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Energy Management Optimization for Micro-grid PV and Wind Support System

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Abstract

Nowadays, microgrids play a crucial role in modern power systems due to possibility of integrating renewable energies into the Microgrids system. It is expected in near future that collaborating microgrids as a community has a great affect in providing efficient energy for suppliers. Therefore, optimal operation of a Microgrids, as a first step, is an important issue in this field. In this paper, by considering an integrated MG comprised of conventional generators, photovoltaic and wind a particle swarm optimization (PSO) is applied to minimize the cost function of the MG. Finally, the simulation results are discussed and analyzed to evaluate the system operation.

The study identifies an optimally sized hybrid energy structures that meets technical & economic criteria in line with reliability requirements. Additionally, a sensitivity analysis was performed, emphasizing the impact of Photovoltaic structures contribution as a critical factor in determining the structures' economic efficiency.

Keywords: Microgrids (MGs), wind turbine (WT), **Load profile,** Global Horizontal Irradiation (GHI), Optimum power contribution

1 Introduction

Microgrids (MGs) can be consider as a small power system which are combined with distributed generations (DGs), energy storage systems (ESSs), and loads [1]. Moreover, DGs can produce energy by different types of generators such as diesel generators or renewable source of energy such as solar or wind energy. Therefore, MGs can be integrated with renewable energies (REs) to take advantage of limitless sources of energy with no environmental pollution as a vital commitment to the future of the world [2]. As it can be inferred, an MG can produce and consume energy according to the instantaneous generated energy and load demands. Therefore, the power balance in MGs is more critical due to higher dynamic of the system in comparison with power system. This issue will be more acute when the MG is integrated with REs due to uncertainty, inherent randomness and volatility of renewable generators [3]. As a consequence, energy storage system (EES) plays a vital role in order to provide the power balance especially in standalone operation mode. Batteries, as one of the most common parts of ESSs, can effectively cope with the energy swing in a single MG owing to their high dynamic response to absorb or exude of energy [4]. However, in grid-connected MGs, power system can play the same role of batteries in ESS with more reliability and economically [5] then the importance of ESS reduce significantly. Grid-connected MGs can exchange energy with power system, therefore, the paradigm of conventional power system will be affected by injecting energy to the power system, and it makes some changes in the adjustment related to the power system [6]. Microgrid community is another effective method to reduce the impact of ESS in the single MG. In MG community, energy can exchange between each other in order to provide the power balance [7]. In this case, the setting of the power system will be affected less than a single MG.Energy management system (EMS) in MG community plays a significant role in order to realize some features such as: managing the power flow between MGs and power system [8], optimal operation [9], generation prediction for all RES [10]. One on the most important tasks of an EMS, is realizing the optimal operation of each individual MG in order to determine how much energy can exchange optimally by considering the practical constraints of a particular MG. There are various optimization methods such as evolutionary programing, dynamic programing, genetic algorithm, and artificial neural network approaches, in order to optimize the operation of the system by considering the equality and inequality constraints [11], [12]. In this paper, particle swarm optimization (PSO) is applied to a single MG integrated with RES in order to minimize the operational cost of the system. In PSO each individual particle makes his decision using his own experience together with other individuals' experiences [13]. The individual particles are drawn stochastically toward the position of present velocity of each individual, their own previous best performance, and the best previous performance of their neighbors [14]. The main advantages of the PSO algorithm can be elaborated as: simple concept, easy implementation, robustness to control parameters, and computational efficiency. In this paper, after determining the configuration of the proposed MG, a particular case or scenario, the cost function, equality and inequality constraints of the power generations will be defined, and the system will be optimized by applying a PSO algorithm. The optimizer determines the economic power generation of all generators based on the load profile. Moreover, the probable surplus energy or required energy from power system can be calculated over this optimization. Finally, the simulation results will be presented in order to evaluate the system operation.

2 System Configuration

As it can be seen from Fig. 1, the considered single MG in order to study in this paper, as a particular scenario, comprises a photovoltaic (PV) power plant, a wind turbine (WT) generator, three conventional diesel generators (G1-G3), and loads which all are connected to the power system (PS). On the one hand, the power profile of the load, over a 24-hour interval, is shown in Fig. 2. On the other hand, Fig. 3 and Fig. 4 show the generated power of photovoltaic, and wind turbine, respectively, also over a 24-hour interval. In addition, the nominal power for each element included in Fig. 1 is listed in Table I.

