Simulation and Optimization of MRES for Remote Power Generation at Bharmour, India

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Abstract

Objectives: In this paper, an analysis is done with an objective to propose a solution to hybrid power system for storage requirements with cost effective. Methods/Statistical Analysis: A feasibility analysis is carried out on various standalone and hybrid systems based on sensitivity analysis of different converter sizes for a remote area situated in Chamba District of Himachal Pradesh, India. This study is carried out considering the effect of with and without Battery Energy Storage System (BESS) in standalone and hybrid systems. Findings: From the analysis, it is found that total net present cost (NPC) for hybrid system is much less than that of standalone systems, thus ensuring the reliability and continuity of power in case hybrid system is incorporated in the case study. A Lithium ion battery is used in conjunction with hybrid system consisting of wind farm, mini/micro hydro and solar PV plant integrated via power electronic interface. Improvement: It is seen that BESS helps in improving load leveling by charging when demand is less than generation and by discharging in vice-versa case.

Keywords: Battery Energy Storage System (BESS), Distributed Generation (DG), Lithium Ion Battery, Multiple Renewable Energy Sources (MRES), Net Present Cost (NPC)

1. Introduction

In today’s era, India faces very big challenge to fulfill energy demands of consumers having good power quality in a sustainable way and at economic tariff. To achieve millennium development goals 7 and 8, India required 8-10% economic growth in next 25 years to exterminate power completely.

The implementation of a small scale energy system for rural electrification involves many different costs and components whose price varies with the many factors such as advancement of technologies and the use of resources etc. The most important factor to be considered is economic costs and benefits of a plan in order to make it sustainable and profitable. The chapter analyzes the configure ration of hybrid system proposed in HOMER for electrification and the economics related with the use of wind, hydro, diesel and battery for meeting various energy requirements 12.

Hybrid systems are composed of one or more RES which works in isolated or grid connected mode. Various sources like wind, mini/micro hydro etc. is considered as they are reliable source of electricity. In our research study, we have taken wind and mini/micro hydro sources as they are reliable source of electricity. Due to intermittent nature of wind, conventional diesel generator and storage devices are also integrated with hybrid system in order to deliver deficient load to consumers 34-6.

The objective of this study is to optimize and carry out cost analysis to find out the best optimum and feasible solution out of number of hybrid systems with and without battery storage device. Microgrid optimization HOMER software is used to carry out cost optimization analysis of system comprising of dispersed generation in addition to storage devices.
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The economic analysis of standalone and hybrid systems is carried out in Microgrid optimization HOMER software with and without battery storage device. The data for wind speed and average water flow is taken for a particular site in Bharmour, Chamba district of Himachal Pradesh. The data for solar irradiation for a particular year is taken from NASA website. The load or demand assessment is taken on hourly basis of a minor area of Chamba district. The economics of all the cases is kept same at annual interest rate of 5% and total life of hybrid system is expected to be 20 years. The rate of diesel fuel is also according to current tariff. The sensitivity analysis is carried out by considering different size of diesel generator and thereafter, optimization analysis is carried out which presents most optimum and feasible solution for all the cases. The production and consumption of plants for various cases is presented in result analysis and NPC are compared and validated.

The simulation of multi-RES (MRES) and its optimization for rural area power generation where multi-objective evolutionary algorithm (MOEA) evaluates objectives within geographical and economic constraints is presented. The objectives are maximizing generation and system reliability and minimizing cost to meet given load demand. MRES includes real site specific data for wind and solar hybrid model and also analyze biomass generation along with backup of diesel generator and storage devices at critical loads using isolated island of Fernando de Noronha, Brazil as a case study. MOEA provides solution which satisfies three objectives viz. combining...
optimal performance range with results of operational performance measures for a period of one day, providing optimal operational performance period of configured MRES and an insight into improvements for control and dispatch strategies and potential sizing concerns of MRES that could be realized by simulating system alone.\(^\text{23}\)

