Modelling and cost optimization of a community microgrid

N Himabindu1, Rajashekar P Mandi and H Santoshkumar
School of Electrical and Electronics Engineering, REVA University, Bengaluru-560064, Karnataka, India
1E-mail: hima.bindu@reva.edu.in

Abstract. With the increasing energy demand and promotion of usage of renewable energy resources to reduce the environmental effects, hybrid renewable energy system (HRES) has become very feasible and attractive. In this paper grid-connected hybrid power system model consisting of Solar PV and Wind turbine as HRES are considered to carry out the techno-economic feasibility study. The potential of wind and solar energies are estimated by collecting the data from various resources of a community Microgrid located at the geographical location with latitude of 14.135° N, longitude of 76.239° E in Chitradurga District, south Indian state of Karnataka. HOMER Pro software is used for simulation and promising results are obtained.

Keywords: renewable energy, hybrid renewable energy system (HRES), Solar PV, optimization

1. Introduction
Electrical energy has become an essential factor in the socio-economic development of the human life. Also with the exhaustion of fossil fuels and growing environmental distress associated with climate change and global warming, there aroused the need of the hour for identifying suitable alternative energy resources which are cleaner, cheaper and sustainable. There is a huge potential in terms of power generation by the abundantly available energy resources like solar, wind and small hydro [1-3]. These are termed as renewable energy sources and power generation can be in a cleaner and sustainable manner. With the rapid increase in population and energy demand, to improve the standard of living of the rural community and for economic empowerment, these alternative energy resources are to be installed.

In spite of numerous advantages of wind and solar systems, large scale power generation as in conventional energy sources is mere difficult. An off-grid or stand-alone system with wind and solar cannot continuously meet the load demand due to their stochastic nature. Hence, for reliable power supply an additional storage system is essential which leads to increased investment cost. As a result the off-grid system is exorbitant.

In this work, a systematic evaluation of the available resources and the load was conducted for the community selected for the study. The collected data is given as input to HOMER (Hybrid Optimization Model for Electrical Renewable). For the selected location, wind and solar PV resources are found to be best renewable sources. HOMER simulates and optimizes the given hybrid renewable system and gives the optimized feasible combinations which can meet the load demand. For grid-connected system PV, Wind and battery are used and for off-grid system PV, Wind, DG and battery are considered. These results are compared for optimal solution.
2. System Description
HOMER Pro tool is used for designing and evaluating the off-grid and on-grid hybrid power system configurations. For the selected site, the load demand, available resources and system units need to be fed as input data to evaluate and analyze the optimization.

2.1. Site Load Profile
The area chosen for analysis has average energy consumption of 1147.59 kWh/day and the peak load 136.30 kW. Figure 1 shows daily average load variations for January month and Figure 2 shows the monthly average load variations.

![Figure 1. Load profile of the selected location (Daily)](image)

![Figure 2. Energy load profile of the selected location per annum](image)

The maximum load varies between 100.75 kW and 136.3 kW monthly. Figure 3 shows the monthly load profile of the site selected.

2.2. Solar Resource
Chitradurga District is geographically located at latitude of 14.135° N, longitude of 76.239° E in Indian state of Karnataka. Solar radiation for this selected area was obtained from NASA Surface methodology. The average solar radiation per annum is 5.55 kWh/m²/day
Figure 3. Monthly load profile of the selected location

Figure 4. Monthly average solar radiation and clearness index at the selected location

Figure 4 shows average monthly Global Horizontal Irradiance (GHI) Data for the considered site. It is observed from the figure that the average monthly solar radiation is highest in the months of April and March which are 6.810 kWh/m²/day and 6.803 kWh/m²/day.

2.3. Wind Resource

For the hybrid power system, to evaluate the expected power output of wind turbine, monthly mean data of the wind resources for the selected location is obtained from the literature. Monthly variation of the wind speed for the selected location is given in Figure 5. It is observed that mean wind speed is highest in June month i.e. 5.15 m/s and lowest of 1.73 m/s in the month of November [4]. Also the annual average wind speed is obtained as 2.89 m/s.
3. Proposed System Configuration

Two hybrid models are designed and compared using HOMER simulation software. The grid-connected HRES model consisting of Wind Turbine, Solar PV array, load, converter, and grid is represented in Figure 6 and Figure 7 represents the same HRES model without connection to the grid.

The main units of the proposed hybrid power system model are wind turbine, solar PV array, battery bank, and a power converter. To maintain the energy flow between the AC and DC buses, converter is added. As a backup power supply battery is employed. When renewable generation exceeds the load, battery stores energy and discharges when the load demand exceeds the generation from renewable resources.

Based on the load profile of the selected site, the components size is chosen. The following section gives specifications of the main components of the proposed hybrid power system.
3.1. Photovoltaic Model
Solar PV system is the combination of number of solar cells in series/parallel to convert sunlight into electricity. HOMER tool models solar PV array as a device producing dc electricity proportional to the incident global solar radiation. The following equation is used in calculating output power [5] from the PV array using HOMER.