Table 1. Nominal power of the units

Power generation and load demand	Nominal power	Minimum power	Maximum power
Photovoltaic	5 kW	0	5 kW
Wind	5 kW	0	5 kW
Diesel generator 1	10 kW	2 kW	10 kW
Diesel generator 2	25 kW	4 kW	25 kW
Diesel generator 3	15 kW	3 kW	15 kW
Load	------	0.6 kW	50 kW

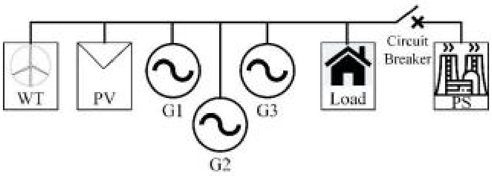


Fig. 1. Block diagram of the considered single MG. It comprises a photovoltaic (PV) power plant, a wind turbine (WT) generator, three conventional diesel generators (G1-G3), and loads which all are connected to the power system (PS).

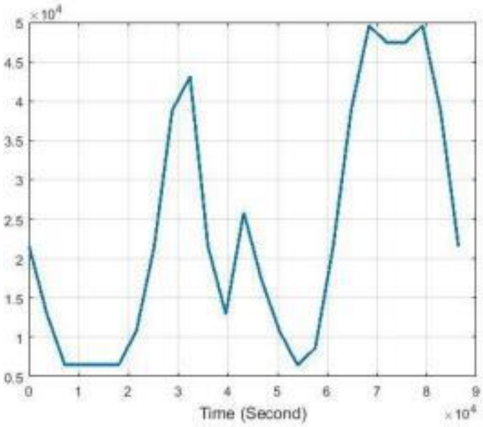


Fig. 2. Load's power profile.

3 Methodology

The purpose of this chapter is to describe the approach taken to finish the project.

3.1 Introduction

The primary objective of this study is to determine the optimal design for a diesel-based hybrid wind/photovoltaic renewable energy structures. Important parameters that are considered during the optimization process include the number of wind turbines, the number of solar panels, the number of autonomous days to determine battery capacity, & the number of dwellings in a village that can share the renewable hybrid energy structures. The total structures cost consists of the annualized investment cost, replacement cost, operating & maintenance costs for structures components, & diesel generator fuel costs.

Two crucial conditions limit the optimization problem: lowering the LCOE & preserving the maximum permitted dependability index. PSO is used as the optimization approach to solve this multi-variable, constrained optimization issue. The best combination of wind turbines & PV panels, battery autonomy duration, & number of homes sharing the structures is found using the PSO algorithm. When creating a sustainable hybrid energy solution for rural electrification, this method guarantees both structures dependability & economic viability.

3.2 Simulation Approach

In this study, a 100% structures reliability is assumed, implying that the hybrid energy structures must operate without any interruptions in power supply under all conditions. Even in times when renewable energy sources like solar or wind are not available, the structures can consistently meet the load requirement because to this strict dependability criterion. This is accomplished by optimizing the hybrid structures's main variables using a specially designed software tool. To guarantee that the structures continuously meets energy dem&s while abiding by the dependability restriction, the program methodically chooses the best size & arrangement of components, such as wind turbines, PV panels, battery loding, & diesel generators.

3.2.1 Load profile

A st & alone hybrid renewable energy structures provides a practical substitute for traditional grid-based electricity provision in rural & isolated tribal communities. However, a detailed examination of the load profile of the area is necessary in order to build a dependable & effective structures for such places. The load profile, which comprises the daily energy usage pattern, is a critical factor influencing the sizing & modeling of structures components, especially the battery loding. The timing & magnitude of peak dem& periods, as well as consumer behavior, significantly impact the structures's overall reliability. Furthermore, these factors influence the resulting cost of electricity as well as the ideal sizing of components, including batteries, wind turbines, & solar panels. The hybrid structures is designed to efficiently meet this particular daily energy requirement using the hourly load profile of a typical rural area, as shown in Figure 3-1.