**Table 1.** Average Wind Speed Data for three years (2009-2011)

| Month    | Wind speed (m/s) |
|----------|------------------|
| January  | 2.38             |
| February | 2.53             |
| March    | 2.98             |
| April    | 3.13             |
| May      | 3.13             |
| June     | 2.98             |
| July     | 2.24             |
| August   | 1.79             |
| September| 1.79             |
| October  | 2.09             |
| November | 2.24             |

When DG and grid is connected, it has both technical and economic impact. Storage devices are extensively used to be operated at the times of critical loads and for reduction of power transfer between grid and hybrid system. The impacts of DG with storage devices on distribution system are presented.\(^\text{8}\) The technical simulation performs transient stability analysis of hybrid system under consideration along with various storage devices such as battery, super-capacitor etc. DG comprises of small synchronous and induction generators. Various DG technologies, fault location and type and varying penetration index of SG are analyzed and it is found that storage device used have irrefutable effects the stability in terms of transients. The analysis pertains to cost effectiveness of various Generation topologies available at customer end with paucity or reserves of generation available. The analysis is being carried on with HOMER software, evaluating and comparing the effects of various devices used for storage in conjunction with Different Generation resources.\(^\text{8-12}\)

**Figure 3.** Monthly Average Solar Radiation.

**Figure 4.** Hourly Load Consumption.
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2. Selection of Site for Analysis

The hybrid system design depends on various sensitivity variables for optimizing cost and size efficaciously. Thus, before starting cost analysis, certain design parameters like wind speed, water flow, solar irradiation, load profile etc. should be studied thoroughly and data should be collected for some time duration. The study area is situated in Bharmour, Chamba district of Himachal Pradesh state, India and it geographically extends over south-eastern portion of Chamba district. The positional values in terms of latitude and longitude of Bharmour, Chamba district are 32°26' N and 76°32' E respectively.

2.1 Wind Speed Data

The analysis is carried on the data is of three years viz. 2009-2011 for this site location and average wind speed is found to be 2.43 m/s. The analysis is carried on monthly basis (m/s) and shown in Figure 1 and wind speed probability distribution is depicted in Figure 1. Average speed is being calculated, in addition to this, the speed of wind is tabulated in Table 1 and synthesized using HOMER. The investment in installation, depreciation and incurred cost in maintenance and operation capital, replacement and O&M costs are shown.

2.2 Mini/Micro Hydro Plant Data

While during the course of eastern monsoon, falling in month hailing from May onwards for a period of four months, maximum rainfall is recorded. The average rainfall of this district is found to be 27.32 cumecs and it is mostly erratic. Figure 2 shows monthly average water flow in liters/second and Table 2 shows monthly average water flow. The investment in installation, depreciation and incurred cost in maintenance and operation capital, replacement and O&M costs are shown.

2.3 Solar PV Plant Data

The solar irradiation data on a hourly basis is taken for a year from National Aeronautics and Space Administration (NASA) website. The average solar radiation is 5.05 kWh/m²/d. In solar power, irradiation is of prime importance; therefore CI and average value of is taken on yearly basis, while analysis is also done using HOMER for graphical representation shown in Table 3 and Figure 3 respectively. The investment in installation, depreciation and incurred cost in maintenance and operation capital, replacement and O&M costs are shown.

2.4 Load/Demand Assessment Data

Electrical load comprises of one or more equipments which consume electrical power. Load assessment is carried for a residential block of Chamba district. The expected load profile for daily consumption of an area is shown in Figure 4 and it is found to be 675 kWh/day consumption in a specified area (residential) whereas peak load is found to be 1500 kW. Table 4 depicts load consumption for one day.

![Table 1. Monthly Average Wind Speed](image)

![Table 2. Monthly Average Water Flow](image)

![Table 3. Monthly Average Solar Radiation](image)

![Table 4. Load/Demand Assessment Data](image)
2.5 Diesel Generator Data

In this hybrid model, a sensitivity analysis is carried out on diesel generator size. The size varies on accordance of total power generation, load and battery size. The simulation includes sizes ranging from 10 kW to 30 kW in the steps of 5 kW. The investment in installation, depreciation and incurred cost in maintenance and operation capital, replacement and O&M costs are also depicted. Diesel generator supplies load when power generation from wind, mini/micro hydro and solar PV plant is deficient and battery power is also depleted.

