NUMERICAL INVESTIGATING OF THE MICROGRID OPTIMAL HYBRID CONFIGURATION AT VILLAGE BAKHAR JAMALI

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Abstract

Alternate energy sources such as hybrid renewable energy off-grid systems are under the focus of researchers to improve their reliability and feasibility for rural areas. A hybrid power system uses a combination of renewable as primary and fuel-based power systems as a backup. Reliability, affordability, and cost depend upon the number of power systems used and the efficiency of these systems. However, the hybrid system is facing different challenges such as high cost, fluctuations in power, and proper infrastructure. This study aimed to determine the best configuration for village Bakhar Jamali, having a total of 162 houses and a 380 kW peak load. This study has been carried out using HOMER Pros to check the different sets of hybrid configurations. To find optimal power different sets of schemes were carried out. It was concluded in this study that the combination of Wind turbine, Solar PV, Biogas Generator, Diesel generator, Battery, and Converter give the optimum hybrid system with the following rated capacity, 150 kW of Solar PV, Specification of 3 kW of 50 Wind Turbine, Auto size Diesel Generator of 420 kW, Biogas Generator of 150 kW, Number of Batteries of 1 kWh 3832 and Converter capacity of 470 kW.

Keywords: Hybrid, HOMER Pro, Grid system, Reliability, Optimum, Configurations, Wind, Solar

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I. Introduction

Energy is a country's primary source of revenue and is regarded as its backbone. Unfortunately, Pakistan is currently experiencing energy shortages, allowing renewable energy sources the most important challenge for resolving these issues. Some practical work, such as the construction of solar and wind power plants, has been done to take advantage of renewable energy [I, II]. Because fossil fuels are becoming more expensive in the twenty-first century, clean energy sources such as solar, wind, and biomass will become increasingly essential [III]. The country needs to rely on the standalone electricity generation system, which is not only cheaper but also a locally managed system. Several studies have been carried out in Pakistan and other countries to model development and analyze the hybrid energy system. In Pakistan, there are huge resources by which we can generate more electricity, as well as in the case of reducing the circular debt [V]. The Government of Pakistan planned to reduce the circular debt by about 200 million and keep subsidies to 0.4% of the GDP [VI, VII]. Hybrid energy systems are a more effective and reliable source of electricity, the Pakistani government may help rural areas overcome energy shortages by promoting the installation of such systems. The proposed hybrid renewable source-based configuration in this study can be used in remote rural areas to make them grid-independent [VIII]. Various research from all over the world has the analysis and evaluation of renewable energy integration for rural electrification were presented. [IX-XI]. For smart-grid systems, HOMER Pro employs a combination of conventional and renewable resources [XII]. J Ahmed et al.[XIII] carried out a case study for hybrid renewable resources for rural areas at Kallar Kahar Pakistan and conclude the total cost for 73.6 MW was 180 million dollars and the Levelized CEO was 0.0574 $/Kwh. Sen and Bhattacharyya [XV] suggested that hybrid system load can be divided into two sessions in summer and winter sessions, and they observed from their work that the hydropower cost will be more low for the production of energy. Stiel & Skyllas – Kazaeos [XVI] researched the feasibility of a hybrid energy system and concluded that a hybrid system is cost-saving and environmentally friendly because the installed system saved 11.9 million dollars and a 1000 ton reduction of emission. Nigussie et al., [XVII] researched the feasibility study for the hybrid system and model development and they used HOMER Pro software. The designed model showed that the hybrid system is cost-effective and environmentally friendly. Binayak et al., [XVIII] worked on a tri-hybrid renewable energy source that included wind, solar, and hydropower that will generate power for off-grid applications. Their finding reveals that for the remote area where the grid system is not accessible, the hybrid system is cost-effective. Jibran et al., [XIX] researched stand-alone biomass energy sources Animals, bagasse, and municipal solid waste are three widely available resources in Pakistan that are the focus of this study. Biomass energy will account for roughly 24% of total electric power output from various other conventional sources, according to the findings. Furthermore, review articles have been published on renewable energy integration, hybrid energy system sizing and optimization, grid configurations, system design, and modeling methodologies [XX-XXIII].