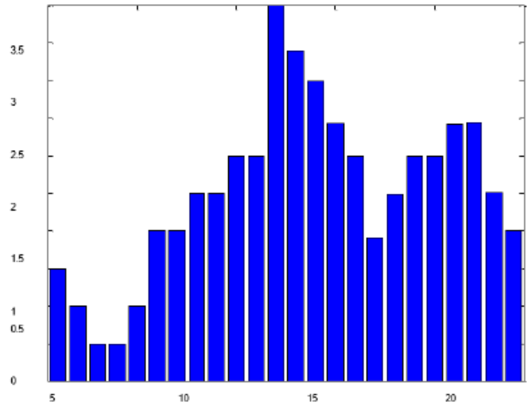


Figure 3:Hourly typical rural domestic load profile (kW)

3.2.1.1 Design of battery bank

Based on the load, the battery capacity (kW) of the structures is designed using the following formula:

$$C_B = \frac{E_L AD}{DOD.\eta_{inv}.\eta_{B}}$$

For instance, assuming autonomy days = 3, depth of discharge (DOD) = 80%, & ηinv = 95%, ηb = 85% for a single home with the load profile mentioned above, the battery bank's capacity would be:

$$C_B = \frac{(1*averageload)\times 3}{0.80\times 0.95\times 0.85} = 4.64(averageload(kW))$$

The capacity of the battery bank should be constructed for 4.5 times the usual dem&, in this case 2.54 kW, so that it can meet the load for a maximum of three days when there are not enough renewable energy sources. For instance, if the lead acid battery is 12 volts & 100 amps & the DC bus is 48 volts, then 4.64 X 2.54 = 11.7856kW, 11785.6/48 = 245 amps. Four batteries would need to be linked in series in order to measure the DC voltage level at the DC bus. Since the amount of batteries in parallel would be 245/100=2.45≈3, one residence would need 12 batteries.

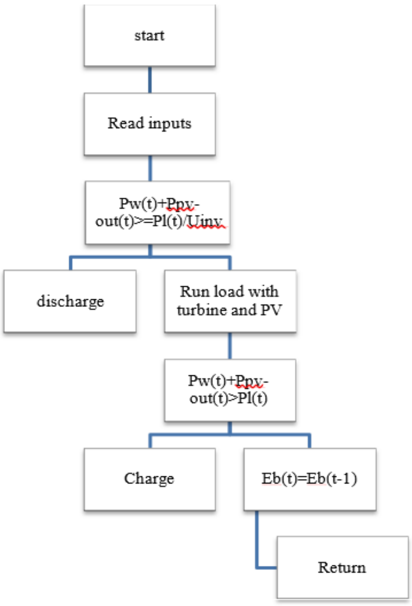


Figure 4:Mainflow diagram of the hybrid structure

4 RESULTS

4.1 Introduction

Using local weather data, a hybrid PV-wind structures has been built to satisfy load dem&s in remote places, including seasonal imbalances & the intermittent nature of renewable energy sources. The findings of the simulations conducted with Metrics Labotary program, notably version 7.11, are presented in this chapter. The findings show the many component configurations for an effective hybrid structures that can supply a typical load in rural locations.

This study explores two optimization approaches. The first involves analyzing the outcomes of multiple simulation scenarios & recommending the optimal configuration based on a comparative evaluation. The second approach employs Particle Swarm Optimization (PSO) to minimize the fitness function while considering various constraints, aiming to identify the most suitable structures configuration.

4.2 Renewable energy outputs

Energy poverty in rural areas can be addressed with renewable energy sources since it is either impractical or economically unfeasible to extend the grid over challenging terrain & dense forests. This study explores the feasibility of electrifying rural areas using renewable resources like solar & wind power.

4.2.1 Wind output

Particularly in isolated locations, wind is a plentiful & renewable energy source with significant electrification potential. The Solar Energy Research Group at UKM conducted a noteworthy study on wind energy in the early 1980s, collecting wind speed data from 10 stations throughout Malaysia during a ten-year period (1982–1991). These stations, mainly located at airports & coastal regions, were carefully selected to capture the effects of both l&& sea breezes on wind patterns. The dataset, consisting of hourly wind speed recordings, indicated that the average wind speed in Malaysia was generally low—rarely exceeding 2 m/s—owing largely to the isolated nature of many sites. However, the study also emphasized that wind speeds vary significantly by region & season. The East Coast, in particular, recorded the highest wind speeds, with daily peaks in the afternoon & the lowest values occurring just before dawn.