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S}$$

Where,
- $P_{PV}$ is power output from PV array
- $f_{PV}$ is derating factor
- $Y_{PV}$ is capacity in kW
- $I_T$ is solar radiation incidence on the surface in kW/m$^2$
- $I_S$ is Standard radiation

Three units of the Generic flat plate PV panel of capacity 25kW is selected for this system arrangement. The capital cost for 25kW PV module is approximately $24000 and replacement cost is considered as $20000. The O&M cost is considered as $100/year. A derating factor of 80% and 25 years lifetime is considered.

3.2. Wind turbine model
Kinetic energy from the wind is converted into electrical energy and the energy available in the wind can be expressed using equation (2).

$$P_w = \frac{1}{2} \rho A V^3$$

Where,
- $\rho$ = density of air (kg/m$^3$)
- $A$ = the swept area (m$^2$)
- $P_w$ = power in the wind (W)
- $V$ = instantaneous wind velocity (m/s)

The electrical power output from the wind turbine can be expressed by equation (3).
\[ P_{\text{out}} = \eta_t C_p \frac{1}{2} \rho AV^3 \]  

Where \( P_{\text{out}} \) = output power of wind turbine  
\( \eta_t \) = Overall efficiency of the transmission system  
\( C_p \) = the power coefficient

The initial cost of one unit of 100kW wind turbine is considered as $45000. Replacement and O & M costs are considered to be $45000 and $500/year respectively. The lifetime of the turbine is considered as 20 years. Three such units are used.

### 3.3. Battery energy storage system

To extract maximum benefit from the stochastic renewable resources, a battery is required for storage. The storage capacity of the battery is given as;

\[ C_{\text{Wh}} = \left( \frac{E_L \times A_D}{\eta_{\text{inv}} \times \eta_{\text{Bat}} \times D_{\text{bat}}} \right) \]  

Where,  
\( E_L \) is the average daily load energy (kWh/day),  
\( A_D \) is daily autonomy of the battery,  
\( D_{\text{bat}} \) is depth of discharge of a battery,  
\( \eta_{\text{inv}} \) and \( \eta_{\text{Bat}} \) are inverter and battery efficiency, respectively

For 1kWh of energy storage 12V lead acid battery is considered which costs $300 for 1kWh. Replacement and maintenance costs were assumed to be $250 and $10/year respectively. The string size of the battery is 2 and throughput of each battery is assumed to be 800 kWh.

### 3.4. Power Converter

To maintain the flow of energy, a power electronic converter is used. Leonics MTP-413F 25kW converter is selected. The capital and replacement costs are considered as $300. The O & M cost is estimated to be $10/Year and the efficiency and the lifetime of the converter is assumed to be 95% and 10 years respectively.

### 3.5. Diesel generator model

As renewable energy sources are stochastic in nature, a DG system is considered in off-grid system model. The power supplied by a DG depends directly on the fuel consumption. In order to have an optimum system operation, proper energy balance is required [6-8].

\[ F_G = B_G \times P_{G\text{-rated}} + A_G \times P_{G\text{-out}} \]  

Where,  
\( F_G \) is amount of fuel consumed,  
\( P_{G\text{-rated}} \) is nominal power of DG,  
\( P_{G\text{-out}} \) is output power,  
\( A_G, B_G \) are the coefficients (fuel consumption)

The initial investment cost of the DG is estimated to be $40000. Replacement, operational and maintenance costs were assumed $40000W and $2.0/h, respectively.

### 3.6. Grid

Sufficient power cannot be generated with solar PV and wind turbine alone due to their heavy capital cost. Hence, in grid connected model, grid is used to meet the balance load demand. As per the resource availability data, wind and solar resources can be selected for the site considered. A battery energy storage system is included in case of off-grid mode.
3.7. Economic Input

Net Present Cost (NPC) represents the life-cycle cost and it constitutes the capital, replacement costs, maintenance cost per annum and fuel costs [9-10]. It is given by:

\[ C_{NPC} = \frac{TAC}{CRF(i, N)} \]  

(6)

Where,

- \( TAC \) is total annualized cost ($/year)
- \( CRF \) is capital recovery factor and is given by:

\[ CRF(i, N) = \frac{i(1 + i)^N}{i(1 + i)^N - 1} \]  

(7)

HOMER simulates to find an optimal system configuration and evaluates for minimizing the NPC and cost of electricity (COE).

4. Results and Discussion

The primary objective being to compare the on-grid and off-grid HRES modules for the cost-effective configuration and to attain the optimal design for a rural community. A comparative analysis is made on criteria like NPC, energy cost and renewable fraction by making use of Homer Pro software. For the selected location the average energy consumption is 1147.59kWh/day and the peak load is 136.30kW. This gives the average energy consumption as 418870.35kWh/Year. With three units of 25kW flat plate PV panel the production is 89429kWh/Year. The production from three units of 100kW wind turbine is 84640kWh/Yr. The remaining 244801kWh/Year can be taken from grid. The energy production and consumption summary for grid-connected model is given in Table 1 and Table 2 respectively. Figure 8 represents the monthly average electrical production in the selected location.

