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GENETIC ALGORITHM BASED TECHNO-ECONOMIC OPTIMIZATION OF AN ISOLATED HYBRID ENERGY SYSTEM

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Abstract

Implementation of optimal hybrid renewable energy technology is one of the most promising and environmentally beneficial ways to supplement the national grid energy supply to meet the energy needs of smart cities and rural areas. Renewable energy unpredictable growth is one of the system primary weaknesses, with a high initial cost, low reliability, and low total energy delivery technology, which can be remedied by using sufficient storage devices or by different interconnecting energy sources. An isolated hybrid energy system efficiency is improved using a genetic algorithm-based model developed in this research. The wind turbine, solar photovoltaics, diesel generator, and storage batteries are considered for data analysis and validation. The findings acquired using the standard program named HOMER are compared to the results obtained. The model input variables, energy costs, energy loss probabilities, and renewable portion are used to generate numerous factors such as sizing, number, and prices of various compounds, temperature, and autonomy days, as well as environmental considerations.

Keywords:

Hybrid Energy System; Optimization; Genetic Algorithm; Renewable Energy Resources; Smart cities

1. INTRODUCTION

With a hydroelectricity producing capacity of 42000 MW, solar generation of 3000 MW, and wind generation of 2100 MW, Nepal has a lot of renewable energy resources to tap into [1]-[3]. However, more than 9.3 per cent of Nepalese are without access to electricity, and even those who are linked to the national grid cannot rely on a consistent and sufficient supply of electricity [4] [5]. Considering that 60% of Nepal population lives in hilly regions, connecting everyone to a national grid is a huge challenge [6]-[8]. Off-grid energy systems are a viable option in certain situations for supplying electricity [5] [9]. However, there are significant hurdles in off-grid renewable energy systems, including high costs, poor stability and power quality, low load factor, renewable source periodic nature, and maintenance and monitoring issues [10] [11].

Energy generated by renewable energy sources (RES) such as solar and wind is unreliable. This intermittent aspect of energy can be enhanced by using enough storage devices or by interconnecting several energy supplies, a process known as optimum hybridization [10] [12] [13]. An optimized hybrid energy system (HES) is a promising technology in cost, power quality, and reliability for supplying electricity to areas where expanding the national utility grid system is complex and costly [9] [14]. It can be improved in terms of efficiency and cost-effectiveness by minimizing the downsides associated with these technologies [9] [15].

2. OPTIMIZATION TECHNIQUE

It is an undeniable fact that we all are an optimizer because we all decide to maximize in some way our quality of life, productivity in time, and well-being. This fact leads to the development of a vast number of methods in this field. The efforts of many brilliant philosophers, mathematicians, scientific experts, and engineers have brought about the high standard of civilization that we are enjoying here today [16].

There are different optimization approaches, and nowadays, various software tools and approaches are developed to analyze and optimize renewable energy systems. Software and tools are easy to use because of the simple interface and are commercially accessible. Professional training is not required, while the cons are that it is a black box approach where the algorithm and calculations are not visible. Conventional techniques are more straightforward, but constrained handling is not satisfactory. It requires more computational time, gets stuck in local maxima or minima, and does not provide the optimal global solution. The nonconventional technique can find global optima with less computational time and is suitable for several parameters. The multi-objective evolutionary algorithm can optimize multi-objectives. However, the drawbacks are complex compared to a single objective and hard to analyze as the objectives are conflicting in nature [17] [18].

3. INPUT DATA AND ASSUMPTIONS

For our analysis, an academic block of Nepal Engineering College, located at Bhaktapur, Nepal, was taken as a case. The load data is extracted from the data logger installed at the premises of the college.

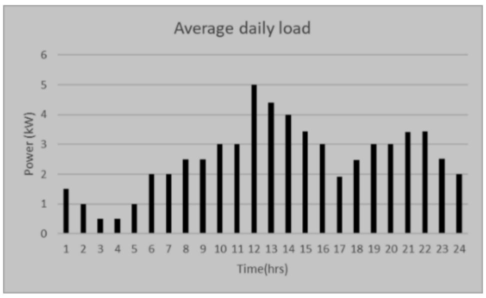

Fig.1. Average daily load pattern

The Fig.1 shows the average hourly load for the year 2017, and Fig.2 shows the solar radiation of the place. The solar radiation data was imported from the online data of NASA Prediction of Worldwide Energy Resources, which was 4.97

kW/m2/day, with an average clearness index of 0.558. Similarly, the wind resource is determined by the average wind speed over the year for the location at 50 m head and presented in Fig.3. The sizing and price of the components assumed to be used in the proposed system are listed in Table.1.

