Optimal sizing of standalone for hybrid renewable energy system by using PSO optimization technique

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ABSTRACT

Providing electricity to rural regions is difficult for developing countries, such as Iraq, particularly in remote parts without grid connections. The electrical demands of Zerbattiya, a community in southern Iraq near the Iranian border, are discussed in this paper. The proposed system includes wind turbines, solar panels, diesel engines, batteries, etc. This study suggests a techno-economic viable and optimal size for each component to generate electricity for this area. This research uses particle swarm optimization techniques (PSO). The best hybrid renewable energy system (HRES) design is achieved by balancing the lowest possible cost of energy (COE) with the lowest possible loss of power supply probability (LPSP) and the greatest possible reliability factor value. As a result of the findings, the respective ideal values of number of photovoltaics (NPV), number of wind turbines (NWT), number of diesel generator (NDG), number of batteries (NBT), COE, LPSP, and reliability are 138, 43, 2, 324, US$/KWh 0.129, 0.0508%, and 99.9492%, respectively. Finally, it was discovered that implementing a HRES is an effective way to address the electrical demands of remote rural regions in Iraq and other developing countries with similar climates.

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NOMENCLATURE

PSO	: Particle swarm optimization	NPV	: Number of photovoltaics
COE	: Cost of energy	NWT	: Number of wind turbines
NPC	: Net present cost	NDG	: Number of diesel generator
LPSP	: Loss of power supply probability	NBT	: Number of batteries
REL	: Reliability	NGB	: Global best particle number
RF	: Renewable factor	CRF	: Capital recovery factor
IC	: Initial capital cost	i	: Real interest rate
C-Rep	: Replacement cost	W	: Inertia weight
C-O&M	: Operation and maintenance cost	C_1	: Cognitive parameters
RE	: Renewable energy	C_2	: Social parameters

RES	: Renewable energy source	V_k^i	: Inertia
HRES	: Hybrid renewable energy system	P^i	: Best individual particle positions
RF	: Renewable factor	P^g	: Best global position
PV	: Photovoltaic	X	: Particle position
WT	: Wind turbines	NPOP	: Number of populations
DG	: Diesel generator	N-Ite	: Number of iterations
BT	: Battery	NGB	: Number of global best

1. INTRODUCTION

Accessibility to an electric power source that is reliable and affordable is an essential need for all communities. Nevertheless, the United Nations Development Program (UNDP) report reveals that more than 25% of the global population continues to be without electric power, especially in communities located in remote areas [1], [2]. Remote areas are typically unconnected to the national grid and in difficult terrain, like hilly regions or thickly forested areas. Extending electricity transmission lines in some regions might be too expensive or unfeasible [3]. In such circumstances, the potential is in renewable energy (RE), from renewable energy resources, like solar, wind, and others, which are invariably present, plentiful, clean, free, and conveniently obtainable [4]. Renewable energy provides an ideal, dependable, and affordable option for using locally available renewable energy resources. They make it possible to generate centralized electricity locally by integrating renewable energy sources into a system that uses a diesel generator (DG) as a backup. These systems can range from a modest single-phase offering electric power for one residence to a sizeable three-phase network capable of supplying an entire community [5].

Furthermore, they can conveniently scale up for connection to the national grid should there be substantial growth in demand or when the community is extended. In the current study, using a diesel generator is not viable because of several factors: fuel price fluctuations, fuel transportation challenges, and high operational expenses [6]. Furthermore, there is a matter of diminishing fossil fuel use and environmental pollution. For these reasons, renewable energy is the preferred option to generate power as it eliminates the problem of harmful emissions [7]. Integrating various renewable energy sources, such as solar and wind, with a battery bank enhances the effectiveness of the hybrid renewable energy system (HRES) and renders it more reliable [8]. Using different optimization techniques, the ideal solution for the hybrid renewable energy system is assessed based on the minimum cost of energy (COE) [9]. An appropriate technical methodology is required to techno-economically analyze and determine the use of energy sources for the hybrid renewable energy system [10]–[15].

2. RURAL REGION DETAILS

2.1. Population density and geographic location

Zerbattiya is a small town near the Iranian border in south-eastern Iraq Figure 1. Al-Shammari *et al*. [16] at an elevation of 95 m above sea level. With a land area of 170 km^2, it is located at N°33.26 and E°45.91. It has a population of approximately 7,000 [17]. The chosen population comprises communities in isolated areas near big cities. These remote areas are mostly populated by low-income communities that have no access to any grid connection [17].

