Power Management and Sizing Optimization for Isolated Systems Considering Solar, Battery, and Diesel Generator based on Cost and Reliability under Murzuq and Sabha Cities Weather

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Abstract - Grid-isolated electrification for rural areas is a crucial task where the utility grid can not be reached or is costly to connect. Developing Renewable Energy Sources (RESs) in southern Libyan cities is required to be further investigated due to the power crises and increasing population. Two cities in the southern west side of Libya as highly radiated solar-radiated cites namely (Murzuq and Sabha) as studied cases in this study. The implemented climatology data has been sourced from the Global Solar Atlas. The proposed system consists of Photovoltaic (PV), Battery (BT), Diesel Generation (DG), and converters, integrated into the domestic load. Utilizing one of the recent nature-inspired metaheuristic algorithms namely Gray Wolf Optimization (GWO) for sizing the aforementioned hybrid system components due to its simplicity and flexibility. The obtained result has been validated with other metaheuristic methods namely Cat Swarm Algorithm (CSA) and Particle Swarm Optimization (PSO) in terms of cost and loss minimization as objectives along with the sizing configurations. The analyzed data and obtained simulated results have been implemented in a very well-known software program called Matlab. This article presented to be as a reference for scholars who are interested in the field of growing using Renewable Energy Sources (RESs) in the country rather than conventional sources to achieve Sustainable Development Goal seven (SDG7) for (Affordable and Clean Energy) and Sustainable Development Goals (SDG13) for (Climate

Action). The authors recommended utilizing other RESs and techniques to find a better solution to overcome the energy and environmental crises.

Keywords: Murzuq, Sabha, Losses, Cost, Off-Grid, Nature-Inspired Metaheuristic Algorithm.

I Introduction

Due to the fear of depleting reserves sources by utilizing fossil fuel globally, solar and other alternative sources are applicable in Libya as reported in [1] and considered to address power limitations. Because of recent developments in power, electronic storage devices, and lowering component prices, solar and wind power have become popular technologies for supplying electrical load in remote and off-grid places [2]. Due to their unexpected and changeable character, the combination of solar and wind energies adds to the complexity, posing technological, environmental, and socio-economic issues. Considering the implications of the thermal load on solar concentrated Photovoltaic (PV) [3]. Power can be delivered based on different forms: grid-connected, grid-isolated, or hybrid systems [4]. The last mentioned is a preferable system, however, it is costly due to the integrating converters.

The energy crises in the country made scholars utilize different forms of energy considering alternative sources and components to provide clean and sustainably green power energy [5]. Different studies consider the autonomous hybrid system to satisfy the load demand and improve the standard of living in various isolated areas globally [6]. A study conducted the metaheuristic approach namely Multi-Objective Particle Swarm Optimization (MOPSO) for optimizing microgrid systems considering hybrid systems consisting of PV, Battery (BT), and Wind Turbine (WT) [7]. In [8], considering PV, WT, Diesel Generator (DG), and battery for off-grid supplying 5 residential loads. Another conducted study considering [9]. An investigation of the utilized RESs in the country is considered in [10]. in [11], different hybrid configurations have been considered to get power systems for an isolated area in Iran utilizing a stand-alone system. In addition to the considered studies in the literature, some of the studies considered in Libya utilizating the RESs due to its meits [12].

The PV applications become popular in hospitals, houses, and public buildings in Libya, but, solar systems are still costly [13]. Using crow search algorithm and PSO for sizing hybrid RESs system in Libya [14]. In the RESs prospects, Solar panels can be classified into three main types which are Mono-crystal, Poly-crystal, and Thin film [15]. The efficiency of each panel is producing different energy depending on the location. The two first-mentioned solar panels are applicable for the considered location depending on the season and the availability of climatology conditions (temperature and irradiance) [16]. Microgrids are classified as mentioned in [17] and can operate in two modes: on-grid and off-grid [18]. When the end-user is connected to the grid, the former is performed, whereas the latter is performed when the end-user is fully disconnected from the grid. Mini-grid off-grid system using RESs [19]. Optimal sizing for hybrid system considering PV/WT/BT [20]. PV-Battery in morocco as different site global scholars planning to address power and environmental barriers, [21], provides a study for rural areas considering the RESs (PV, WT, and Biomass integrated with energy storage battery). The aforementioned study utilized the Artificial Bee Colony (ABC) algorithm for sizing the system components and has been verified with HOMER and PSO [22]. As the considered location has high potential photovoltaic in terms of high solar irradiance, in [23] study various integrated systems. Besides, the current state of the utilized electrical supply systems has been reported in [24] as the only electricity company supplying electricity in the country. In addition, domestic areas use different electric appliances for the considered country as listed in [25].

Different prospects for using energy systems in Libya as in [26]. In terms of sizing optimization using either of two methods heuristic or metaheuristic algorithms. The former means “to discover” that have less consideration among scholars due to the mathematical equation. The latter is known as higher level or “beyond” and is used among widely range scholars to overcome optimization problems due to the exact result provided [27]. Several metaheuristics algorithms have been reported in the literature in order to address optimization problems along with numerous techniques [28]. Some of these algorithms are Monte Carlo Method Simulation (MCMS) [29], Gray Wolf Optimizer (GWO) Algorithm [30], Cat Swarm Algorithm (CSA) [31], Social Spider Optimizer (SSO) [32] and Particle Swarm Optimization (PSO) [33] are considered in the state-of-the-art for sizing and benchmarking purposes. The GWO has been used in the literature several times with its variants due to its special outcome in engineering sector [34]. Another study conducted the GWO for utilizing RESs integration [35].

The article's contribution is the acquisition of the ideal number of configurations by applying sizing algorithms as stochastic algorithms to generate power at a low cost.. Besides, addresses the flown power by Energy Management strategy rule-based. While the rest of the article is organized as follows: Section 1 presents the general introduction and the literature review.

