB), however, they differ in proving exact results [6]. The idea behind the third mentioned which is RB-EMS depends on the (IF and THEN) statement as illustrated in Figure 5 [13]. The last-mentioned have been considered in this study due to the decision making faster than others in terms of time and providing an exact solution.

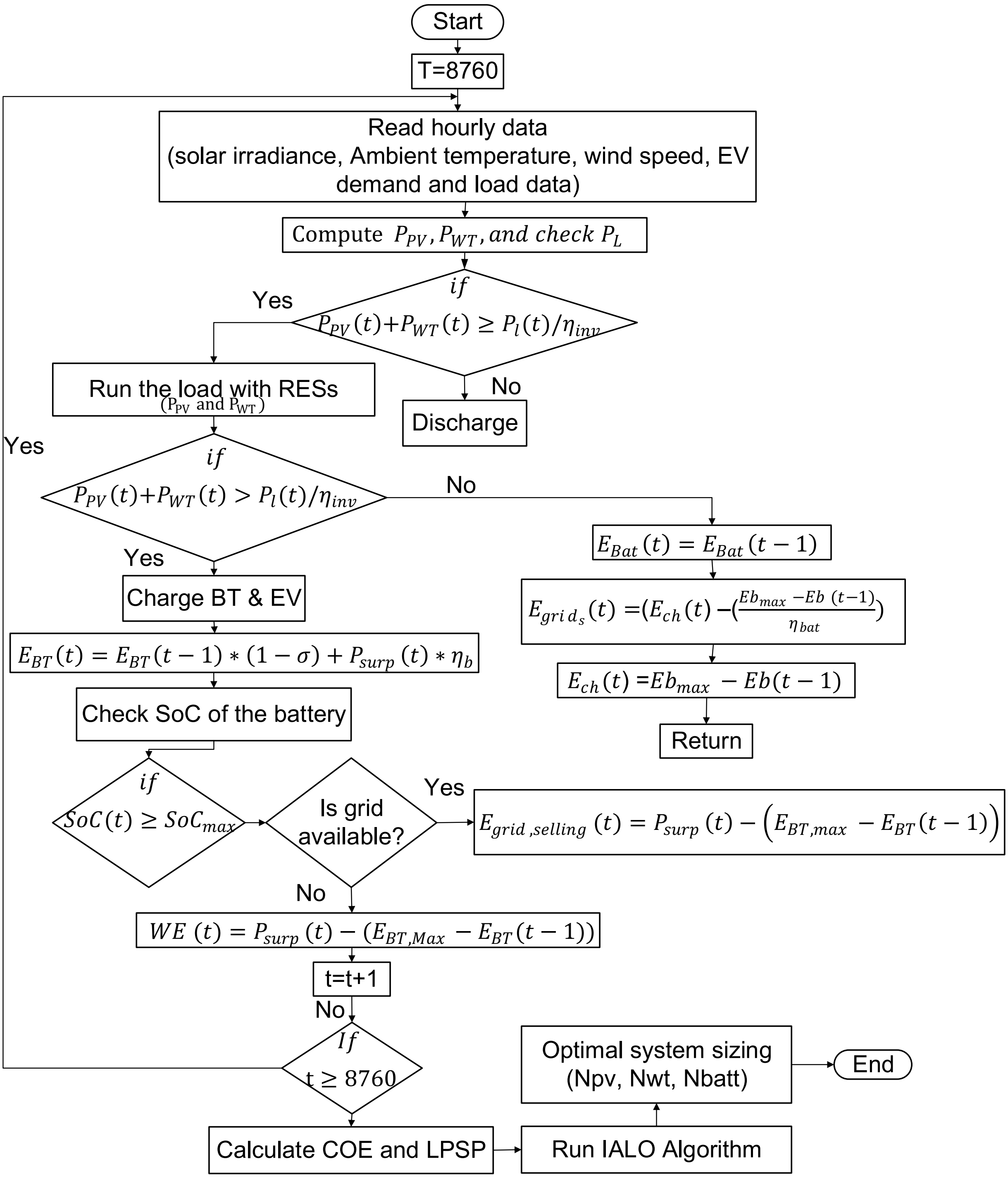


Figure 5. The mechanism of Rule-Based Energy Management Strategy.