Figure 1. Geographical location

2.2. Load estimation

Zerbattiya village is not connected to the national electrical grid. As stated in Table 1, Zerbattiya is made up of (83) small houses (11), business buildings, schools, and clinics, according to figures from Iraq's Ministry of Planning [16]. According to estimates from Iraq's Ministry of Electricity [17], energy consumption rates in households, establishment buildings, clinics, and schools are approximately (36.41) and (145.64), (31.54), and (35.96) kwh/day, as shown in Table 1. According to the Iraqi Ministry of Electricity's reports, the demand for electricity in Iraq has grown by 1 % annually. Furthermore, because the proposed system's average life expectancy is 20 years, it will be estimated that the power supply will be 1.2 times the current load during the system's lifetime. The loads will be around 5,629.932 kwh/d after 20 years, the load profile presented in Figure 2.

Table 1. Energy consumption

N	Load equipment	Quantity	kwh/d	Total kwh/d
1	House	83	36.41	3,022.03
2	Establishment building	11	145.64	1,602.08
3	Clinic	1	31.54	31.54
4	School	1	35.96	35.96
		Total average daily energy load	4,691.61 kwh/d	

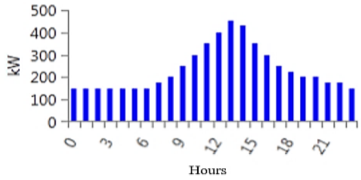

Figure 2. Load profile

3. UNIT SIZING OF HRES

The proposed HRES model is employed in designing a PV/Wind hybrid renewable energy system with batteries to store electricity and a diesel generator to maintain the uninterrupted flow of electricity to meet the demanded load [18]. The ideal component sizes and techno-economic analysis of the hybrid renewable energy system are determined based on annual hourly mean resource (PV/wind) data. The loss of power supply probability (LPSP) approach is used to assess reliability. The ideal hybrid renewable energy system arrangement is ranked based on the minimum cost of energy (COE). To regulate the functioning of the battery bank (BB) and diesel generator (DG), a dispatch approach is required when available renewable power is insufficient to meet the load demand.

3.1. PV panel

Iraq is blessed with relatively plentiful solar energy due to its geographical position, and various studies have proposed that solar energy be used as a viable source of renewable energy (RE). However, it is unfortunate that the use of solar energy as renewable energy is still low. Photovoltaics (PV) converts solar energy to DC electricity to create power [19]. Table 2 lists the specific characteristics of the PV panels used in this suggested study [19]. Data about solar radiation was obtained from NASA surface meteorology database 2022 [20]. As indicated in Figure 3, the average yearly solar radiation has been (5.14) kwh/m^2/d.

3.2. Wind turbine (WT)

An electric generator converts wind energy into mechanical energy, which is subsequently turned into electrical energy. Wind turbine energy primarily depends on the wind and rotor interactions. The information was utilized to assess the feasibility of wind energy harvesting [19]. Table 2 shows the specifics of a specific wind turbine [19]. NASA's Surface Meteorology Database provided the wind speed data [20]. Figure 4 shows the average wind speed of (5.36) m/s.

3.3. Battery bank (BB)

Batteries are among the most expensive components in most renewable energy production systems. The fickle nature of solar and wind energy necessitates the usage of battery storage capacities in photovoltaic and wind turbine power systems to produce consistent electricity. As a result, the battery serves as a storage device, ensuring an uninterrupted flow of energy to fulfill demand [21]. Table 2 shows the details of a particular battery [22].

The battery’s input power can be positive or negative because of the charging and discharging process.

$$aP_{PV}^{T} + P_{WT}^{T} = P_{Demand}^{T} \quad (1)$$

In this situation, total RE (P_{PV}^{T} +P_{WT}^{T}) is equal to load demand.

$$P_{PV}^{T} + P_{WT}^{T} > P_{Demand}^{T} \quad (2)$$

In this situation, total RE (P_{PV}^{T} +P_{WT}^{T}) is higher than load demand.

$$P_{PV}^{T} + P_{WT}^{T} < P_{Demand}^{T} \quad (3)$$

In this situation, total RE (P_{PV}^{T} +P_{WT}^{T}) is less than load demand.