The case study and analysis of the collected data and mathematical models of the utilized parameters are positioned in Section 2. Section 3 placed the objective functions of the study. The listed nature-inspired nature-inspired algorithms for sizing the system components are listed in Section 4. Section 5 presented the energy management scheme of controlling the power flow in the system. discussion of the acquired result is summarized in Section 6. The conclusion followed by the acknowledgments and the list of references closes the article.

II Study area and Seasonal variations

The considered study areas are located in the western-south of Libya namely Murzuq and Sabha which are close to the desert as the Libyan map shows in Figure 1 [1]. The population of the first-mentioned city is 12746 and the second-mentioned is 157747 with an area of 58000 and 15330 km^2, respectively [1]. Besides, Murzuq coordinated with a longitude of 25°.5449 N and the latitude is 13°,5510 E, while Sabha longitude and latitude are 27°.088 and 014.798584°, respectively.

The two considered locations have different climatology conditions as the analyzed collected data show that illustrated in Figure 2, Figure 3, and Figure 4. The data has been sourced from the Global Solar Atlas that has been developed by the National Renewable Energy Laboratory (NREL) [36]. The considered study location has four weather seasons (winter, spring, summer, and autumn) as mentioned in [9].

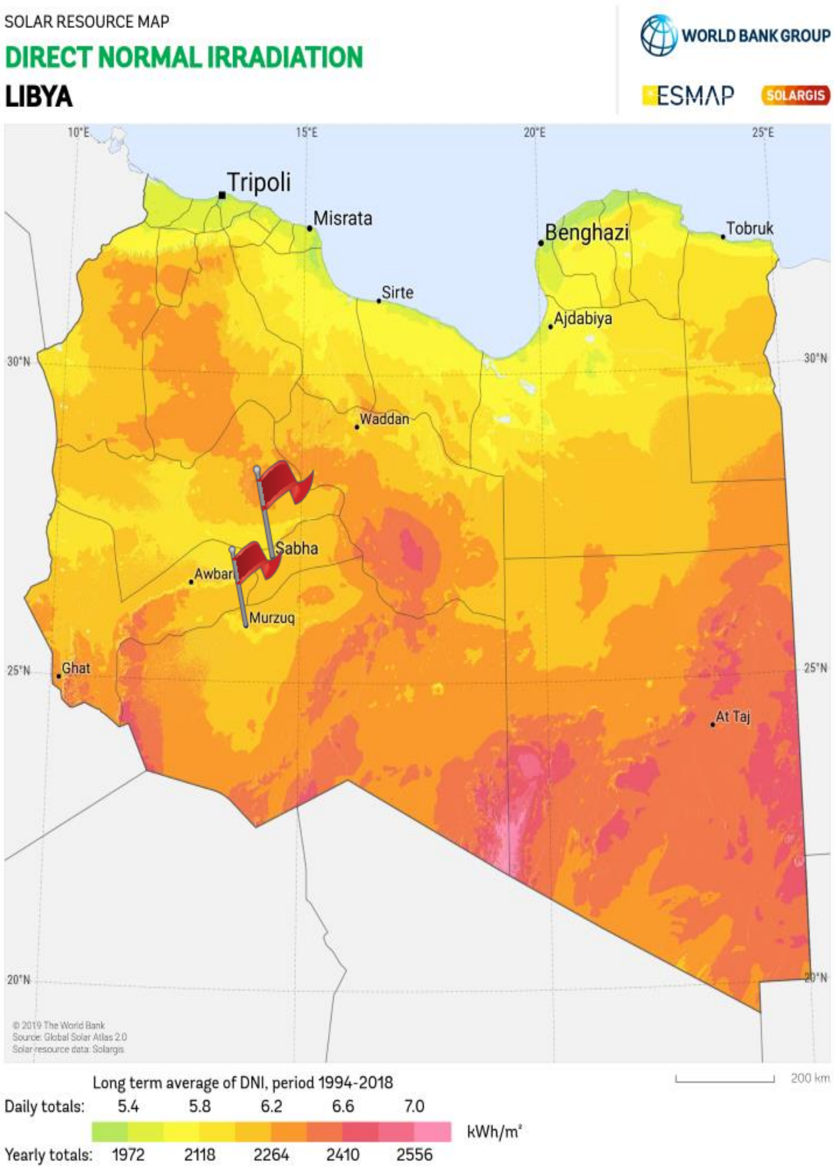

Fig.1. Libyan map considering two study areas [37]

2.1 Collected Data

The climatology data was obtained from the Global Solar Atlas and evaluated using Microsoft Excel and MATLAB as shown in Figure 2 for the annual average high temperature in (°C), while the solar direct irradiance is demonstrated in Figure 3.