2.6 Battery Data

DG systems comprising of Wind and solar counterparts have variable nature in input are not sustained continuous power supply. In order to supply load continuously, battery storage device is essential for smoothing the mismatch between load and wind power or solar PV.

Table 4. Load Consumption of a Day

| Hours | Load consumption (kW) | Hours | Load consumption (kW) |
|-------|-----------------------|-------|-----------------------|
| 0 – 6 | 1000                  | 13 – 16 | 1250                  |
| 7 – 10| 1250                  | 17 – 20 | 1750                  |
| 11 – 12| 1500               | 21 – 24 | 1000                  |

2.7 Layout of Systems

Figure 5. Layout of Standalone Systems Consisting of Diesel Generator without Battery Storage (a) Wind (b) Mini/Micro Hydro and (c) Solar PV without Battery Storage.

Figure 6. Layout of Hybrid System Consisting of Wind, Mini/Micro Hydro and solar PV along with Diesel Generator (a) Without and (b) With Battery Storage.

Figure 7. Optimized Result for Standalone System.
generation and for system maintenance. The major cost involved in small scale off-grid system is on account of battery. In this hybrid system, a battery of 6 V, 360 Ah is taken and batteries per string are taken as 2 giving 12 V DC bus. The cost summary, technical details of components and other required input parameters for hybrid system simulation in HOMER software is shown in Annex I and II.

3. Standalone and Hybrid Systems

The standalone systems and hybrid systems along with diesel generator are simulated in HOMER software with and without battery storage. The layout of three standalone systems viz. wind, mini/micro hydro and solar PV consisting of diesel generator without battery storage to power the load has been modeled using micro grid optimization software HOMER as shown in Figure 5(a), (b) and (c) respectively. The layout of hybrid system consisting of wind, mini/micro hydro and solar PV along with diesel generator integration with and without battery storage to deliver the load has been modeled using HOMER software as shown in Figure 6.

4. Simulation Procedure

Simulation has been carried out with different topologies having storage or paucity of reserves.

A. Without Battery Storage
   a. Wind – Diesel
   b. Mini/Micro Hydro – Diesel
   c. Solar PV – Diesel
   d. Wind – Mini/Micro Hydro – Diesel
   e. Mini/Micro Hydro – Solar PV – Diesel
   f. Wind – Solar PV – Diesel
   g. Wind – Mini/Micro Hydro – Solar PV – Diesel

B. With Battery Storage
   a. Wind – Diesel
   b. Mini/Micro Hydro – Diesel
   c. Solar PV – Diesel
   d. Wind – Mini/Micro Hydro – Diesel
   e. Mini/Micro Hydro – Solar PV – Diesel
   f. Wind – Solar PV – Diesel
   g. Wind – Mini/Micro Hydro – Solar PV – Diesel

These fourteen different configure rations include different DG connection, storage device and cost analysis in terms of NPC; is found out for each configure ration. The investment in installation, depreciation and incurred cost in maintenance and operation capital, replacement and O&M costs. The NPC includes initial cost for initialization, depreciation and operational costs including labour and fuels incurred for the project.

5. Results and Discussion

The standalone system is simulated in HOMER software which finds an optimum solution for all sensitivity variables. The optimum solution for standalone system with battery storage is shown in Figure 7. For solar PV-Diesel standalone plant, the total NPC is $951,151. The total fuel used by diesel generator is 52,066L per year and annual generator run time is 8760 hours. The cost of diesel is $1.19 per liter for whole year and total cost incurred is $71,661 per year. Figure 8 shows the monthly average electric production of the system which is totally produced by solar PV-Diesel plant.

