Research Article

Multicriteria Decision Analysis for Renewable Energy Integration Design: For an Institutional Energy System Network

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The hybridization of a renewable energy generator with an existing system in a specific building plays a vital role in solving many important problems of electrical energy systems such as reliability, cost-effective, and ecological option. In this perspective, a modified energy system is proposed in an existing building with integrated renewable energy using multicriteria decision analysis (MCDA). To achieve the sustainable energy solution, the hybrid power source configurations available in the locations are analyzed to ensure reliability using the HOMER software tool. Among these, the best configuration is identified by using the Best Worst Method (BWM) based MCDA approach. The study examined the technical, economic, and environmental perspectives for the achievement of the Sustainable Development Goals (SDGs) such as affordable, reliable, sustainable, and modern energy. The results of the survey in the building show that the best optimal hybrid configuration of the proposed location is the Grid-PV-Wind-based systems for the specific location based on the key techno-economic-environmental criteria of the SDGs.

1. Introduction

In rapidly growing and most populous countries like India, it is significant to convert the energy found in sunlight, wind, ocean waves, tide, falling water, geothermal heat, or biomass (renewable energy) into electrical energy [1–3]. According to the International Energy Agency (IEA), renewable energy production would surpass coal and become the world’s largest source of electricity by the early 2030s. However, in some remote locations, the major disadvantage of a single-source power station is no more reliable in providing electricity for the continuous period [4]. As a result, over the past few decades, researchers have concentrated on improving the performance of the hybrid renewable energy source (HRES) around the world [5, 6]. HRES links two or more renewable energy sources for the continuous production of electricity, which must overcome the limits of the single-source energy system [7, 8]. It has better efficiency, more reliable, and minimum cost of electricity generation in the SDGs (i.e., SDG7). In India, the 2020-Energy Policy Review shows that implementing a new framework takes a hybrid approach from point-of-interconnection prediction to a safe, affordable, and sustainable energy system for robust economic growth [9]. The proper selection of HRES generates power for the maximum number of hours in a particular location.

For the lack of focus on optimal design and proper sizing, these energy systems are oversize or have low reliability, which also increases the cost of the system. HOMER is a highly effective optimization software tool that is extensively used for HRES. It gives a wide range of mechanism to optimize, and it is user-friendly, fast in processing [10]. The feasibility studies of hybrid sources of renewable energy, such as wind energy, geothermal energy, and solar energy systems with conventional energy systems in educational buildings are tested and analyzed with different software tools [11]. A new methodology is developed to identify the different configuration problems and maximize the techno-economic benefits of distribution systems for all envisaged cases and scenarios [12]. As well, other studies have identified the most convenient HRES option for the Public Library building, the
hotel building, and other locations by evaluating the potential for energy sources in the proposed area using HOMER and a similar assessment tool [13–18]. When hybridizing energy sources, over one energy source in the system makes performance evaluation and decision-making complex and requires thorough technical, economic, and environmental analysis. But HOMER fulfills only one objective, such as the identification of the total net cost of energy and cannot be planned for multiobjective issues such as technical, economic, and environmental impacts. A single criterion does not capture and measure the overall performance of the system [19].

It is desirable to analyze different aspects of energy sources, such as technical, financial/monetary, and other external factors while integrating sources, in order to determine the optimum configuration of energy sources. MCDA has become more popular and can provide a methodical and coherent approach to processing multiple performance criteria in both quantitative and qualitative formats [20–24]. This technique was developed to choose the best alternative using different parameter criteria. The purpose of the MCDA is to assist decision makers confronted with such multiple criteria problems in continuous spaces. Multiple-criteria design problems typically require
the solution of a series of mathematical programming models in order to reveal implicitly defined solutions [25]. Pairwise comparisons (through an expert or a team of specialists) are made to demonstrate the relative performance between each of these two criteria (best and worst) and the remaining criteria. A maxi-min problem is predicted and resolved in determining the weights for the various criteria. Weights of alternatives for various criteria are met through an equivalent process in Best-Worst MCDA approach [26, 27].

There is still a lack of specialized work in HRES, in fact by selecting the best hybrid configuration among the energy sources in a particular place by considering various parameters such as economic, technical, and environmental factors. Hence, considering all these essential requirements, the aim of this proposed work is focused on optimum configuration planning and sizing of the different components used in the HRES through Multicriteria Decision Analysis [28] in the study area southern region of India (Karaikudi, Tamilnadu) and to help the decision-makers and identifies the sustainable HRES configuration by including the multi-criteria indicators using BWM MCDA method.