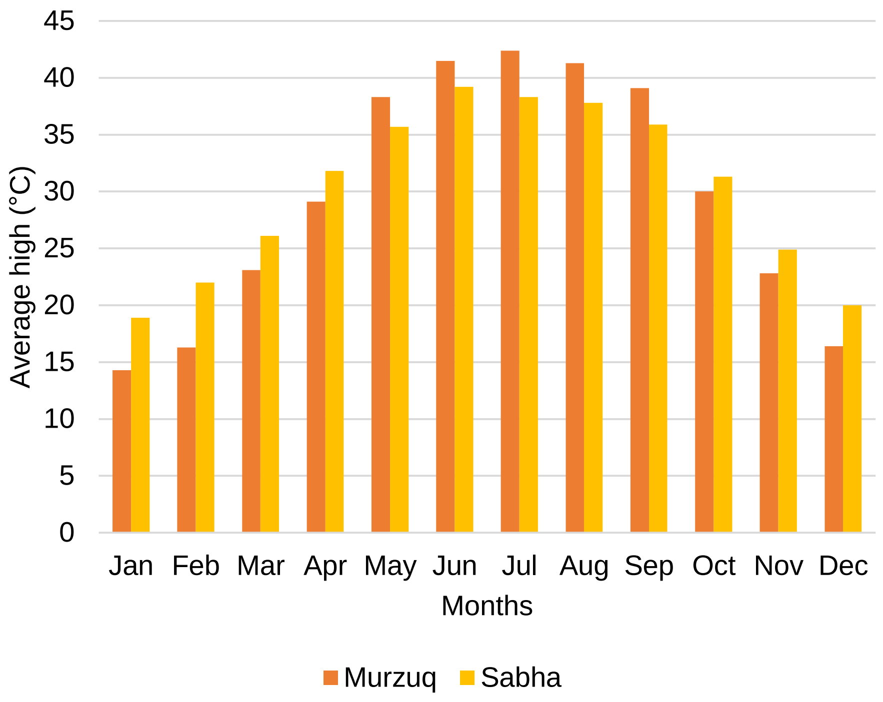

Fig.2. The average high temperature for the case study is (°C).

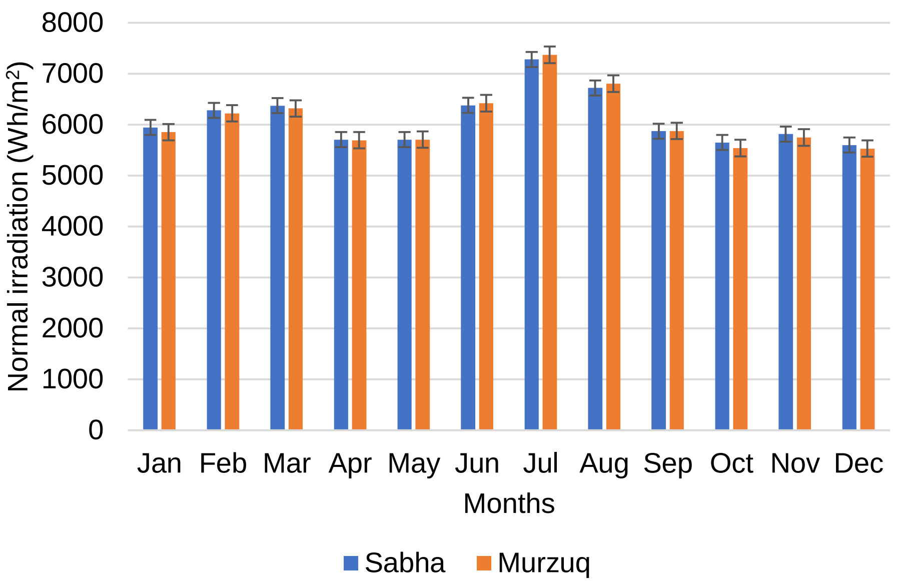

Fig.3. Direct normal irradiation for Murzuq and Sabha in (Wh/m^2).

The comparison of the case study with other cities in the same country for normal irradiation is shown in Figure 4. Based on the plotted chart, different values of normal irradiation can be seen due to the distances and different climatology conditions starting with Sebha and ending with Taraghin, respectively.

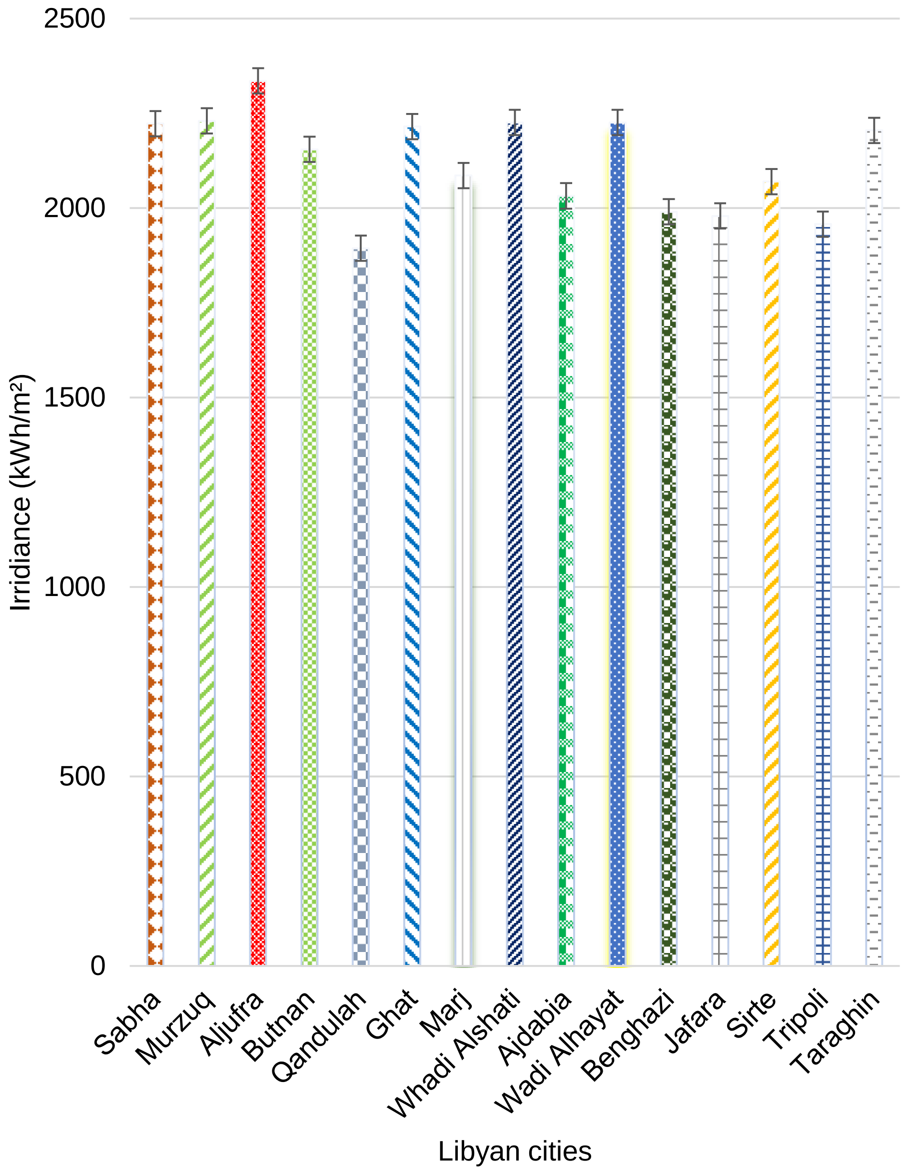

Fig.4. The comparison of annual solar irradiance of Libyan cities.