Despite the generally light average wind flow, certain regions such as remote isl&s & the East Coast demonstrate promising wind energy potential. For example, during cold air surges from the north, wind speeds in areas such as Sabah & Sarawak can reach as high as 15.4 m/s. Furthermore, from October to March, wind speeds can average up to 10.2 m/s, making these regions suitable for wind energy exploitation (Shafie, Mahlia et al., 2011). Among the most favorable locations identified are Peninsular Malaysia's east coast is home to Mersing & Kuala Terengganu. The Kota Kinabalu & Tawau stations in Sabah record steady wind directions all year round. In particular, wind power density is higher in Kota Kinabalu towards the end of the year, whereas it is higher at the Labuan station at the start of the year. The comprehensive hourly wind speed data gathered for this investigation is shown in Figure 5.

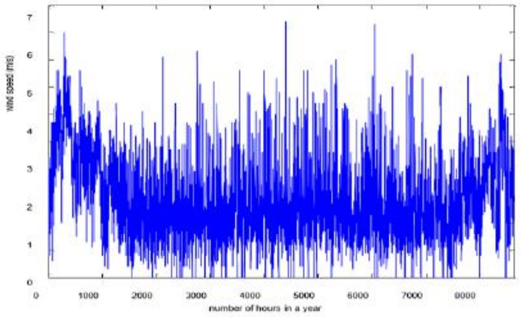


Figure 5: Hourly wind speed data.

Data analysis shows that rural households without connection to the national grid could use tiny wind turbines to generate electricity (Sopian, Othman, et al. 1995). In order to construct the hybrid structures, a tiny wind turbine with a rated output of 0.3 kW is taken into consideration in this study. Table 4-1 lists the specific features of the chosen wind turbine. Figure 6 displays the wind turbine's daily output power, which is determined using equation (2.14).

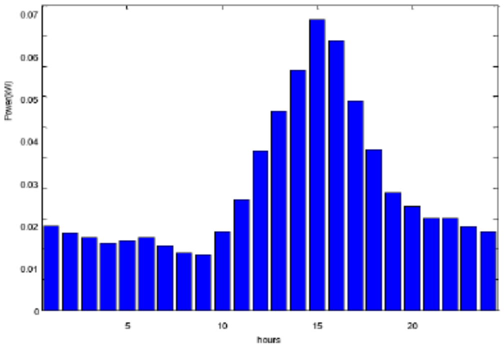


Figure 6: Typical daily output power as of wind turbine.

4.2.2 PV output

This section explores the potential application of solar energy, particularly in rural areas, where electrification needs are often unmet by conventional power structuress. Numerous earlier studies have focused on analyzing solar radiation data to evaluate its feasibility for photovoltaic (PV) structures deployment. Because Malaysia continuously receives a large amount of solar radiation throughout the year, its climate is ideal for using solar energy. The region has a comparatively high degree of solar radiation by international st & ards, which encourages the widespread usage of solar energy structuress. According to estimates, the potential of solar energy is almost four times larger than the world's total supply of fossil fuels.

The solar radiation levels in Malaysia vary seasonally, ranging from approximately 0.61 kWh/m² per day in December to about 6.8 kWh/m² in August & November. The northern region & parts of the east receive the highest annual average solar radiation, exceeding 3 kWh/m², making these areas particularly suitable for PV structures installation. Furthermore, the environmental benefits of solar energy are noteworthy; An estimated 40 kg of CO2 emissions can be avoided annually by installing just one square meter of solar panels (Sovacool & Drupady, 2011). Because solar radiation levels directly impact the quantity of power generated by the panels, they have a significant impact on the performance of PV structuress. Structures design & optimization depend on precise PV output estimation. Typically, Daud & Ismail (2012) describe techniques for calculating the power generated by the solar panels that take into account the panels' efficiency metrics & radiation intensity:

$$P_{pv-out}=P_{N-pv}\times\frac{G}{G_{ref}}\times[1+K_t((T_{amb}+(0.0256\times G))-T_{ref})]$$

