Optimal sizing of a hybrid system through particle swarm optimization for rural areas in Iraq

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ABSTRACT

In today's modern world, any community has the right to access basic electricity. With this in mind, efforts are being made to provide electric power to even the most remote locations. Solar and wind energy are examples of renewable energy sources that are both clean and versatile. For a distant rural school in south-eastern Iraq, this research presents particle swarm optimization (PSO) to reduce the cost of energy (COE) according to the maximum dependability of a hybrid renewable energy system (HRES) by utilizing an integrated electrical generation system. The suggested hybrid system consists of photovoltaics (PV), wind turbines (WT), and batteries (BT), all of which are subject to a specific investment restriction. Results showed that the optimal sizing of the number of photovoltaics (NPV) is equal to (9), the number of wind turbines (NWT) equal to (6), the number of batteries (NBT) of (29), the cost of energy (COE) (0.536 US$/kwh), loss of power supply probability (LPSP) (0.091%), reliability (REL) (99.909%) and renewable factors (RF) (100%) with (59%) PV penetration, and (41%) WT penetration. As a result, the use of the hybrid system is justified from a technological, economic, and humanitarian standpoint.

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NOMENCLATURE

NPC	: Net Present Cost	V_k^i	: Inertia
IC	: Initial Capital Cost	$\mathbf{P^i}$	: Best individual particle positions
Rep	: Replacement Cost	$\mathbf{P^g}$	: Best global position
i	: Real interest rate	**X**	: Particle position
W	: Inertia weight	**NPOP**	: Number of Populations
C_1	: Cognitive parameters	**N-Ite**	: Number of Iterations
C_2	: Social parameters		

1. INTRODUCTION

Renewable energy is considered the energy derived from a natural source that can be replenished in a short amount of time. It can come indirectly or directly from the sun, changing the environment or generating natural movement. A sustainable energy system strongly correlates with any country's socioeconomic development [1].

Due to the accessible technology on economic and commercial investment evidence, solar energy and wind energy as renewable energy can have a great potential in electrical energy generation; in addition, renewable energy provides an ideal, dependable, and affordable option for using locally available renewable energy resources [2], [3]. Furthermore, various governments offer different incentives to encourage the use of solar and wind energy to maintain energy capacity performance and, as a result, indirectly affect low-carbon society awareness and behaviours, which are invariably present, plentiful, clean, accessible and conveniently obtainable [4], [5].

Yet, the uncertainty regarding a single renewable source reduces the used reliability, necessitating redundant system design and the installation of sufficient battery storage for the period when the source is absent. Therefore, the hybrid renewable energy system (HRES) was created by integrating various storage systems and renewable energy sources for flexibility, stability, and reliability, as well as a reduction in energy costs and capital investment in comparison to a single renewable source [6]-[8]. Also, the hybrid renewable energy system (HRES) design is primarily based on the size of optimal components, which leads to economic, technological, and policy feasibility for launching the system into the energy market. This optimal design combination selects the best components from a pool of options based on an objective function with particular limitations and bounds [9], [10].

Furthermore, the higher the system complexity, the more it depends on component behaviour, which could have non-linear and linear features, renewable source uncertainties, and design conditions, which might be discrete or continuous [11], [12]. This study presents the best preliminary design for hybrid system scaling between PV modules and wind turbines. Particle swarm optimization (PSO) is used to find the lowest cost of energy (COE) while maintaining maximum reliability (REL), with the investment limitation weighted between solar and wind capacity [13]-[15].

The remainder of this work is arranged in the following manner. Section 2 goes over the geographical location and load energy demand in detail. Section 3 examines the system components of a hybrid renewable energy in terms of several combinations depending on key parameters such as replacement costs, initial costs, maintenance and operating costs, and rated power, as well as the site's renewable energy potential. The optimization process, modelling, and cost analysis are all covered in section 4. Lastly, the conclusion and results with simulation results and system design are covered in sections 5 and 6.

2. SYSTEM DESCRIPTION

2.1. Location selected site

Figure 1 shows a remote rural school in Zerbattiya, a village in south-eastern Iraq near Iranian borders [16]. It has a population of about 7,000 people and is located at 45°51.7'E longitude and 33° 24.2 'N latitude, with a 170 km^2 surface area and elevation of 95 m [16]. Many rural areas in Iraq, especially in the southern part, have limited access to the electricity grid. Thus, other optional energy sources, such as photovoltaic panels, and wind turbines, could help provide the electricity needs in such areas.