The considered residential houses consist of two rooms, two bedrooms, a living room, a kitchen, and two bathrooms using the electric appliances that are illustrated in the bars in Figure 5.

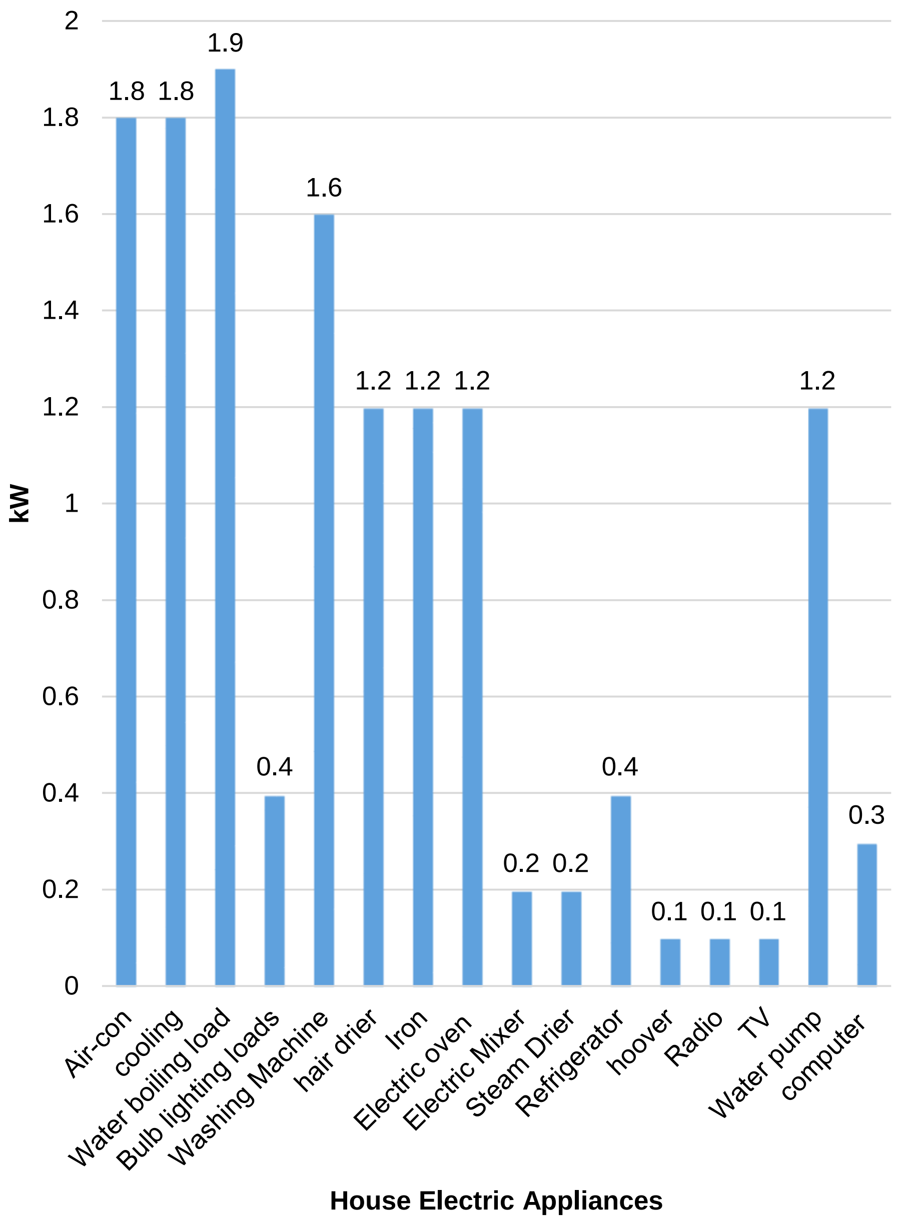

Fig.5. House electric appliances load with the usage hours per day.

2.2 Modeling of system components

The proposed energy system comprises one RES which is PV, energy storage battery, diesel generator (DG), inverters, and integrated with the residential load as AC load as shown in Figure 6. The considered autonomous system is completely isolated from the utility grid that is utilized to satisfy the load demand in rural areas and fulfil in whole time for the two considered locations which is used as a paradigm that demonstrated to address the current issues [17]. Besides, the specific details of the exploited components are tabulated in Table 1.