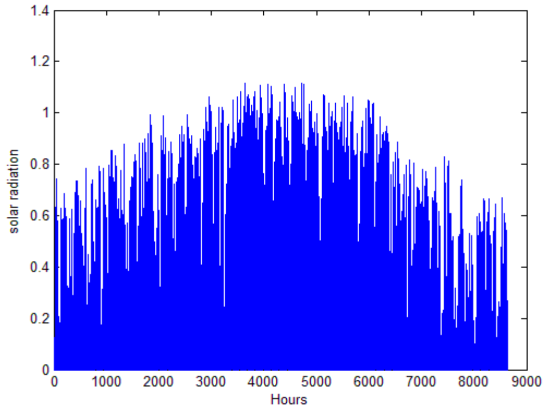

Figure 3. Annual hourly solar radiation

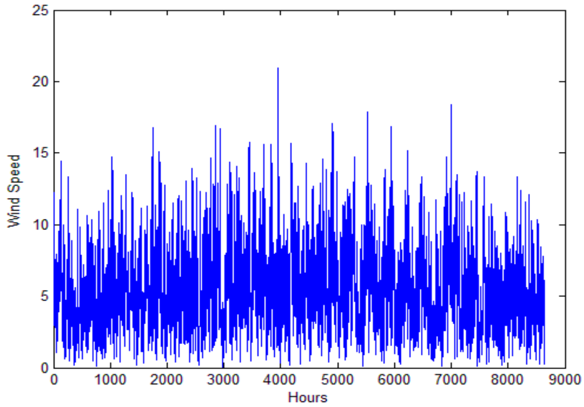

Figure 4. Annual hourly wind speed

3.4. Diesel generator (DG)

The PV-WT hybrid system is often unreliable, which is a major impediment to the commercial growth of these renewable energy systems (RES). Diesel generators have become suitable for enhancing systems reliability [22]. As a result, diesel generators have shown to be effective in improving system dependability. Table 2 shows the specifications of a specific diesel generator [19].

Table 2. Input parameters

Parameters	Unit	Value	Parameters	Unit	Value
PV			Diesel generator		
Initial cost	$/KW	1,250	Initial cost	$/KW	125
Replace cost	$/KW	1,250	Replace cost	$/KW	125
O&M cost	$/unit/year	10	O&M cost	$/unit/hour	0.25
Rated power	Watts	1000	Rated power	KW	100
Lifetime	year	25	Lifetime	hours	15,000
Wind turbine			converter		
Initial cost	$/KW	1,700	Initial cost	$/KW	500
Replace cost	$/KW	1,700	Replace cost	$/KW	500
O&M cost	$/unit/year	120	O&M cost	$/unit/year	10
Rated power	KW	10	Rated power	KW	1
Lifetime	year	20	Lifetime	year	20
Battery			System lifetime	year	20
Initial cost	$/KWh	500	Economic parameters		
Replace cost	$/KWh	500	Real interest	%	4 [23]
O&M cost	$/unit/year	10	W		0.5
Rated power	KWh	1	$C_1 = C_2$		1
Lifetime	year	10	N-Iteration		1,000

4. OPTIMIZATION

In designing a low-cost but highly efficient hybrid microgrid system (HMGS), the sizing of system components should be prioritized. Combining generating devices and employing only parts significantly influences the system's lifetime and reduces consumer electricity costs, especially in remote locations. Various methods and algorithms are regarded today as artificial intelligence algorithms.

– Particle swarm optimization (PSO)

In general, artificial algorithms have their basis in the population and must have some simulations. The ideal plan for such a hybrid system of high reliability is considerably complicated and involves

exhaustive computation. Particle swarm optimization (PSO) was initially defined by Kenney and Eberhart in 1995 [1], [9], [21], [24], [25]. The PSO algorithm comprises three major stages presented below.
Stage 1: Evaluating the fitness of each particle.
Stage 2: Updating individual and global best fitness and positions
Stage 3: Updating the velocity and position of each particle.

5. RESULTS AND DISCUSSIONS

All variables and data for the location were inserted that concerned the renewable energy sources and hybrid systems, like the solar radiation, temperature, wind speed, size of PV, WT, DG, and BT available, the project lifetime, the location coordinates, all price details such as initial cost (IC), replacement cost, Operating and Maintenance cost (O&M), the component numbers of hybrid power system generation, etc. Particle swarm optimization (PSO) achieved optimal PV, WT, BT, and DG ratings. The optimal solutions are presented in Table 3 and Figure 5. In addition, Table 4, Figure 6, and Figure 7. PVs, WTs, and DGs generate a certain annual percentage of energy with a swarm motion in 1,000 iterations for each population. Specifications of the hybrid renewable energy system (HRES) components in the Table 1 include (1 KW) PV panel, (10 KW) WT, (100 KW) DG, and (83.4 Ah) BT.