Figure 1. The geographical location of Zerbattiya

2.2. Load profile

The chosen school is a small one. Schools' electrical and lighting equipment don't require much electricity [16]. The mean annual daily energy need in the school has been about 35.96 KWh/d based on load information data [16], as seen in Table 1. Figure 2 depicts the school profile load.

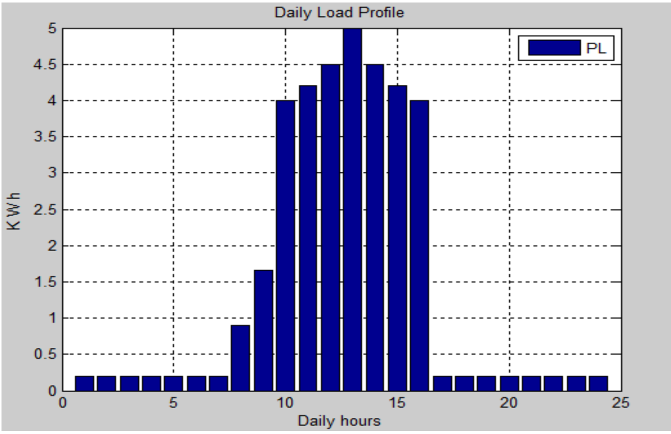

Figure 2. Hourly load profile

Table 1. The energy required of a typical school in Zerbattiya

N	Load equipment	Quantity	Power (watts)	Time of use (h)	Energy required (W/h)
1	Lamps	20	20	8	3,200
2	Lamps(out)	4	20	10	800
3	Refrigerator	1	200	8	1,600
4	Water heater	1	500	3	1,500
5	Radio	1	30	2	60
6	TV set	1	100	8	800
7	Ceiling fan	20	100	8	16,000
8	Air conditioning	1	1,500	8	12,000
	Total Average daily energy load				35.96 KWh/d

3. SYSTEM COMPONENTS

Various project components have been compiled based on goods available on the Iraqi market, with pricing obtained from various manufacturers and sales agents. Thus, the most appropriate and best components have been selected, considering their maintenance and operating qualities, capital costs, lifetime, and any variation costs (see Table 2). Each system's component has its distinct configurations and capital, maintenance and replacement prices. Photovoltaics (PV), wind turbines (WT), and batteries (BT) are all required components of the hybrid system to assure a constant supply to the load.

Table 2. Input parameters

Parameters	Unit	Value	Parameters	Unit	Value
PV [17]			O&M cost	Unit/y	10
Initial cost	$/kW	1,250	Rated power	kWh	1
Replacement cost	$/kW	1,250	Lifetime	year	10
O&M cost	Unit/y	10	**Converter [17]**		
Rated power	Watts	1,000	Initial cost	$/kW	500
Lifetime	year	25	Replacement cost	$/kW	500
Wind [17]			O&M cost	Unit/y	15
Initial cost	$/1.5 kW	2,000	Rated power	Watts	1,000
Replacement cost	$/1.5 kW	2,000	Lifetime	year	15
O&M cost	Unit/y	60	**Economic parameters**	[17]	
Rated power	Watts	1,500	Real interest	%	4
Lifetime	year	20	W		0.5
Battery [17]			$C_1 = C_2$		1
Initial cost	$/kWh	500	NPOP		1
Replacement cost	$/kWh	500	N-Ite		100

3.1. PV panels

Solar PV modules turn sunlight into energy, then distributed via an inverter. The step-up transformer boosts the voltage of the generated power and distributes it through the utility transmission line. NASA's surface meteorology database [17] was used to obtain hourly solar radiation data. The average annual solar radiation was measured as (5.14 KWh/m^2/d). As demonstrated in Figure 3, solar radiation is higher in the summer months. The PV's details are shown in Table 2 [17].