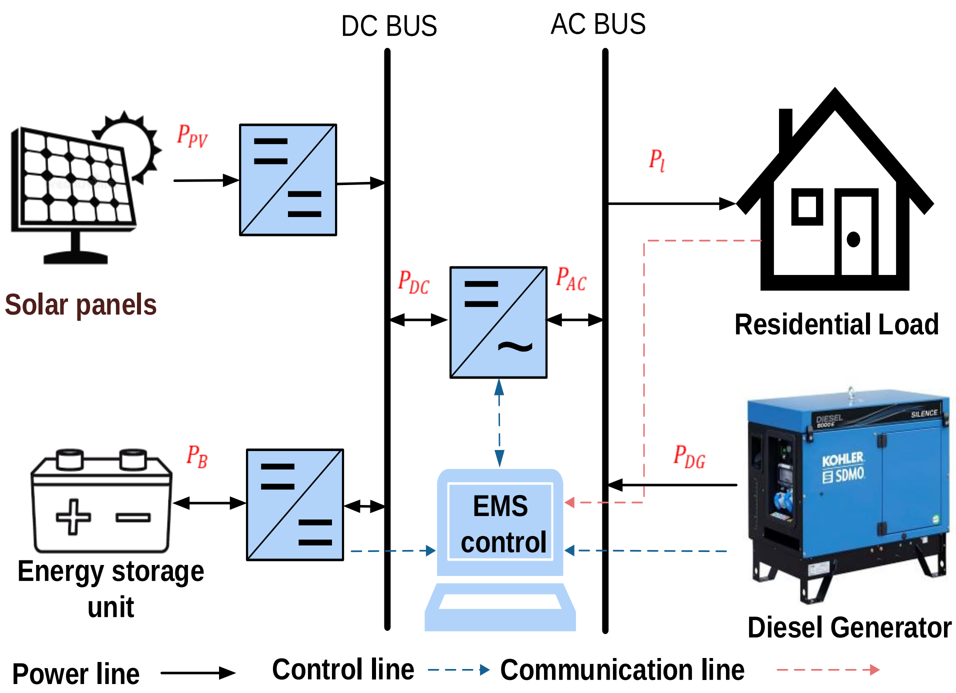

Fig.6. Proposed hybrid energy system

A hybrid energy system incorporates many renewable energy sources and is typically more cost-effective and reliable than a single energy source system.

The utilized sources in this study as already mentioned are PV, BT, and DG, integrated into the utility grid. To successfully and safely use energy storage as a flexible grid asset that can deliver numerous grid functions, EMS and optimization methodologies are necessary [38]–[40].

Photovoltaic: The PV is widely used RES to harness the sunlight and convert it to heat or electricity through solar panels [41].

Eq. (1) represents the output power from the PV ($P_{pv_{out}}$) as mathematically expressed with the help of cell temperature for standard test cells as presented in Eq. (2) [42].

$$P_{pv_{out}}(t) = P_{(PV_{rated})} \times \frac{G_{(t)}}{1000} * \left[1 + \alpha_t \left(T_{amb} + \left(\left(\frac{NOCT - 20}{800}\right) \times G_{(t)}\right)\right) - T_{C_{STC}}\right] \quad (1)$$

$$T_{C(STC)} = T_{amb} + G_{(t)} * 0.0256 \quad (2)$$

where $G_{(t)}$ is the solarIndicatesnce data for the study site, $P_{(PV_{rated})}$ Indicats the rated power of the PV, T_{amb} is the ambient temperature data for the study area, α_t coefficient the nominal operation cell temperature ($NOCT$) is provided from the mamanufacture and the $T_{C(STC)}$ refers to the cell temperature that presented in Eq. (2).

Energy storage system: It is the responsible device for steadying power balance and absorbing transients within the range of maximum and minimum of SoC of the battery.

Depends on the charge and discharge cycles of the battery which compute the lifespan of energy storage [42]. The battery is considered in the system to deal with the intermittent nature of Renewable Sources (RS). The utilized battery in the system is Lithium-iron phosphate ($LiFePO_4$) and its datasheet of the battery is reported in [41].

The capacity of the battery can be computed by Eq. (3), while the charge and the discharge amount of the battery can be calculated by Eq. (4) and Eq. (5), respectively [41].

$$C_{BT} = \frac{E_L \times AD}{DOD \times\times \eta_{inv} \times \eta_{BT}} \tag{3}$$

where the E_L refers to the average load demand, the AD representse autonomy days, DOD refers to the depth of discharge, η_{inv} refers to the inverter efficiency, and η_b is battery efficiency. The two operations for charging and discharging to show the battery status as SoC as presented in Eq. (4) have been taken into consideration for charging and discharging as presented in Eq. (4) and Eq. (5), respectively.

$$SoC_{Min} \leq SoC_t \leq SoC_{Max} \tag{4}$$

$$SoC(t) = SoC(t-1).(1-\sigma) + \left(\left(P_{pv}(t)\right) - \frac{P_l(t)}{\eta_{inv}}\right) * \eta_{BT} \tag{5}$$

$$SoC(t) = SoC(t-1).(1-\sigma) + \left(\frac{P_l(t)}{\eta_{inv}} - (P_{pv}(t)\right) * \eta_{BT} \tag{6}$$

Equation (5) represents the battery status in charging mode considering the $sigma\ that$ that refers to the self-discharging rate of the battery bank

Converters: When a system has both AC and DC components, power converters such as DC/AC and AC/DC are necessary. While the considered load is AC, solar PV panels and batteries produce DC output [43]. The converter size is determined by combining peak load demand ($P_l^m(t)$) with inverter efficiency (η_{inv}), while the inverter rating ($P_{inv}(t)$) is determined using Eq. (7) [21].

$$P_{inv}(t) = \frac{P_l^m(t)}{\eta_{inv}} \tag{7}$$

Diesel generator: The DG will work when the energy on the battery is depleted (minimum of DoD accomplished) [44]. The modeling mathematical equations can be calculated by Eq. (8) with the help of Eq. (9) and Eq. (10), respectively [45].

$$FC_{(t)} = A_G \times P_{DG} + B_G \times P_r^{DG} \tag{8}$$

$$FUELC = \left(S_f \sum FC_{(t)}\right) \times CPV \quad (9)$$

$$CPV = \frac{r_i(1+r_i)^n}{(1+r_i)^n} - 1 \quad (10)$$

where the $FC_{(t)}$ in Eq. (8) refers to the fuel consumption that measured in (Liter/kW), A_G is the cofficen of FC that equals 0.24, P_{DG} is the generated power from the DG, B_G is the constant valve or cocoefficient of FC equlas 0.084, and P_r^{DG} refers to the rated power, respectively. Additionally, the cost of fuel $(FUELC)$ is mamathematically formulated in Eq. (9), the S_f denoted as the current price of diesel fuel per lilitre $FC_{(t)}$ represents the modeled of fuel consumption, CPV denoted as the cumulative present value which mathematically can be expressed in Eq. (10).