2. Case Study Area: ACGCET Campus

The study site is at 10.091°N and 78.797°E. The campus has a maximum allowable energy demand of 210 KVA from Tamilnadu Generation and Distribution Corporation Limited (TANGEDCO). An electricity distribution network on the ACGCET campus includes an electricity grid line (Electricity Board), solar photovoltaic system, wind and diesel...
generator, distribution panels, automatic power factor correction panels, breaker, cables, and loads. The ACGCET Campus EB invoice includes the cost of energy (CE) per month approximately $2,857, the penalty includes the Demand charges per month approximately $943 and the compensation for low power factor per month approximately $100, and the total cost is $4,000 per month (roughly $48,000/year). In this situation, reducing the energy costs of existing energy sources is required besides reliability and the environment-friendly. Figure 1 shows a complete schematic of the energy distribution system at the study location.

To meet the energy demand at various locations such as the commercial and industrial load campus, different energy sources and its hybrid are involved. In this proposed study location, the energy source configurations, i.e., grid only, grid-diesel generator, grid-wind, grid-photovoltaic, grid-wind-diesel generator, grid-photovoltaic-wind, grid-photovoltaic-diesel generator, and grid-photovoltaic-wind-diesel generator are taken for analysis, and best configuration is identified to meet energy demand and manage the distribution network of ACGCET campus with reliability, minimize-cost, and emission free.

Using the load and load duration curve of power distribution network of study location, it is observed that the optimum planning and decision-making analysis play a vital role in the existing electrical network, which leads to identifying the best suitable hybrid power source configuration for ACGCET Campus among renewable or nonrenewable source for more reliable and environmentally friendly energy option. Single Criterion Optimization (COE) is carried out using the HOMER simulation software tool. Second, optimization using multiple criteria, the decision-making problem is carried out using MCDA methods using BWM for three criteria and seven subcriterion like (1) technical: PV capacity factor, renewable fraction; (2) economical: initial cost, cost of energy, return on investment, payback period; (3) environmental: emission.

2.1. Optimization through COE. The proposed HES system is modeled using the HOMER (Hybrid Optimization of Multiple Energy Resources) programming tool to get the best HES configuration via COE. It carries out the simulation of various combinations of the HES considering various sensitive parameters such as technical, economic, and environmental criteria. It is equipped with integrated power converters (DC/DC converter and AC/DC inverters), and distributed and other energy sources critical data are needed to model the HES.

### Table 1: Economic data for simulation.

| Existing power source | Capacity (KW) | Capital cost ($) | Stand-in cost ($) | O&M cost ($) | System life period (years) |
|-----------------------|---------------|------------------|-------------------|-------------|--------------------------|
| Diesel generator      | 144           | 10214            | 9286              | 0.11*       | 15000*                   |
| Solar PV array        | 20            | 25000            | 22500             | 0           | 25                       |
| Wind turbine          | 20            | 24300            | 24300             | 250         | 15                       |
| Converter             | 20            | 280              | 240               | 50          | 20                       |

*per Hours.

### Table 2: Configuration parameter.

| Configuration no. | Name | Notation |
|-------------------|------|----------|
| Configuration I   | Grid | G        |
| Configuration II  | Grid-diesel generator | G-DG |
| Configuration III | Grid-photo voltaic | G-PV |
| Configuration IV  | Grid-wind | G-W |
| Configuration V   | Grid-diesel generator-photo voltaic | G-DG-PV |
| Configuration VI  | Grid-diesel generator-wind | G-DG-W |
| Configuration VII | Grid-photovoltaic-wind | G-PV-W |
| Configuration VIII| Grid-diesel generator-photo voltaic-wind | G-DG-PV-W |

2.2. Resource Consideration and Load Assessment. The four commonly available resources and their combinations are used in this proposed study: Grid-Solar PV-Wind Diesel Generator through HOMER tool. Other critical preassessment data are the one-day electrical load profile on the study site. Using these data, sensitive analysis is carried out in the HOMER tool. The average total load and peak demand is noted for 24 hours and is around 45.85 kW and 98.42 kW, respectively. Figure 2 shows the daily load profile of the ACGCET campus. Geographic and seasonal differences were noted and included in the HES modelling to allow the suggested system could respond load demand with this change. Figure 3 illustrates that the months of March and June are expected to reach the maximum demand, and lowest load demand is reached during February, then in May and November. Therefore, it was advisable to design a HREM for peak loads using campus overall load profile and yearly load profile obtained from the HOMER simulation tool, and approximately, it is taken as 178 KVA. The highest maximum load observed in the daily load profile is 98 kW, while the average load was 45 kW in the specific period. It is also noted that every day the demand for energy is about 1043 kWh/day.