3.2. Wind turbines

Wind turbine energy primarily depends on the wind and rotor interactions. NASA's surface meteorology database [17] provided the wind speed data. The information was utilized to assess the feasibility of wind energy harvesting. Because of its geographical position and condition, wind energy is possible in Zerbattiya, where the average annual wind speed is 5.36 m/s. Figure 4 depicts the baseline data for the wind source. The specifics of the system's recommended wind turbine are listed in Table 2 [17].

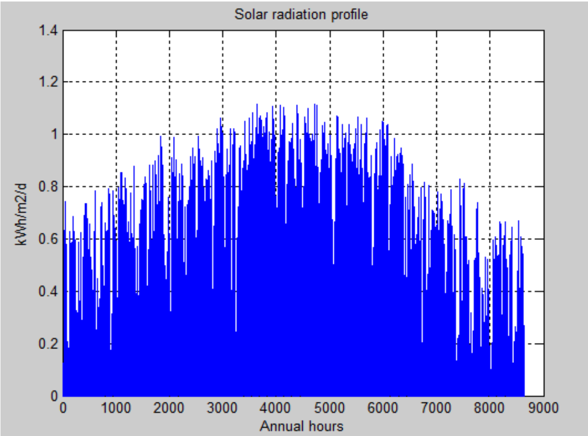

Figure 3. Annual hourly solar radiation

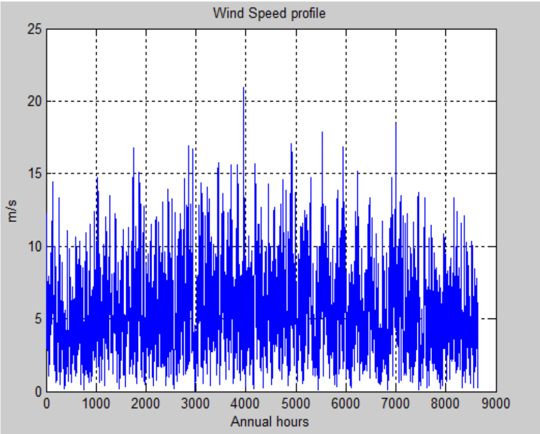

Figure 4. Annual hourly wind speed

3.3. Batteries

Generally, batteries are among the costliest components in renewable energy (RE) production systems. Due to the fact that solar and wind energy is by nature irregular, a PV panel and wind turbine system necessitate the use of battery storage capabilities to supply power at a stable level. Therefore, the battery comes into play as a storage facility, with the battery making up any shortfall in power supply relative to demand. The battery might store a specific amount of electricity and could only be charged and discharged so many times before it is damaged. Table 2 contains the details of batteries suggested in the system [17].

4. OPTIMIZATION

The component sizes should be determined to design an affordable and efficient hybrid microgrid system (HMGS). Integrating the generation sources and utilizing superior quality components significantly influence the system's life and can lower the consumer cost of energy (COE) in remote sites. The cost of energy is defined as the constant price per unit of energy. It is computed employing by (1) [18]-[25].

$$\text{Cost of Energy (COE)} \left(\frac{\$}{\text{KWh}}\right) = \frac{\text{Total Net Present cost (\$)}}{\sum_{\text{H}-1}^{\text{H}-8760} \text{P}_{\text{Load}}(\text{h})(\text{KWh})} \text{CRF} \quad (1)$$

Loss of power supply probability (LPSP) is a statistical factor [17] that can be calculated and explained (2).

$$\text{LPSP} = \frac{\sum(P_{load} - P_{pv} - P_{wind})}{\sum P_{load}} \quad (2)$$

5. RESULTS AND DISCUSSIONS

In the presented work, the rural city of Zerbattiya has been chosen to investigate the optimization of a hybrid micro-grid system (HMGS). The average annual daily energy for a load profile is around (35.96 KWh/d). The hybrid microgrid system (HMGS) power management approach was implemented to ensure an uninterrupted power supply in various operation modes based on load demand. As a result, using a battery bank to meet the load demand is required at this site. Optimization results at the site imply that a hybrid micro grid system (HMGS) could be used for the site, resulting in excellent reliability, low costs, and a high renewable energy contribution. The particle swarm optimization (PSO) algorithm was created using MATLAB software. All data and variables for the location which concerned hybrid systems and renewable energy sources were inserted, like solar radiation, wind speed, PV panel, wind turbine and battery size and available, location coordinates, project lifetime, and all price details like initial capital costs, replacement costs, Operation and maintenance cost (O&M), and hybrid power system component numbers. Photovoltaics, wind turbines, and batteries were all optimized via particle swarm optimization (PSO). Table 3 shows the best options, and as can be seen, the particle swarm optimization (PSO) gives adequate dimensions for this location.