Table 1. System input parameters [29], [41], [44], [46].

Components	Parameters	Value	Units
Photovoltaic	Photovoltaic module (STP275S-20/Wem)		
	Initial power at STC	275	W
	Initial Cost	2.15	$/W_P$
	Lifetime	25	Years
	Mantinance cost	20	$/year
	Nominal operating cell temperature	45	°C
	Temperature coefficient	$-3.7\text{x}10^{-3}$	1/°C
	Module efficiency	16.9	%
	Replacement cost	0	$/year
	Regulator cost	1500	$
Battery	Lifetime	2	Year
	Nominal voltage	12	V
	Hourly self-discharge rate	0.007	%/hour
	Initial cost	280	$/kWh
	O&M Cost	5	$/%
	Rated capacity	45.2	kWh
	Maximum DOD	70	%
	Max SoC	100	%
	Min SoC	30	%
	Replacement cost	280	$/year
	Maintenance cost	5	$/year
Inverter	Lifetime	15	Years
	Efficiency	92	%
	Initial cost	2500	$
Desil generator	Initial cost	1000	$/kWh
	Rated power	4	kW
	Lifetime	24000	Hours (5 years)
	Replacement cost	1000	$/kWh
	O&M Cost	0.064	$/L
	Fuel cost	0.689	$/L

Economic parameters details	Project lifetime	25	Years
	Inflation rate	5	%
	Interest rate	3	%

III Objective Functions

Cost and losses are the two stated ultimate study objectives to be minimized. Using the mathematical equations described in the subheading, determine the value of the aforementioned objectives.

3.1 Cost of energy

The objective equations of computing the CoE that measures the generated electricity is presented in Eq. (10). The CoE ($/kW h) measures the total net present cost ($TNPC$) with the help of the costs (O&M, investment, Replacement cost) and the CPV [44].

$$CoE = \frac{TNPC}{\sum_{t=1}^{8760} P_l} \times CPV \tag{10}$$

3.2 Losses

Using Deficiency of Power Supply Probability (DPSP) as a statistical index that present the probability percentages of supply failures and ranges between 0-1, where 0 refers to the met demand while 1 is the other side [41]. Moreover, the mathematical equations of calculation of the DPSP are formulated in Eq. (11) [46].

$$DPSP = 100 * \frac{\sum_{i=1}^{N} hours\ [p_{supp}(i) < (p_{dem}(i)]}{N} \tag{11}$$

where the time interval is denoted as (N), the p_{supp} refers to the power generated, $p_{dem}(i)$ the amount of load demand [44].

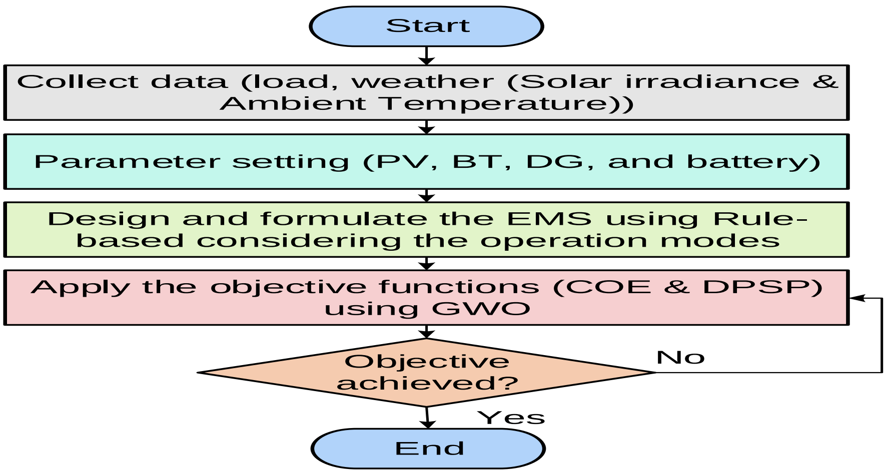

Fig.7. Flowchart of a systematic approach for achieving objectives.

IV Sizing Optimization approach

Since there are three searching types of optimization methods namely stochastic, deterministic, and hybrid methods [47]. The aforementioned methods differ from each other in terms of providing the best solution to optimization problems in various fields.

The first mentioned is utilized in hybrid renewable energy systems as considered by an enormous number of scholars in order to address the limitation of the deterministic method such as avoiding local optima. The considered algorithm for sizing the system components is the Gray Wolf Optimizer (GWO) Algorithm that counted as stochastic based and demonstrated the flowchart of GWO in Figure 8 [30].

While the benchmarks are Cat Swarm Algorithm (CSO) [31], and Particle Swarm Optimization (PSO) [33] are considered in the same regard. The second is not suitable for optimization problems with various local optima, which is disposed of by local optima [48]. Where the prons of deterministic-based are low computationally cost and provide reliable results with the same result.

The cons are highly dependent on the initial solution is why has been exploited in limited studies. Additionally, the last-mentioned method can be used to combine the mentioned algorithms and others. To form a hybrid system to gain an accurate result by solving complex optimization problems. Where the control parameters (design variables) are set before running the optimization algorithm.