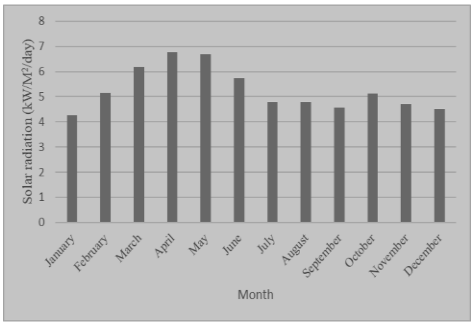

Fig.2. Solar radiation pattern at the site

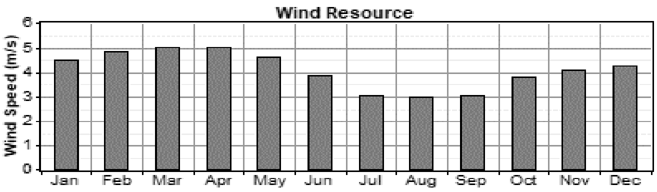

Fig.3. Wind resource at the site

Table 1. Input value for cost estimation

Component	Size	Capital Cost ($)	Replacement Cost ($)	O&M Cost	Minimum Life
Solar PV	1kWp	850	850	12 ($/yr)	25years
Wind Turbine	1kW	1200	1200	12 ($/yr)	25years
Diesel Generator	4kW	500	500	Intercept Coeff. (L/hr/KW rated) = 0.0814 Slope(L/hr/kW) =0.246	20000 hours
Battery	1kWh	280	280	10($/yr)	6yrs

4. METHODOLOGY AND MODEL DEVELOPMENT

In this study, a techno-economic optimization of a standalone system containing solar PV, wind turbine, batteries, and DG set has been analyzed using a multi-objective genetic algorithm and verified with HOMER standard tool.

The Genetic Algorithm (GA) is one of the examples of the search process, which utilizes a random choice as an instrument to guide a handy search through the parameter-space-coding process. GA differs from conventional methods completely, and it was implemented successfully in various engineering optimization problems to deliver optimal results in single and multitarget problems. In the renewable hybrid system, GA is used to deduct the size of components and provide optimized results.

Generally, fitness functions are used in genetic programming to guide the simulation towards optimal design solutions. The objective functions for the cost of electricity (COE), loss of power supply probability (LPSP), and nonrenewable energy fraction are used as the system input. The COE is the constant price per unit of energy (or cost per unit of electricity), and the following expressions can calculate it:

COE=(Annualized cost(AC)($))/(Sum of load(kWh/year)) (1)

where,

$$\text{AC} = \textit{initial cost} \times \textit{CRF} \tag{2}$$

$$\text{CRF} = \frac{i(1+i)^n}{i(1+i)^n - 1} \tag{3}$$

Similarly, LPSP is a statistical measure that shows the likelihood of power supply failure due to either a loss of power supply from an insufficient resource or technical faults that disrupt the system ability to satisfy demand. Equation 4 is used to calculate it.

$$LPSP = \frac{\sum\left(P_{load} - \left(P_{PV} + P_{WT} + P_B + P_{DG}\right)\right)}{\sum P_{load}} \tag{4}$$

where, P_{load} is the power used by load, P_{PV} is the power generated by solar PV, P_{WT} is the power generated by the wind turbine, P_B is the power discharged by battery and P_{DG} is the power delivered by a diesel generator.

On the other hand, the nonrenewable energy factor is the fraction of energy generated by renewable energy sources to the nonrenewable energy sources. It can be calculated using Eq.(5).

$$NREF = \frac{P_{DG}}{P_{PV} + P_{WT} + P_B + P_{DG}} \tag{5}$$

where, P_{PV} is power generated by solar PV, P_{WT} is power generated by the wind turbine, P_B is power discharged by battery and P_{DG} is the power delivered by a diesel generator.

After defining the objective function, the model was developed using a genetic algorithm. The program was initially started, and the input data of different components were fed, the solar and wind power output, and summed. In the developed model, the total generation from renewable energy resources is calculated and forwarded to further procedures as follows:

- If total generation = load: Supply provide to demand
- If total generation > load: Supply provide with demand + battery charging.
- If total generation < load: Supply provide to demand via energy resources and battery.

5. RESULT AND DISCUSSION

This study created the fitness function in MATLAB with the required mathematical modelling for the technical and economic parameters.