Furthermore, Figure 5 depicts the annual percentage of energy created via PVs and WTs. In addition, the number of populations at work is one. The swarm motion in 100 iterations for each population is graphically depicted in Figure 6. The optimum combinations are selected at several sites with the same fitness value in the objective domain. Still, designing those systems with differing layouts could be complicated.

Table 3. PSO results

N	Station		Results
1	Number of photovoltaics	NPV	9
2	Number of wind turbines	NWT	6
3	Number of batteries	NBT	29
4	Cost of energy	COE	0.536 $/KWh
5	Loss power supply probability	LPSP	0.091 %
6	Reliability	REL	99.909 %
7	Renewable factor	RF	100 %
8	Number of global best	NGB	64
9	Photovoltaic production	PV %	59 %
10	Wind turbine production	WT %	41 %

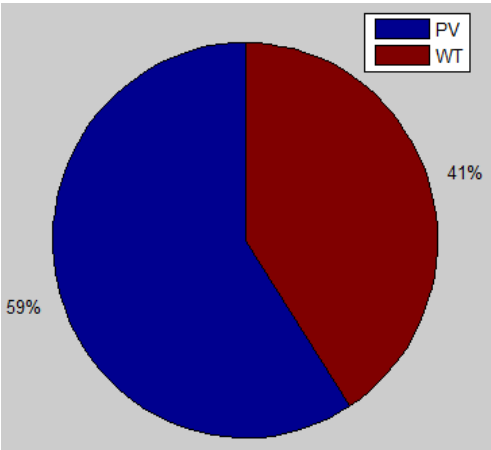

Figure 5. Annual percentage of Energy provided

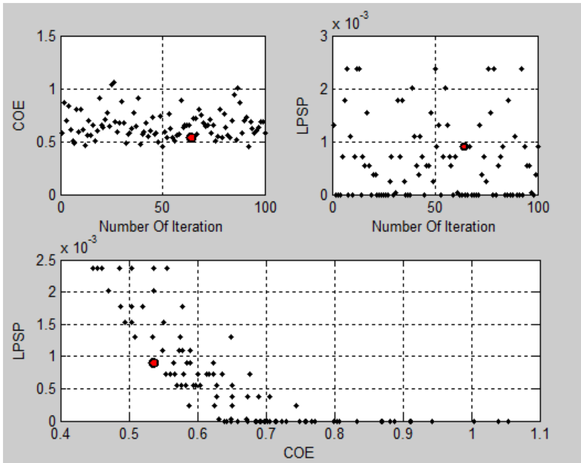

Figure 6. PSO simulation process for 100 iterations

6. CONCLUSION

Solar and wind energy are the most widely used renewable energy sources, owing to technological advancements and commercial economies of scale in production, resulting in lower manufacturing costs. The tendency to use renewable energy sources as well as electric distribution generating. On the other hand, using solar and wind as separate renewable sources might result in oversizing specification design and greater cost of energy (COE). As a result, the hybrid renewable energy system (HRES) was created to integrate multiple renewable energy sources dependably and lower the cost of energy (COE). A hybrid renewable energy system (HRES) model was established in this research to account for both energy output and project lifespan costs. Particle swarm optimization (PSO) was used to reduce the planned setup's cost of energy (COE). The wind turbine power curve extracts the wind power matching any wind speed range. In addition, solar power is created using a solar PV module. The cost of energy (COE) and loss power supply probability (LPSP) as objective functions might be specified as soon as the PV module and wind turbine are configured as a hybrid renewable energy system (HRES). Particle swarm optimization (PSO) is, after that, utilized to find the best hybrid renewable energy system (HRES) configuration for minimizing the cost of energy (COE) while maintaining optimum dependability while staying within the investment budget. This work's minimum cost of energy (COE) is (0.536 $/KWh) with reliability (REL) (99.909%).

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