Pakistan is currently facing the problems of energy crises which are increasing daily by daily, and the price of the electricity bill is increasing rapidly. Due to the
shortage of electricity, the Central Grid power is more expensive, so it has been decided that a study has been taken on stand-alone smart grid station where we can get the advantages of renewable resources [XXIV].

The key objectives of this study would be to analyze the smart-grid systems in the other countries and look into the possibility of the implement in Bakhar Jamali village in Pakistan, To estimate the potential of solar PV and wind energy in Bakhar Jamali, and develop a model for techno-economic feasibility analysis for Bakhar Jamali [XXV].

II. Scope and limitations

The smart-grid is the critical factor in the energy field it is useful during the disturbance of the central grid or at the time of maintenance of the central grid, or any problem that occurs in the distribution process. During the peak load, both grids can be used the central grid as well as micro-grid. There are several environmental benefits with low or zero emissions. By using the micro-grid user can also save money so it can be called economically efficient and it is more efficient than the central grid [XXVI].

There are several disadvantages of the micro-grid like balancing of the energy which should be under control. For balancing of energy three main parameters must be considered Voltage, Frequency, and power quality. Another disadvantage is related to space and maintenance for storing the energy battery bank should be used thus requiring space and maintenance is necessary. Implementation of the microgrid is one of the essential factors and important challenges for the user [XXVII].

III. Methodology

Under this study, HOMER Pro is to be used for modeling of a smart-grid National Renewable Energy Laboratory (NREL) developed. Because HOMER simulates the real technologies and components and gives very detailed results for analysis and evaluation it is fast to run the many combinations and the results of HOMER could be helpful to learn the system configuration and optimization. Homer uses a mix of Conventional and renewable resources for the smart-grid system [XXVIII-XXX]. Bakhar Jamali village has good renewable energy resources like Solar, Wind, and Biomass but till now no serious action has been taken, and no research work has been done in this area. The research work has been carried out in three steps, data collection, model development, and finally, result from analysis. First of all the load was calculated and the techno-economic data was used as input to the HOMER for model development. The results were analyzed by the scenarios of share of fuels in the electricity generation.
Figure 1. Map of Selected Site

As compared to urban areas the demand load of the rural areas is low. Total demand is considered for a domestic load like as Fan, Bulbs, Television, Refrigerator, Air conditions, Electric Motor. The total demand season is divided into two seasons one is summer (March-November) and the second is winter season (December-February). The total estimated demand for village Bakhar Jamali is on the following table 1.

Table 1: Load estimation of Village Bakhar Jamali during the summer season

| S.No | Load Type    | No. in Use | Ratings | Power(kW) | Hrs./day | kWh/day |
|------|--------------|------------|---------|-----------|----------|---------|
| 1    | Fan          | 488        | 78      | 38.064    | 15       | 570.960 |
| 2    | Bulbs        | 772        | 15      | 11.58     | 10       | 115.800 |
| 3    | Television   | 54         | 100     | 5.4       | 7        | 37.800  |
| 4    | Refrigeration| 108        | 600     | 64.8      | 20       | 1296.000|
| 5    | Air Condition| 38         | 1800    | 68.4      | 12       | 820.800 |
| 6    | Electric Motor| 79         | 600     | 47.4      | 6        | 284.4   |
|      | Total        |            |         | 235.64    |          | 3125.76 |
Hybrid system resources

The solar radiation of the village Bakhar Jamali located at $26^\circ2.8\,\text{N}$ latitude and longitude of $68^\circ23.9\,\text{E}$ was achieved from the NASA Surface Meteorology and Solar Energy Website. The average yearly solar radiation was $5.24\,\text{kWh/m}^2/\text{day}$, and the average clearance index was .585.