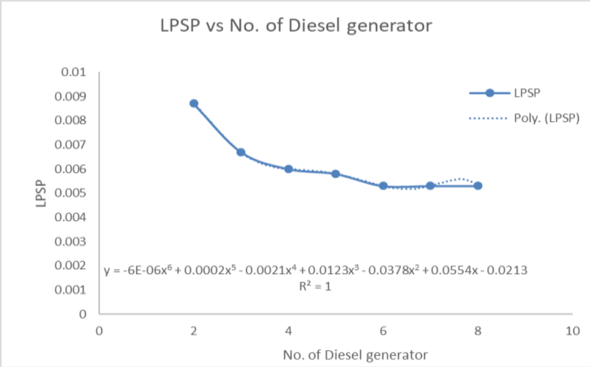

Fig.3. LPSP vs. Number of Diesel generator

The optimization solver in MATLAB is used for solving the genetic algorithm. For the first scenario, the variance of power supply loss probability and electricity price is shown to be the smallest for a varied optimum combination of diverse generation sources. However, the LPSP is maximum which is beyond the acceptable limits. Similarly, beyond the second case, LPSP is within permissible limits, but the electricity price increases. Therefore, the final case is taken as the best solution where the price of electricity is minimum for an acceptable value of LPSP.

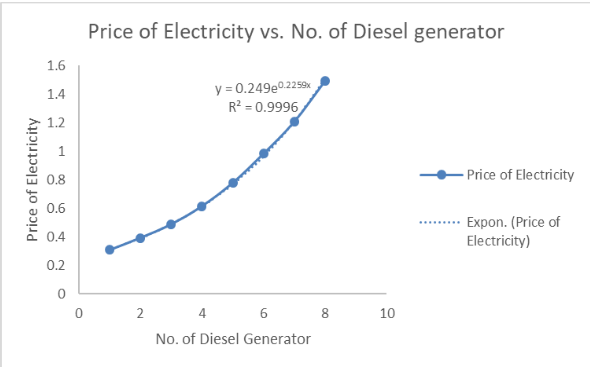

Fig.4. Equation fit for trend line of Price vs. Number of Diesel Generators

Nevertheless, the decimal value cannot be taken so when using an integer value for solar 20kW, seven autonomy days, three wind turbines, and the number of a diesel generator. Similarly, the LPSP, nonrenewable energy fraction, and price of electricity are calculated to be 0.070, 0.0140, and 0.3084, respectively. With the variation in the number of diesel generators, the characteristics of LPSP were observed and presented in Fig.3. From Fig.3, the LPSP is decreasing linearly with the increasing number of diesel generators. Similarly, Fig.7 presents the correlation between the number of the generator and the COE. From Fig.4, it is shown that the price of electricity is directly proportional to the number of diesel generators used; when the number of diesel generators is increased, the price of electricity also increases and vice versa. The actual output of this study is shown in Table.2. Loss of Power Supply Probability, electricity price, and nonrenewable energy portion are the output data that are minimized to optimize hybrid energy systems. The created model results were validated by comparing them with those from HOMER software, as shown in Table.2. The input parameters used in the developed model were used in HOMER, and it was found that LPSP, COE and non-renewable energy fraction were 0.00091, $0.695, 0.15 using 20kW PV, 1unit of the wind turbine of 1 kW rating and 5kW of a diesel generator.

Table.2. Compared output between Genetic algorithm and HOMER

Model	**LPSP**	**COE**	**Non-renewable energy fraction**
Genetic Algorithm	0.003	$0.45	0.03
HOMER	0.00091	$0.695	0.15

The above data shows that the price of electricity for the system in genetic algorithm and HOMER is $0.45 and $0.695. The Non-renewable energy fraction used by the genetic algorithm system is 3%, and HOMER is 15%. The loss of power supply probability is high in the genetic algorithm system with 0.3% and 0.09% in the HOMER system.

6. CONCLUSION

The standalone renewable energy system is regarded as one of the alternatives for remote electrification. However, the high initial cost and the unpredictable nature of these resources and the dependency on weather conditions are drawbacks for their development. Hence, the concept of energy mix using different energy resources with proper optimization will be an excellent option to electrify the rural area. In this study, a genetic algorithm-based model was proposed and analyzed with a case study. The techno-economic analysis for optimizing the hybrid energy system was performed and verified with standard software based on the developed model. This study concluded that the developed model is appropriate for the optimization of an isolated hybrid energy system. It is also concluded that the price of electricity is directly proportional to the number of diesel generators used. The price goes to the increase when increasing the nonrenewable fraction.

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