The output power of a photovoltaic (PV) structures is influenced by several factors, including solar radiation, temperature, & the rated capacity of the panels under st&ard test conditions. The PV output power, denoted as Ppv−outP_{pv-out}Ppv−out, is calculated based on the rated power at reference conditions PN−pvP_{N-pv}PN−pv, the incident solar radiation GGG (in W/m²), the reference solar radiation GrefG_{ref}Gref (1000 W/m²), the reference cell temperature TrefT_{ref}Tref (25°C), the temperature coefficient of maximum power KtK_tKt (–3.7×10⁻³ per °C), & the ambient temperature TambT_{amb}Tamb. These parameters together provide a more accurate estimation of the actual energy produced by the PV modules in real environmental conditions.

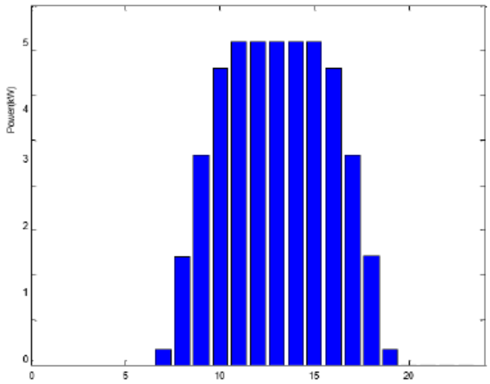


Figure 7:Regular daily output power as of PV.

4.3 Economic analysis

The initial cost of PV panels is clearly the highest of any structures component, & this has a significant impact on the overall structures investment. Apart from the component expenses, several critical environmental, technical, & economic parameters are used as input variables in the structures simulation & optimization program.

Environmental Inputs & Constraints:

- Global Horizontal Irradiation (GHI): Ranges from 1200 to 2200 kWh/m²/year, depending on the location.
- Mean Wind Velocity at 40 m Height: Varies from 1.2 m/s to 8.6 m/s, with significant regional & seasonal fluctuations.
- Temperature Range: Exceeds 40°C in summer & drops to a minimum of –30°C in winter, indicating the need for components with high thermal resilience.

Optimization Objectives:

- COE: The structures aims to minimize the COE, making electricity affordable for rural communities.
- LPSP: A critical reliability index, with the goal of minimizing the LPSP to ensure continuous power supply.
- Renewable Energy Factor: Indicates the dominance of renewable sources (PV & wind) over diesel in the annual energy production.

Demographic Target:

- The structures is designed for villages with more than 20 households, highlighting its application in rural or remote settlements.

The device incorporates a tiny wind turbine with a 2 kW rating for wind energy conversion. For precise energy estimation, wind speed must be adjusted to the turbine hub height because wind speed readings are frequently taken at lower elevations (e.g., 10 m). The power law equation is used to do this:
v2v1=(h2h1)α\frac{v_2}{v_1} = \left(\frac{h_2}{h_1} \right)^\alphav1v2=(h1h2)α
Where:

  - v2v_2v2 = wind speed at the desired hub height h2h_2h2
  - v1v_1v1 = wind speed at the reference height h1h_1h1
  - α\alphaα = Hellmann exponent or friction coefficient, typically assumed as 1/7 (≈ 0.143) for open rural terrain

Since wind turbine power production is a function of wind speed cubed, this correction is essential for accurate calculation. The energy yield of the structures is greatly impacted by the precise modeling of wind speed at hub height, particularly in areas with low average wind speeds.

The production substructures under consideration is the wind, solar, diesel, & battery combination. When wind or solar availability is limited, battery loding & diesel are employed as backups to ensure supply reliability.

:

$$\begin{cases} 0 & V<V_{cut-in,}\, V>V_{cut-out} \\ V^3\left(\dfrac{P_r}{V_r^3-V_{cut-in}^3}\right)-P_r\left(\dfrac{V_{cut-in}^3}{V_r^3-V_{cut-in}^3}\right) & V_{cut-in}\le V<V_{rated} \\ P_r & V_{rated}\le V\le V_{cut-out} \end{cases}$$

Vcut-out, Vrated, Vcut-in : cut in wind speed, nominal wind speed and cut out wind spe

Location Average wind speed (m/s)_ Average solar radiation (kWh/m2/d)