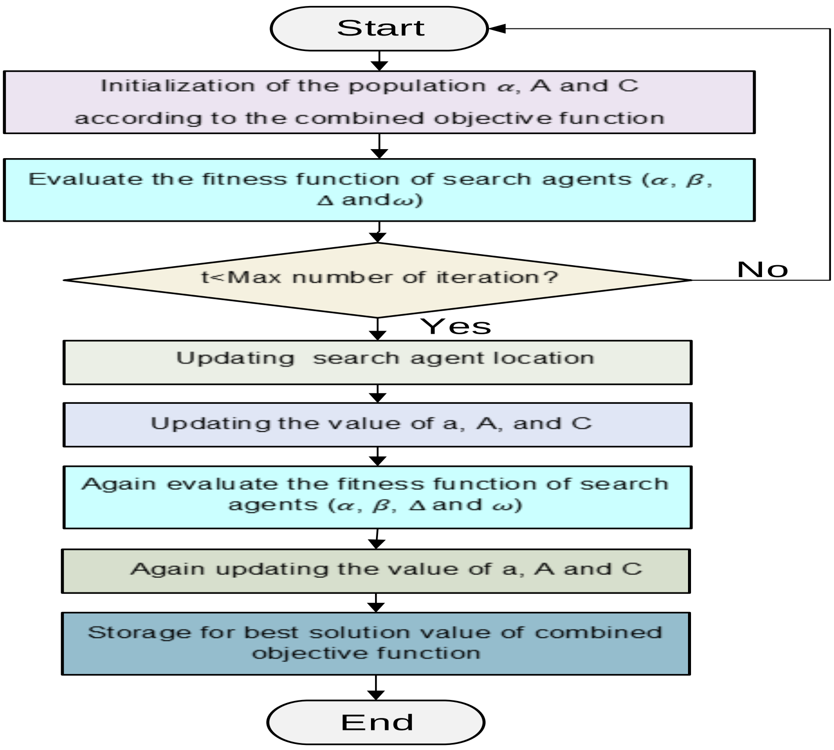

Fig.8. Flowchart of Gray Wolf Optimizer (GWO) [49].

Energy Management Schemes

As humans rely on the system based on IF then STATEMENTS and nature-inspired metaheuristic algorithms [50], EMS is thought to supply the load requirement through a variety of techniques [51]. Besides, it reduces the system operation cost, and BT SoC power balance, and is resource-dependent [38].

The acquired results from controlling strategies are not accurate without considering the design variable as key features by exploiting sizing algorithms as the flowchart presented in Figure 9 [50]. different criteria for utilizing the supervisory control algorithm are proposed below:

1. Supply the electric appliances by PV in case of the absence of a battery
2. Use a battery for supplying the system
3. Utilize DG to run the system in case of the absence of PV and BT or not sufficient to meet the demand.

All the aforementioned strategy points for simplicity are implemented by the EMS algorithm.

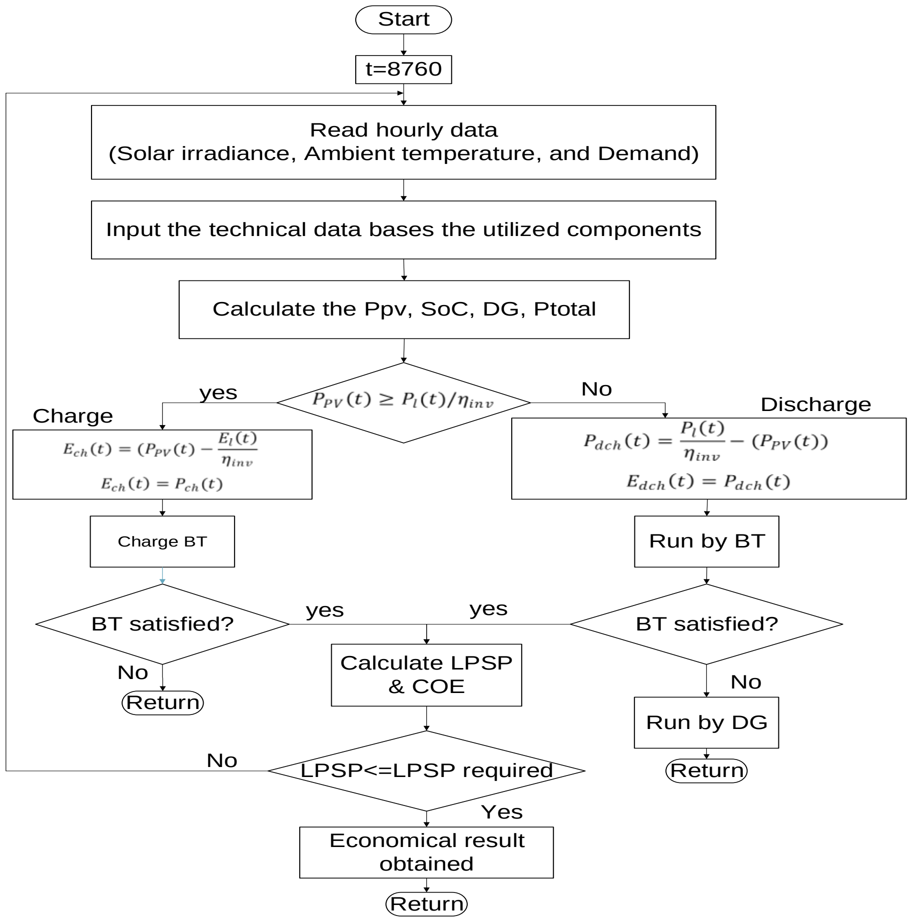

Fig.9. Energy Management Strategy scheme.

V Results and Discussions

Based on the proposed model that is demonstrated in Figure 6 its main objective is to have 0% of DPSP, the acombished results are presented and discussed. To develop the suggested GWO algorithm, the benchmarking algorithms CSA and PSO, as well as the EMS have been implemented using MATLAB R2021a on an Intel (R) Core (TM) i5-8250U CPU @1.60 GHz.

It has resulted that the GWO is performing better in terms of cost and losses based on the tabulated result in Table 2. Generally, the generated power from RESs is intermittent in nature and time-varying as demonstrated in Figure 10 which represents the output power from the exploited PV. As the aforementioned statement provides challenges in the hybrid system that have been addressed by coupling EMS with optimization algorithms. The comparison between the nature-inspired metaheuristic algorithms in terms of convergence is illustrated in Figure 12.

Table 2. Breakdown of the sizing and controlling.