Diesel is another source, in addition to wind. Diesel fuel is a combination of hydrocarbons derived from crude oil distillation. The cetane number (or cetane index), fuel volatility, density, viscosity, cold behavior, and sulfur concentration are all important characteristics of diesel fuel. Diesel fuel standards fluctuate depending on the gasoline grade and country.
As discussed above the HOMER software has been used for the modeling of the smart grid, and the components used in the modeling of the smart grid also has been discussed in this section. Here the basic inputs and specifications of the components will be discussed. Solar PV is used for model development.

Generic flat Plate PV with the capacity of 1 kW has been used. The input of the search space was 30 kW, 60 kW, 90 kW, 120 kW, and 150 kW with the derating factor of 80%. The Capital cost for 1 kW is taken as 50,000 PKR, Replacement cost is 40,000 PKR and Operation, and maintenance cost is taken as 1000 PKR. Angle for the plates 45-degree inclination with no tracking system. The lifetime for solar PV is 25 years.

For the development of the Model, the Wind turbine has been used for generating more electricity. The Wind turbine is used with the capacity of 3 kW of one
turbine with the Capital Cost, Replacement Cost, and Maintenance and Operation Cost of 90,000 PKR, 80,000 PKR, and 2000 PKR respectively. In the input of the search space, the number of a wind turbine is 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50. The lifetime for the wind turbine was 20 years, and the maintenance schedule has been taken into account for the Inspection of the wind turbine. An Autosize diesel generator has been used for the model development for the reason when no renewable resources are available for example at night time no solar resources and sometimes no wind is available that is why a diesel generator has been used. The Capital, Replacement and Operation and Maintenance cost for 1 kW of the generator is 12000 PKR, 10000 PKR, and 1000 PKR respectively. Diesel price considers as 100 PKR for 1 Liter.

By taking the advantage of Biomass resources for producing more electricity the Biogas generator has been used. The Capital, Replacement, and Operational and Maintenance Cost has been taken into account for 1 kW are 25000 PKR, 20000 PKR, and 1000 PKR respectively. The input for search space was 50 kW, 100 kW, 150 kW, 200 kW, and 250 kW. The maintenance Schedule is also considered for the downtime of 200 hours for the biogas generator, and the remaining technical parameter is left as the default system.

The converter is also used in the model for converting the DC output of the solar PV into AC. The Capital, Replacement and Operation and Maintenance Costs for 1 kW taken into account are 15000 PKR, 13000 PKR, and 1000 PKR. The input for the search space are 10 kW, 20 kW, 30 kW, 40 kW, 50 kW, 60 kW, 70 kW, 80 kW, 90 kW, 100 kW, 110 kW. The remaining technical parameter is considered as default.

The battery bank is used for storing the electricity which can be used in shortage conditions. The battery used in the type of Lead Acid with a capacity of 1kWh with 12 volts and the maximum charge current of 16.7 amperes. The Capital Replacement and Operation and Maintenance Costs for the 1 Battery taken into account are 12000 PKR, 9600 PKR, and 500 PKR respectively. The lifetime of the battery is considered as ten years. The number of batteries for the search space are 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.

V. Results and Discussion

The best hybrid system is one that can provide electricity at the lowest cost, or in other words, one that has the lowest net present value while still supplying electricity at the required level of availability. In this section results obtain from the HOMER simulation will be discussed and the selection of optimal system based on the simulation results. The performance of the optimal hybrid system, hybrid system design, project economic variability, and a brief introduction to energy management in hybrid energy will all be discussed in this section.

Table 2 shows that the best system with the lowest net present cost (NPC) consists of 150 kW solar PV, several wind turbines of specification of 3 kW is 50 and Autosize generator with the capacity of 420 kW, Biogas generator having capacity of with the capacity of 150 kW and the number of the batteries is 3832 and converter capacity of 470 kW. The NPC of the system is 9.76 Billion PKR, COE is 936.63 PKR, Operating cost is 908 million PKR, and the Initial capital cost is 73.9 million PKR with a Renewable fraction of 47.5%.