Table 3. PSO results

N	Station		Results
1	Number of photovoltaic	NPV	138
2	Number of wind turbines	NWT	43
3	Number of diesel generators	NDG	2
4	Number of batteries	NBT	324
5	Cost of energy	COE	0.129 $/KWh
6	Loss of power supply probability	LPSP	0.0508 %
7	Reliability	REL	99.9492 %
8	Global best particle number	NGB	750

Table 4. Annual energy percent provided by PV, WT, and DG

Components	PV %	WT %	DG %
PV-WT-DG	9.77	77.42	12.81

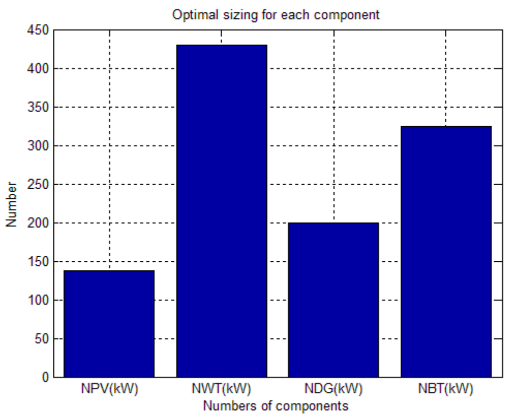

Figure 5. Each component's optimal sizing

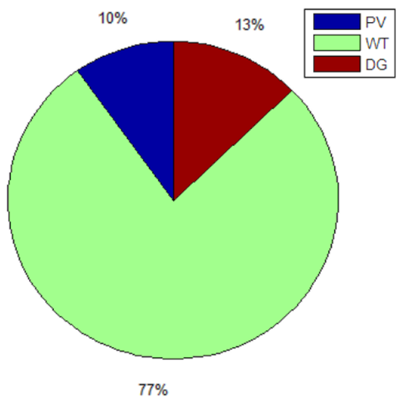

Figure 6. The annual percentage of energy is provided

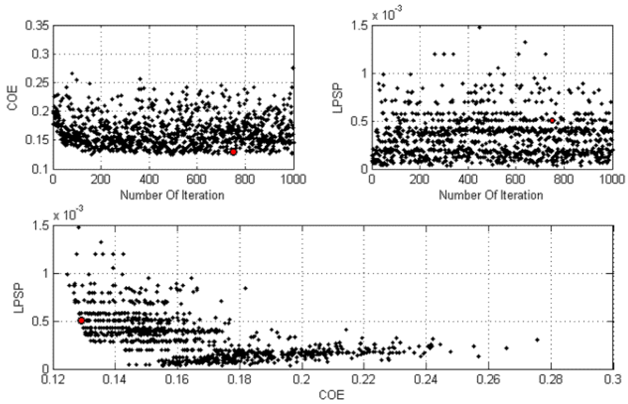

Figure 7. MOPSO simulation process for 1000 iterations

6. CONCLUSIONS

Access to an electricity source is a fundamental requirement for any community. Electrification can enhance living standards by improving the status of education and healthcare and spurring the regional economy. Implementing microgrids is a possible solution to introduce rural electrification by minimizing installation expenses and maximizing the supply. Zerbattiya is the study's subject site, a rural southern Iraq region near the Iranian border. This research suggests a regulating strategy for a hybrid micro grid system (HMGS) that considers the combination of photovoltaic (PV), wind turbine (WT), diesel generator (DG), and battery storage (BT) with variable loads to produce and sustain continuous energy and fulfill the desired load in various operational modes. The multi-objective particle swarm optimization (MOPSO) approach is adopted to obtain the optimal system mix and appropriate component sizes. The loss of power supply probability (LPSP) and cost of energy (COE) are defined as the "objective functions." The respective values of the NPV, NWT, NDG, NBT COE, LPSP, and reliability are (138), (43), (2), (324), US$/KWh (0.129), (0.0508 %), and (99.9492 %), respectively. Zerbattiya's hybrid microgrid system (HMGS) works on PV, WT, and DG. Still, the optimization result shows that using a hybrid microgrid system (HMGS) will be a high value for reliability. As a result, employing renewable energy can improve the accessibility of power to rural places in Iraq while raising living standards.

Furthermore, generating electricity with wind turbines has various advantages compared with PV panels. The suggested method can overcome several technological barriers preventing the implementation of microgrid efforts. In addition, the findings of this study might be utilized as a springboard or tool to accelerate rural electrification programs and speed up the design and implementation of various projects.

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