5

5.04

6

5.45

5.71

5.39

240–250 days of sunshine annually, with the panels supplying an average of 4.5–5.4 kWh/m2 of horizontal solar radiation power

$$P_{pv-out}=P_{N-pv}\times\frac{G}{G_{ref}}\times\left[1+K_t\left(\left(T_{amb}+(0.0256\times G)\right)-T_{ref}\right)\right.$$

Ppv-out : output power of PV,

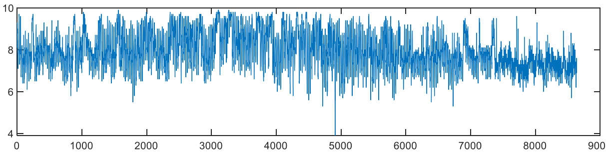
PN-pv is rated power under reference conditions,

G is solar radiation (W/m2),

Gref is 1000 W/m2,

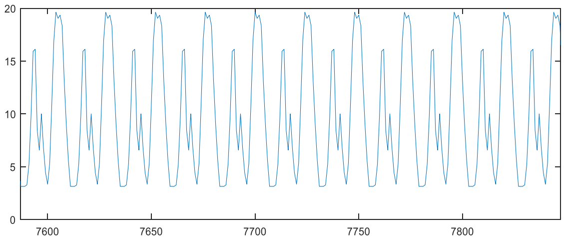
Tref is 25 degree C,

Kt is 3.7*10 $^{-3}$(1/C), and Tamb ambient temperature



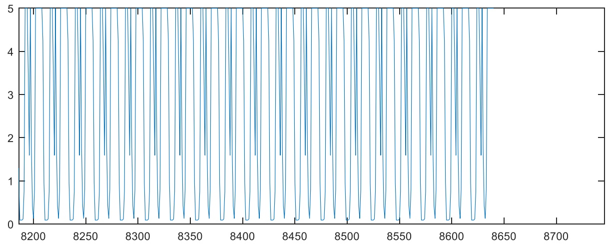
Solar radiation during a year KWh/m^2 with respect to time in hour

In the simulation of the HRES, the following operational scenarios (cases) are considered to manage the power flow & ensure supply-dem& balance:

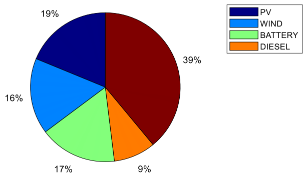


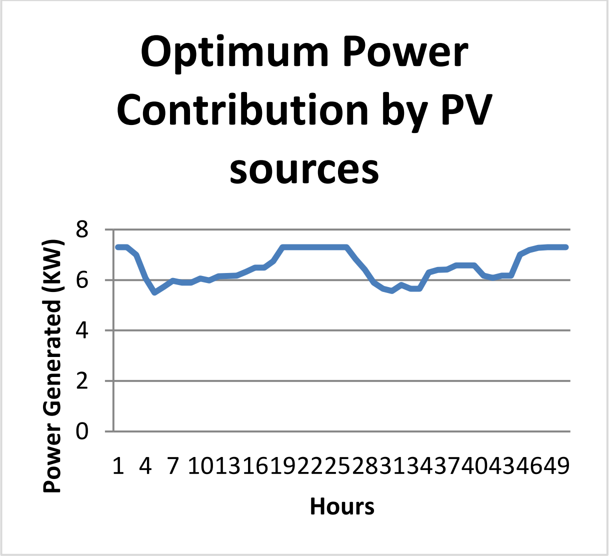
Wind speed (m/sec) with respect to time in hour

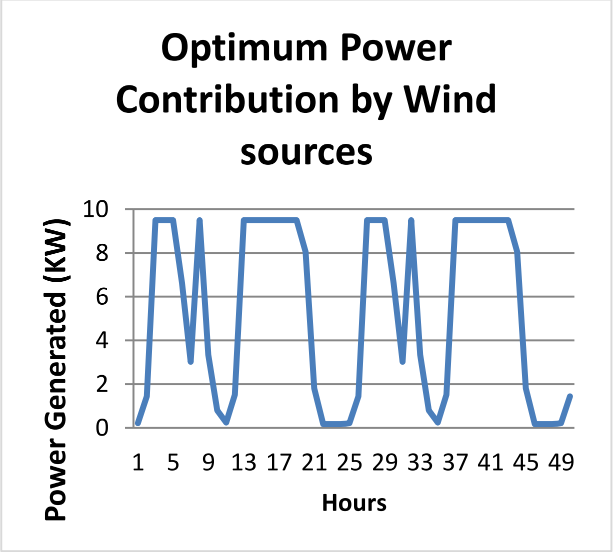
contribution=> pv, wind, battery, diesel contribution in each hour