Meteorological data from the study location were extracted using the National Renewable Energy Laboratory (NREL) web source using campus latitude and longitude (10.091°N and 78.797°E). In this study, the surface of the Earth receives slightly more solar energy almost throughout the year, with relatively long sunny days in summer compared to winter; about it varied from 20.2°C to 38.8°C. The available solar energy database is collected based on weather data, and Figures 4 and 5 show that the mean solar...
Monthly average electric production

(a) Grid mode

(b) Grid-connected diesel generator mode

(c) Grid-connected photovoltaic mode

Figure 7: Continued.
Figure 7: Continued.

(d) Grid-connected wind mode

(e) Grid-connected diesel generator and photovoltaic mode

(f) Grid-connected diesel generator and wind mode
irradiation level and wind speed of the ACGCET campus per year, respectively. Solar irradiation ranges from 4.45 to 6.42 kWh/m²/day. Similarly, the average wind velocity at this location is 13 km/h.

2.3. Load Following Dispatch Strategy. In existing electricity grid models on campus, various energy sources are considered, including both renewable fuel and fossil fuel generators (diesel generator, grid). Under operational conditions, generator components must be controlled, and this can be accomplished using campus energy allocation strategies. The basic requirement is that satisfy the load power requirements of the test site, although less energy is produced from a grid/renewable/other generator. A Load Following (FL) strategy is involved in this work when optimizing the HREM configuration. It guarantees the load demand is always fulfilled. In this approach, when the power produced by solar photovoltaic generators is lower than the desired load requirements, the LF helps to control the operation of the DG in order to meet the insufficient energy requirements of the ACGCET campus.

3. The Proposed Energy System Model

The proposed energy system model works in eight different modes such as grid only mode, grid-diesel generator mode, grid-wind mode, grid-photovoltaic-diesel mode, grid-wind-diesel generator mode, grid-photovoltaic-wind mode, grid-photovoltaic-wind mode, and grid-photovoltaic-wind-diesel generator mode. The HES model projected into the HOMER simulation tool is illustrated on Figure 6. HOMER simulates every component of the system such as the grid, solar photovoltaic, wind, hydro, diesel generator, battery, AC/DC converters, electrolysis, hydrogen tank, and transformer between values. In this study, the major components are involved: grid, PV
array, wind mill, DG with these components, power inverters, and an HES controller. It tests technical and financial options for distributed generation systems. The optimized response shows the list of configurations according to the technical specification of the equipment and other mandatory parameters provided as input and presented in Table 1. The estimated investment costs, operations and maintenance (O&M), and component capacity replacement costs are also included. The cost was estimated by reference to existing market prices.

In addition, for sensitive analysis, the other sensitivity parameters including wind speed (m/s), diesel fuel price ($/L), the nominal discount rates (%), and scaled average solar radiation (kWh/m²/day) rates were used. Meteorological data show that the average solar energy and wind velocity are considered to be in the range of 5-7 kWh/m²/day and 2-4 m/s, respectively, in the proposed location, and the nominal discount rates are expected to fluctuate between 5%-15%, in India diesel fuel prices of $0.75 to $1.2/L. Finally, HOMER automatically displays the best configuration at the top.

The HOMER calculates the COE for different hybrid configurations using the following equations (1) and (2).

\[
\text{Cost Of Energy} = \frac{\text{total annualized cost}}{\text{total load served} + \text{total grid sales}}, \quad (1)
\]

\[
\text{Total annualized cost} = \text{annualized capital cost} + \text{annualized replacement cost} + \text{annualized o\&m cost} + \text{annualized fuel cost(if applicable)}. \quad (2)
\]

The optimization was carried out for the HES configuration modeled according to the data and components. During the optimization process, possibly eight configurations were checked; then, eight HES configurations were compared to a single criterion, like the lowest COE. Different available HES configurations are identified and presented in Table 2. The monthly average power production from the eight workable HES configurations is shown in Figure 7.