### 3. RESULTS AND DISCUSSION

This section is denoted for discussing the attained result for sizing and controlling the results of the system. As the two main RESs utilized in this system as integrated with the grid and the EV is providing the output power as demonstrated in Figure 6 (a) and (b), respectively. Where the maximum power produced from the PV is in the Spring season, which is more than 4 kW. While the power acquired from the WT can be at its maximum of 4.68 kW. The considered batteries in this study are Lithium-iron Phosphate (LiFePO4) and Nickel-Metal Hydride (NiMH) and their SoCmax and SoCmin are 100 % and 20 %, respectively. The season's SoC of the battery for a week is illustrated in Figure 7.

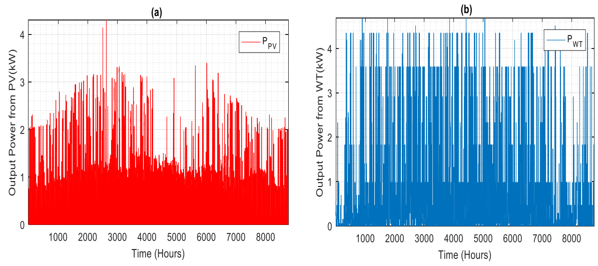


Figure 6. Output power from Renewable Energy Sources (a) PV and (b) WT.

The process of V2G is proving such a great mechanism for exchanging the power between the vehicle and the grid. The time of charging of EV with the amount of exchanging power is demonstrated in Figure 8 (a) and (b), respectively. Furthermore, the EV demand represents the required demand of the EVs from the grid in (Watt).

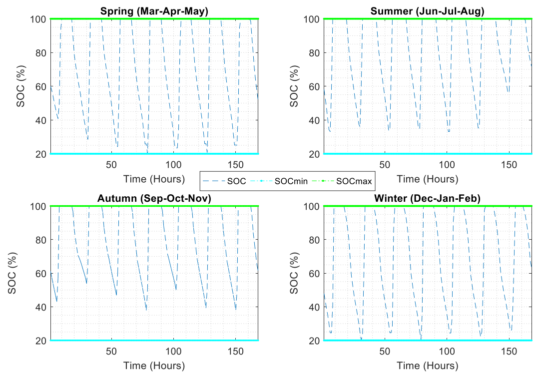


Figure 7. Weekly State-of-Charge four seasons.

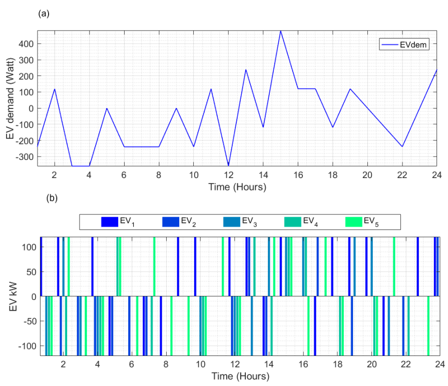


Figure 8. Electric Vehicle (a) Demand and (b) exchange power.

The comparison result between the considered algorithms is tabulated in Table 2. Where the running experimental result on MATLAB shows that IALO is performing better than the benchmark method.

Table 2 Breakdown of the comparison result between the algorithms.

| | $N_{PV}$ (Units) | $N_{WT}$ (units) | $N_{BT}$ (Units) | AD (Days) | COE ($/kWh) | LPSP (%) |
|---|---|---|---|---|---|---|
| IALO | 93 | 12 | 3 | 3 | 0.0936 | 0 |
| PSO | 97 | 14 | 6 | 3 | 0.3350 | 0 |

## 4. CONCLUSION

The study considered a grid-connected system using integration form of RESs and utility grid-connected with EVs in order to reduce the cost and reliability using the IALO algorithm. The IALO is exploited for sizing the system components and coupled with the supervisory control algorithm called RB-EMS to address the proposed objectives. The aforementioned proposed algorithm for the system is presented in order to obtain a cost-effective system using economic and reliable techniques. In addition, IALO performs better than PSO in terms of objectives. The acquired result from the RESs has been obtained by using the provided mathematical modeling. Whereas the weekly SOC was obtained by utilizing the Coulomb counting method due to its accuracy. This work highly recommends exploiting other nature-inspired methods for the V2G system in order to gain a lower system in terms of cost and power losses.

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