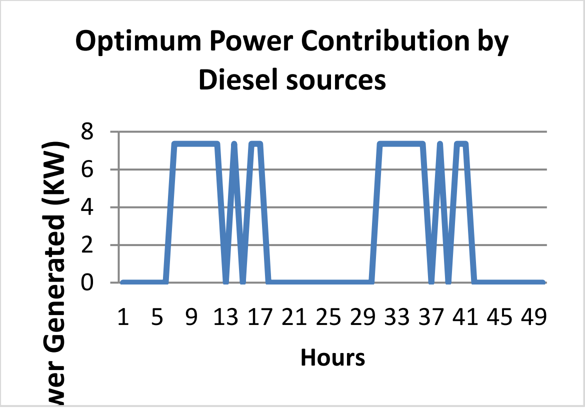


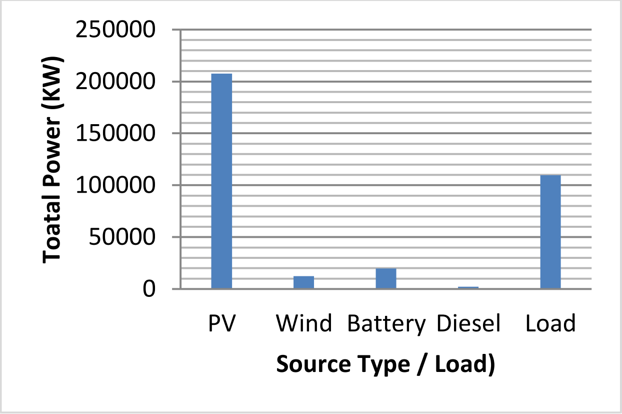
Wind power (kw) with respect to time in hour