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Table 2: Optimum Hybrid system Configuration

| Architecture | Cost |
|--------------|------|
| PV system capacity | 150 kW |
| Number of 3 kW Wind turbines | 50 |
| Generator capacity | 420 kW |
| Biogas generator | 150 kW |
| Battery bank | 3832 kWh |
| Converter capacity | 470 kW |
| Dispatch Strategy | CC |
| Renewable fraction | 47.5% |

**Figure 8.** HOMER Optimization Result
Table 4: Production Summary

| Component            | Production (kWh/yr) | %  |
|----------------------|---------------------|----|
| Generic flat plate PV| 240,343             | 21.4|
| Autosize Generator   | 512,522             | 45.7|
| Biogas Generator     | 362,779             | 32.3|
| Wind turbine 3kW     | 6,368               | .568|
| **Total**            | **1,122,012**       | **100**|

Table 4 shows that the production rate of each component with the percentage ratio. The maximum power generation from Diesel generator with 45.7%, after that the maximum power generation is from biogas generator with the 32.3%, after that the maximum power generation component is Solar PV with the 21.4% and minimum power generation from wind Turbine which is 0.568% of the total generation.

HOMER Pro gives the net present cost (NPC) value which if the NPC is positive it means that the system is feasible otherwise it will be infeasible. Capital investment, non-fuel operation and maintenance costs, replacement costs, energy costs (fuel cost plus any associated costs), and any other costs such as legal fees are all included in NPC. The lowest cost value from the sensitivity analysis is taken into account in this case.

Table 3: Net Present Cost

| Name                   | Capital (Rs.) | Operating (Rs.) | Replacement (Rs.) | Salvage (-Rs.) | Resource (Rs.) | Total (Rs.) |
|------------------------|---------------|-----------------|-------------------|----------------|----------------|-------------|
| Auto size Generator    | 5.04M         | 5.47M           | 2.27M             | 591,811        | 695,196        | 5.46B       |
| Generic 1 kWh          | 46.0M         | 20.5M           | 41.9M             | 2.00M          | 0.00           | 106M        |
| Wind Turbine 3 kW      | 4.5M          | 4.34M           | 858,193           | 430,607        | 0.00           | 9.27M       |
| Biogas Generator       | 3.75M         | 4.14B           | 3.06M             | 334,757        | 0.00           | 4.14B       |
| Flat plate PV          | 7.50M         | 1.60M           | 0.00              | 0.00           | 0.00           | 9.10M       |
| System Converter       | 7.15M         | 5.09M           | 1.95M             | 301,608        | 0.00           | 13.9M       |
| System                 | 73.9M         | 9.64B           | 50.0M             | 3.66M          | 695,196        | 9.76B       |

VI. Conclusions and Recommendations

The main goal of this work was to determine the techno-economic optimal sizing of an off-grid hybrid power system for electrifying a Bakhar Jamali rural community. The work began with the definition of the selected community’s typical load profile. Simultaneously, by analyzing historical data on annual variations in solar

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radiation and wind speed, potential renewable resources for electricity production have been identified and availability of Biomass in Bakhar Jamali and also the consideration of the diesel for a diesel generator. However, because the hydro resource data is not available, it is not taken into account in the analysis.

A thorough market analysis is conducted to identify the most appropriate and commercially available technology for hybrid energy integration. The hybrid energy system is adaptable, allowing it to buy electricity when load demand is high and sell electricity when load demand is low. The research includes the creation of a detailed HOMER Pro simulation model with analysis.

Based on the results of the current study it is recommended to develop a micro-grid-based electricity supply to the rural/far-flung areas. Addressing the possibility of replacing the hybrid system’s diesel generator with locally produced biofuels.

Due to the lack of hydro resources potential data, this system has not been assigned hydro resources as a component in the hybrid system. Therefore, future analysis may be made by including the hydro resources in the hybrid system. The Wind Turbine/ PV Panels/ Battery bank/Biogas generator/Diesel generator hybrid system has been found as the optimum system with the capacities of 150 kW of Solar PV, 50 Wind turbine of capacity 3 kW, 3,832 Batteries of 1 kWh, Biogas generator of 150 kW, Diesel generator of 420 kW with the Levelized cost of Rs. 936.63.

Conflict of interest

All the authors are hereby declared that they have no conflict of interest.

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