### Table 3: HOMER optimization result for different criteria.

| Configuration | Grid (kW) | PV (kW) | Wind (kW) | DG (kW) | Converter (kW) | Total capital cost ($) | Total NPC ($) | Operating cost ($/yr.) | COE ($/kWh) | Renewable fraction |
|---------------|-----------|---------|-----------|---------|----------------|------------------------|---------------|-----------------------|------------|-------------------|
| G-PV-W        | 1,000     | 20      | 20        | 0       | 20             | 49,580                 | 4,42,090      | 30,705                | 0.091      | 0.22              |
| G-W           | 1,000     | 0       | 20        | 0       | 0              | 24,300                 | 4,52,301      | 33,481                | 0.093      | 0.14              |
| G-PV          | 1,000     | 20      | 0         | 0       | 20             | 25,280                 | 4,74,851      | 35,168                | 0.098      | 0.08              |
| G             | 1,000     | 0       | 0         | 0       | 0              | 4,85,255               | 37,960        | 0.1                   |            |                   |
| G-DG-PV-W     | 1,000     | 20      | 20        | 144     | 20             | 59,794                 | 6,76,241      | 48,223                | 0.139      | 0.22              |
| G-DG-W        | 1,000     | 0       | 20        | 144     | 0              | 34,514                 | 6,85,524      | 50,926                | 0.141      | 0.14              |
| G-DG-PV       | 1,000     | 20      | 0         | 144     | 20             | 35,494                 | 7,07,979      | 52,606                | 0.146      | 0.08              |
| G-DG          | 1,000     | 0       | 0         | 144     | 0              | 10,214                 | 7,17,976      | 55,366                | 0.148      | 0                 |

### Table 4: HOMER optimization result for energy production.

| Configuration | PV production (kWh/yr.) | Wind production (kWh/yr.) | DG production (kWh/yr.) | Grid purchases (kWh/yr.) | Grid sales (kWh/yr.) | Grid net purchases (kWh/yr.) | Total electrical production (kWh/yr.) | Diesel (L/yr.) | DG hours (hr./yr.) |
|---------------|-------------------------|---------------------------|-------------------------|-------------------------|----------------------|-------------------------------|--------------------------------------|----------------|-------------------|
| G-PV-W        | 31,600                  | 53,981                    | 0                       | 2,97,954                | 776                  | 2,97,178                      | 3,83,536                             | 0              | 0                 |
| G-W           | 0                       | 53,981                    | 0                       | 3,26,093                | 474                  | 3,25,619                      | 3,80,074                             | 0              | 0                 |
| G-PV          | 31,600                  | 0                         | 0                       | 3,51,159                | 0                    | 3,51,159                      | 3,82,760                             | 0              | 0                 |
| G             | 0                       | 0                         | 0                       | 3,79,599                | 0                    | 3,79,599                      | 3,79,599                             | 0              | 0                 |
| G-DG-PV-W     | 31,600                  | 53,981                    | 49,939                  | 2,50,498                | 3,259                | 2,47,239                      | 3,86,018                             | 25,802         | 1,156             |
| G-DG-W        | 0                       | 53,981                    | 49,939                  | 2,77,185                | 1,505                | 2,75,679                      | 3,81,104                             | 25,802         | 1,156             |
| G-DG-PV       | 31,600                  | 0                         | 49,939                  | 3,02,102                | 882                  | 3,01,220                      | 3,83,641                             | 25,802         | 1,156             |
| G-DG          | 0                       | 0                         | 49,939                  | 3,29,906                | 246                  | 3,29,660                      | 3,79,845                             | 25,802         | 1,156             |

4. Optimization Results

The optimization results of different criteria and energy production for all configurations using HOMER simulation are presented in Tables 3 and 4. It can be seen that grid-connected photovoltaic and wind has the lowest NPC, operating cost, and COE with the highest renewable fraction of 0.22 compared to other configurations.

The analysis of technical parameters, economic and environmental indicators, or emission parameters seems essential to conclude on the best configurations of the HES at the
study site. The HOMER tool is restricted to a single optimization objective purpose only (COE), but it is necessary to investigate the existing power distribution network of study location with multicriteria parameters such as technical, economic, and environmental factors in addition with a NPC and COE, for which it can be achieved by the MCDA technique.

4.1. Multicriteria Decision Analysis. The MCDA analysis is a very important branch of decision-making theory, which explicitly tests multiple conflicting criteria in decision-making. In this research, various sustainable indicators were applied to technologies for integrating renewable energies [29, 30]. The success of the estimate depends on the effectiveness of the indicators for each criterion that may correspond to a challenge and meet the objective. Figure 8 illustrates the framework work of the MCDA model in this case study.