While analysis, some parameters are synthesized in order to identify their impact on a system; involved with sensitivity. The various parameters (nine in number) are identified and simulation has been carried out in HOMER to find an optimal solution to parameters which are sensitive in a mixed system comprising of various topologies, shown in Figure 9. These variables are wind speed, water flow, solar irradiation, five different converter sizes and diesel price. The total cost is $403,085, consumes zero litre of diesel fuel per year and generator run time annually is also zero hours. Thus, total cost incurred per year for the proposed system is also zero. Solar PV penetration is 41% with 101,055 kWh/year of total production. The rest of the load is supplied by wind and mini/micro hydro which is 64.7% with 159,416 kWh/year and 267% with 657,384 kWh/year respectively. Figure 10 shows the generation of electricity on monthly basis, generated by wind, mini/micro hydro and solar PV standalone plants in conjunction in a wind-mini/micro hydro-solar PV-diesel plant. Thus, there is no need of diesel generator for supplying critical loads as the load is fully served by three standalone systems only.

In case of without battery storage device, wind – diesel and solar PV – diesel plants are having more NPC due to large costs involved in construction of WTG sets, solar panels
and absence of maximum power point tracking techniques whereas in case of mini/micro hydro – diesel plant, all the system load is met by hydro plant alone. This is on account of heavy rainfall and large production of electric power generation and as a result, there is no need of diesel plant at all. The NPC of standalone plants is more as compared to hybrid systems as shown in Table 5 & 6. All the hybrid plants overcome limitations of standalone plants and thus, they can be efficiently operated under hybrid mode. Component specifications are presented in Table 7.

In case of with battery storage device, NPC of wind – diesel and solar PV – diesel plants is much more due to addition of battery storage device but at the same time, NPC of mini/micro hydro – solar PV – diesel plant decreases due to load leveling via battery storage device.

Thus, it can be incurred that mini/micro hydro plant can be served as peak power plant whereas solar PV/ wind/diesel plants in combination can serve as base load plant during summer and winter seasons.

This optimization or feasibility study can be further extended to grid integration issues in future. The results of this study can then be analyzed based on various factors.
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### Table 5. Comparison of Predicted NPC for Different Cases

| Plant model                  | Without battery storage | With battery storage |
|------------------------------|-------------------------|----------------------|
| Wind – Diesel                | $895,877                | $943,098             |
| Mini/Micro Hydro – Diesel    | $347,656                | $349,345             |
| Solar PV – Diesel            | $947,153                | $951,151             |
| Wind – Mini/Micro Hydro – Diesel | $374,571              | $376,261             |
| Mini/Micro Hydro – Solar PV – Diesel | $348,299           | $348,299             |
| Wind – Solar PV – Diesel     | $656,997                | $656,997             |
| Wind – Mini/Micro Hydro – Solar PV – Diesel | $401,396          | $403,085             |

### Table 6. Cost Summary of System Components [7-9, 10-11]

| Component                  | Size   | Capital cost ($) | Replacement cost ($) | O&M cost/year |
|----------------------------|--------|------------------|----------------------|---------------|
| WT                         | 10 kW  | 20000            | 20000                | 500 $/year    |
| Mini/Micro hydro           | 100 kW | 300000           | 300000               | 6000 $/year   |
| Solar PV                   | 70     | 26700            | 20000                | 10 $/year     |
| Diesel generator           | 10 kW  | 5500             | 5475                 | 0.5 $/hour    |
|                            | 15 kW  | 6600             | 6600                 | 0.6 $/hour    |
|                            | 20 kW  | 7500             | 7500                 | 0.7 $/hour    |
|                            | 25 kW  | 8000             | 8000                 | 0.8 $/hour    |
|                            | 30 kW  | 8800             | 8800                 | 0.9 $/hour    |
| Battery                    | 6 V, 360 Ah | 450             | 440                  | 10 $/year     |
| Converter                  | 30 kW  | 23000            | 23000                | 10 $/year     |

### Table 7. Specifications of the Components Used [7-8, 10-11]

| Component       | Specification                                                                 |
|-----------------|-------------------------------------------------------------------------------|
| Wind Turbine    | Model: BWC Excel-S | Rated power: 10 kW BWC Excel-S |
|                 | Hub height: 15 m | Lifetime: 20 years |
| Micro Hydro     | Available head: 10 m | Design flow rate: 1000 l/s |
|                 | Min. flow ratio: 80% | Max. flow ratio: 120% |
|                 | Nominal power: 73.6 kW | Efficiency: 75% |

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