	P_{PV} (units)	COE ($/kWh)	DPSP (%)	AD (days)	Battery capacity (kWh)	DG capacity (kW)
GO	27	0.92	0	3	45	5
CSA	30	0.23	0	2	45	5
PSO	33	0.15	0	2	45	5

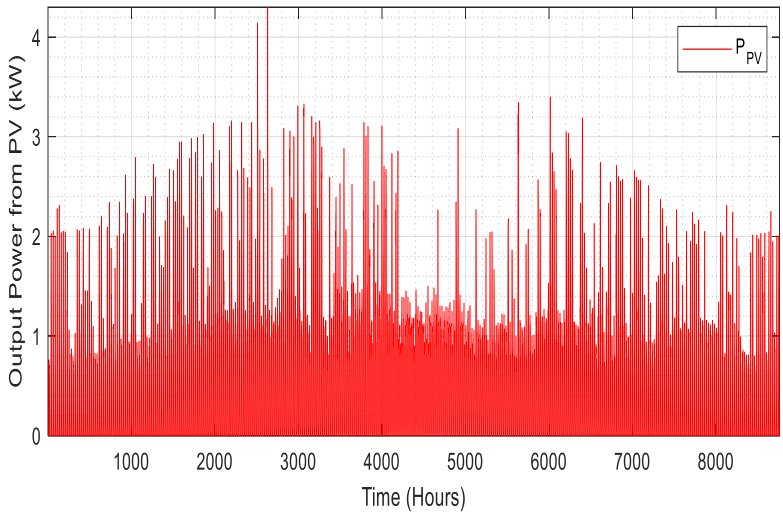

Fig.10. Output power from PV.

The utilized batter in this study is the $LiFePO_4$, the acquired result for the battery SoC during four seasons is demnastrated in Figure 11. As seen, the utilization of batteries differs from seasons to season. Furthermore, winter is the most utilized season due to the cold seasons and lower amount of solar radiation to generate electricity, in this case, the stored energy in the battery is utilized.

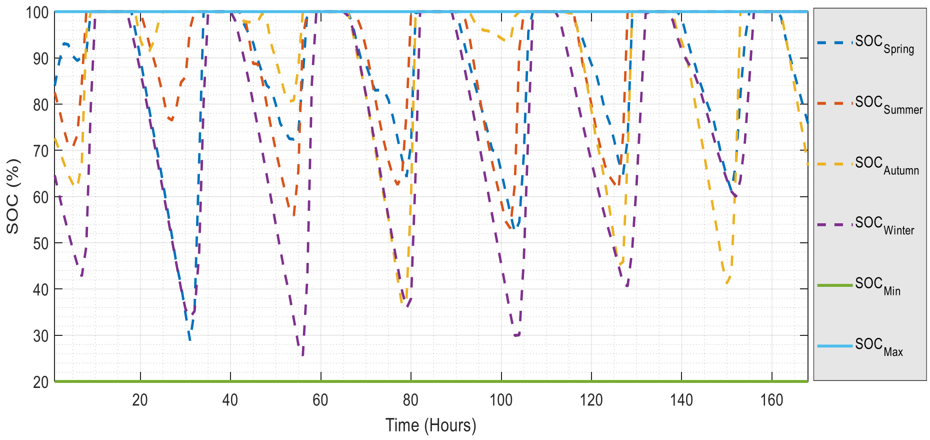

Fig.11. The seasonal state of charge of the battery.

In terms of cost, the comparison convergence among the proposed algorithm and its counterpart is presented in Figure 12. The GWO presents better performance in cost and reliability and number of PV in comparison with other methods as already formulated in Table 2.

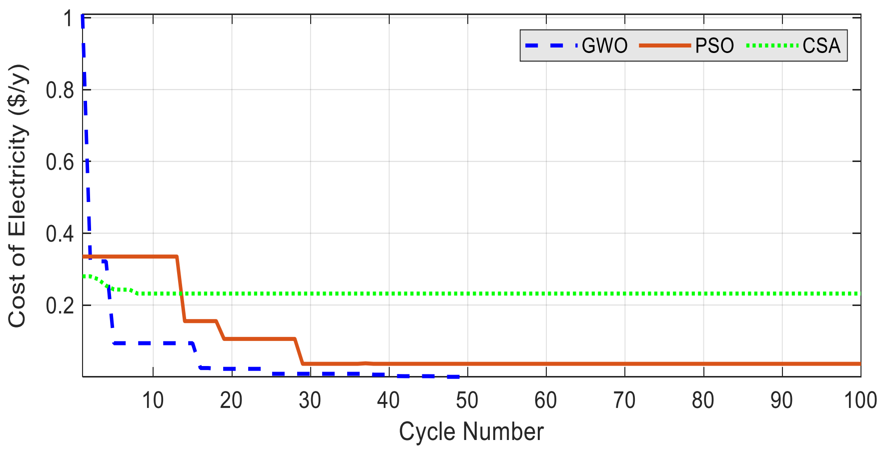

Fig.12. The comparison convergence curve for utilized methods.

VI Conclusion

This paper outlines the usage of PV as RESs to address fossil fuel challenges in meeting load demand in residential areas. Fossil fuels have begun to decline, causing a slew of power and environmental challenges that can be addressed with alternative energy sources. Integration of RESs with other sources solves the limitation faced in power and environment systems. Besides, diesel generator plays a vital role in providing backup power and meeting peak load demands during periods of limited solar energy. Coupling power management strategy and metaheuristic nature-inspired can help ensure a reliable power supply and reduce dependency on the diesel generator, resulting in cost savings and reliability. To deal with the complexity and complexities of PV-wind hybrid systems, nature-inspired optimization approaches and hybrid optimization techniques will be vital for future research. For further direction studies, as two mentioned cities in this study are blessed with high solar radiation, however, the availability of sunlight can be affected by various factors like sandstorms, dust, and cloud cover. These factors need to be considered while sizing the solar panels and understanding the system's performance under different weather conditions.

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