4.2. Best Worst Method. The Best Worst Method is a new science in Multicriteria Decision-Making theory. MCDA problems have two classes in relation to the problem-solving space: discrete and continuous. Within this framework, varieties of substitutes are tested regarding the number of criteria for selecting the simplest option(s). The objective is to choose the best and the worst (ex: most preferred or most significant/least preferred or least significant) criteria are initially determined by the decision-maker [31, 32]. Table 5 shows the characteristic of BWM, which is that it uses an organized procedure to create pairwise evaluations that lead to consistent outcomes [33–35]. Steps for BWM:

1. Identify the set of decision criteria
2. Figure out the best and worst configuration
3. Identify preference for best criteria over all other criteria using a number from 1 to 9, as indicated in Table 5
4. Identify preference of all criteria relative to worst using a number from 1 and 9, which is shown in Table 6
5. Find the optimal weights using equations (3)–(6).

\[
\frac{W_J}{W_i} - a_{ij} \leq \xi, \quad \text{for all } j,
\]

\[
\frac{W_i}{W_J} - a_{ji} \leq \xi, \quad \text{for all } j,
\]

Table 5: Scale of other criteria with best criteria.

| Others to the best | G | G-DG | G-PV | G-W | G-DG-PV | G-DG-W | G-PV-W | G-DG-PV-W |
|-------------------|---|------|------|-----|---------|--------|--------|-----------|
| G-PV-W            | 7 | 8    | 2    | 3   | 5       | 6      | 1      | 4         |

Table 6: Scale of other criteria with worst criteria.

| Others to the worst | G-DG |
|---------------------|------|
| G                  | 2    |
| G-DG               | 1    |
| G-PV               | 7    |
| G-W                | 6    |
| G-DG-PV            | 4    |
| G-DG-W             | 3    |
| G-PV-W             | 8    |
| G-DG-PV-W          | 5    |
\[ \sum_{j} W_j = \xi, \]
\[ W_j \geq 0, \quad \text{for all } J. \]

Figure 9 shows the weights \((w_1, w_2, w_3, w_4, w_5, w_6, w_7, \text{and } w_8)\) of various hybrid configurations using BWM, grid-connected photovoltaic with wind system configuration has the highest optimum weight of 0.3321 through BWM MCDA methods.

5. Results and Discussion

The result of only one criterion (COE) for all configurations is initially used for the analysis and identification of the best hybrid configuration using HOMER tools. In this section, the multicriteria result is investigated for eight different HREM configurations using MCDA techniques based on PV capacity factor, renewable fraction, and economic indicators. These include initial cost, energy cost, return on investment, recovery periods, and environmental indicators or emission parameters in SDGs 7. The modeled major objective of HRES to satisfy its load demand was served. Based on the weights of the different configuration, the overall load at the study campus was well served by the G-PV-wind HRES configuration. It reveals that the existing electrical system needs to be modernized due to energy inefficiency and high service costs. Finally, as determined by the analyzers, the HRES configuration of G-PV-wind is suggested in SDG 7 based on technical, economic, and environmental criteria and meets average energy demand and peak campus demand.

5.1. Environmental Impact. The environmental impact of all feasible hybrid configurations was compared taking into account six different emission parameters, including CO\(_2\), CO, UHC, PM, SO\(_2\), and NO\(_2\), and is presented in Table 7. Among all configurations, the system with lower emissions appears to be sustainable [36, 37]. According to the results of the emissions and environmental analyzers, the G-PV-W configuration is recommended to achieve the sustainable development objective. Compared with other configurations, the kg/year emission rating is significantly below about 12%.

6. Conclusion

This paper presented the multicriteria decision analysis for the optimum design of renewable energy integration of the
university campus located in the southern state of India. The best hybrid configurations have been identified at a minimal cost of energy demand in a building. In this study for single criteria that is COE consideration, HOMER is applied and for multicriteria parameter such as technical, economic, and environmental aspect BWM-MCDA approach with three main and seven subcriteria such as PV capacity factor, renewable fraction, initial cost, cost of energy, return on investment, payback period, and emission was applied. The results analyzed in the building show that the PV and wind configuration connected to the network (G-PV-wind) has a low COE of $0.091/kWh and a high optimal weight of 0.3321 among all configurations considering all criteria parameters. The outcome suggests that G-PV-W is the most appropriate electrical system configuration for this location. In addition, a high renewable fraction was got in the G-PV-wind system, and it ensured maximum energy supplied to and environmental aspect BWM-MCDA approach with appropriate electrical system configuration connected to the network (G-PV-wind) has a low COE of $0.091/kWh and a high optimal weight of 0.3321 among all configurations considering all criteria parameters. The outcome suggests that G-PV-W is the most appropriate electrical system configuration for this location. In addition, a high renewable fraction was got in the G-PV-wind system, and it ensured maximum energy supplied to

Data Availability

The [input data used in the simulation software] used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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