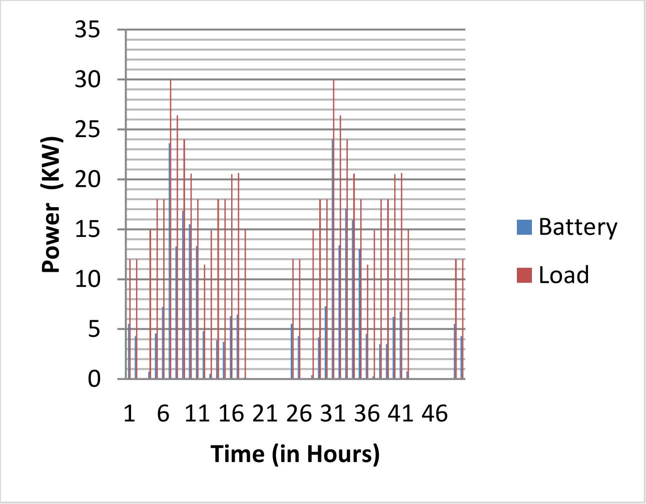


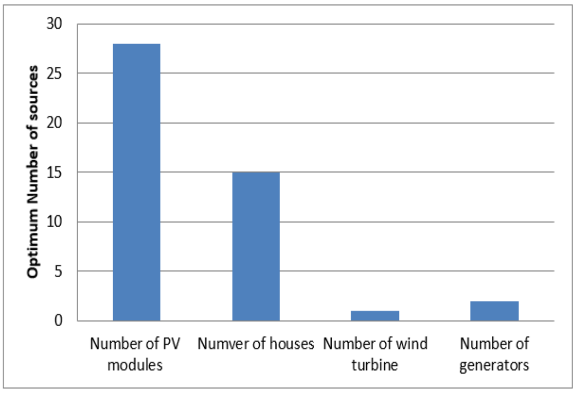


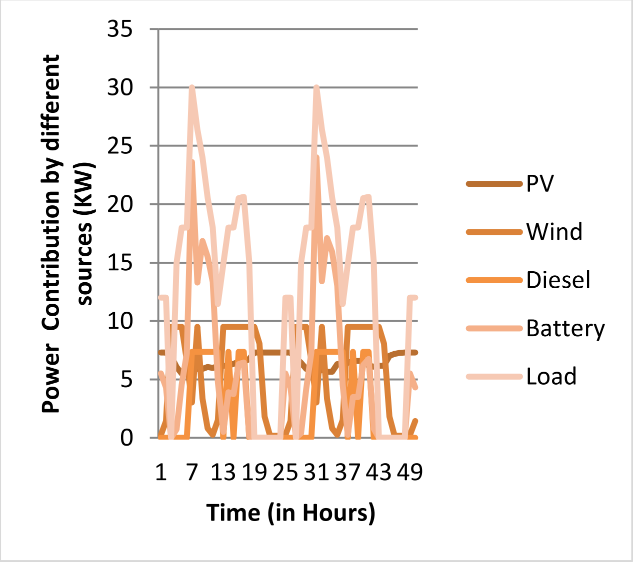


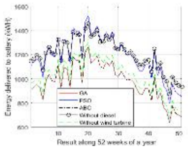

Optimum Power Contribution by Diesel sources
wer Generated (KW)
8
6
4
2
0
1 5 9 13 17 21 25 29 33 37 41 45 49
Hours

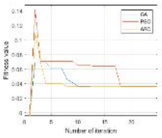

Toatal Power (KW)
250000
200000
150000
100000
50000
0
PV
Wind
Battery
Diesel
Load
Source Type / Load)

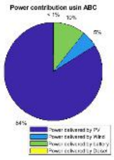

Power (KW)
35
30
25
20
15
10
5
0
1 6 11 16 21 26 31 36 41 46
Time (in Hours)
Battery
Load

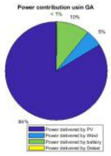

Optimum Number of sources
30
25
20
15
10
5
0
Number of PV modules
Numver of houses
Number of wind turbine
Number of generators


Power Contribution by different sources (KW)
35
30
25
20
15
10
5
0
1 7 13 19 25 31 37 43 49
Time (in Hours)
PV
Wind
Diesel
Battery
Load


Energy delivered to battery (kWh)
1600
1400
1200
1000
800
600
10
20
30
40
50
Result along 52 weeks of a year
GA
PSO
ABC
Without diesel
Without wind turbine


Fitness value
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
Number of iteration
GA
PSO
ABC





Furthermore, by minimizing a fitness function under a variety of operational restrictions, the Particle Swarm Optimization technique is used to identify the ideal structures design. Wind turbines are also incorporated into the structures because of PSO's great adaptability & effectiveness in resolving multi-variable optimization issues. The PSO technique optimizes the primary decision factors, which include the number of residences, wind turbines, days of autonomy, & PV panel capacity.

The objective of the optimization process is to minimize the COE & LPSP, while maximizing the contribution of renewable energy resources. This multi-objective optimization is complex, as improving one parameter often leads to deterioration of another. For instance, increasing structures reliability may raise costs, while reducing costs might lower the renewable contribution or reliability.

The optimal configuration obtained from the simulation results includes a 30 kW PV panel, eight days of battery autonomy, & a structures shared among four households. This design achieves a balance between cost, reliability, & renewable resource utilization.

In summary, the design priorities significantly influence the structures configuration. For example, shared micro-grid structuress are often more cost-effective in village-scale implementations. Conversely, when high reliability is essential—such as for critical infrastructure like emergency healthcare facilities—individual st&-alone hybrid structuress may be preferable. Additional factors such as geographical terrain, distribution of houses, availability of technologies, & local weather conditions also play a vital role in selecting the most appropriate hybrid structures configuration.

CONCLUSION

In conclusion, the optimal design of a HRES depends on the specific priorities of the deployment scenario. For villages seeking cost-effectiveness, a shared micro-grid may be the preferred approach. Conversely, in cases where high reliability is paramount—such as for critical infrastructure (e.g., hospitals)—a dedicated structures per user is advisable. Additionally, factors such as geographical terrain, distribution of houses, available technology, & climatic conditions will further influence the selection & configuration of the most appropriate structures architecture.

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