For grid-connected system, minimum COE achieved from the simulation is $0.109 and the renewable energy contribution is found to be 37.8%. In grid-connected model, optimum NPC is $633352. Figure 9 gives the component wise Net Present Cost of the grid-connected system.

| Module                          | Production(kWh/Year) | %  |
|---------------------------------|----------------------|----|
| Generic flat plate PV(25kW)     | 89429                | 19.7 |
| Wind Turbine(100kW)             | 84640                | 18.7 |
| Grid Purchases                  | 278759               | 61.6 |
| Total                           | 452828               | 100 |

Table 1. Production summary

| Module                     | Production(kWh/Year) | %  |
|----------------------------|----------------------|----|
| AC Primary load            | 418869               | 93.4 |
| DC Primary load            | 0                    | 0   |
| Grid Sales                 | 29487                | 6.58 |
| Total                      | 448356               | 100 |

Table 2. Consumption Summary
In off-grid model, the insufficient energy will be produced using DG set instead of Grid. The production and consumption summary in case of off-grid is represented in Table 3 and Table 4 respectively. For off-grid HRES, the minimum COE achieved from the simulation is $0.391. In this case, the energy contribution from renewable resources is 26.8%. The NPC for off-grid is $2.12M. Figure 10 gives the component wise Net Present Cost of the off-grid connected system.

**Table 3. Production summary**

| Module                | Production(kWh/Year) | %  |
|-----------------------|----------------------|----|
| Generic flat plate PV(25kW) | 89429                | 18.6 |
| Wind Turbine(100kW)   | 84640                | 17.6 |
| DG Set                | 306597               | 63.8 |
| Total                 | 480666               | 100 |

**Table 4. Consumption Summary**

| Module            | Production(kWh/Year) | %  |
|-------------------|----------------------|----|
| AC Primary load   | 418846               | 100 |
| DC Primary load   | 0                    | 0   |
| Total             | 418846               | 100 |
The Net Present Cost, Cost of Energy and Renewable fraction has been compared for both off-grid and Grid Connected models which is represented in Table 5. It is observed that the Cost of Energy is less for Grid connected model as in off-grid COE is more because of requirement of fuel for DG set. Also NPC for off-grid model is more due to the requirement of storage unit. Based on these results Grid connected model is economical.

Table 5. Comparison between off-grid and grid-connected system

|                        | Off-grid ($) | Grid-connected ($) |
|------------------------|--------------|--------------------|
| NPC (Net Present Cost) | 2.12M        | 633352             |
| COE (Cost of Energy)   | 0.391        | 0.109              |
| Renewable Fraction     | 26.8         | 37.8               |

5. Conclusion

The HRES based community grid is presented in this work for the location in Chitradurga district latitude 14.135°N, longitude 76.239°E - in Karnataka state. HOMER software was used for analysis and simulation results which shows that Net Present Cost and the Cost of Energy of the grid connected HRES model was $633352 and $0.109 and for off-grid model it is $2.12M and $0.391 respectively. Although off-grid hybrid model uses renewable energy, there is a requirement for an extra-large battery bank for storage of electricity and a diesel generator as a reserve which increases NPC and COE values. A grid connected hybrid model does not require additional storage system in the form of battery in normal operating condition. Hence for the selected site location, with the available resources, hybrid grid connected model is economically viable. In future work, biomass unit can be included for analysis purpose so that best optimized hybrid model can be designed for given load requirement.

References

[1] Rajashekar P. Mandi 2017 Techno-economic Evaluation of Grid-connected Solar Photovoltaic Power Plant for Rural Banks © Springer International Publishing AG 2017 R. Bansal (ed.), handbook of Distributed Generation, DOI 10.1007/978-3-319-51343-0_11.

[2] N. Himabindu and Rajashekar P. Mandi 2020 Energy Management Optimization Techniques for Hybrid Renewable Energy Systems International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878 Volume-8 Issue-6S pp 89-94.
[3] Sanjeev Dutta, Wang Yue, AiQian, Zhang Yufan, Ashok Adhikari and Li Zhaoyu 2019, Modelling and Cost Optimization of an Islanded Microgrid with an Existing Microhydro using HOMER Software 2nd Asia Conference on Energy and Environment Engineering- ACEEE pp 74-78.

[4] Himabindu N, K N Patil, Rajashekar P Mandi, Swapna Manasani, Santoshkumar Hampannavar and Venkatesh Murthy B S 2020 Wind Potential Assessment of Central Dry Zone of Indian State of Karnataka for Micro Power Generation Science and Engineering Research Support Society Vol.29/Issue 10s pp 4277-4287.

[5] HOMER Guide by HOMER Tool.

[6] Md. Nurunnabi and N. K. Roy 2015 Grid Connected Hybrid Power System Design Using HOMER 3rd International Conference on Advances in Electrical Engineering pp 18-21.

[7] Lanre Olatomiwa, Saad Mekhilef, A. S. N. Huda1 and Kamilu Sanusi 2015 Techno-economic analysis of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: the way forward for rural development Energy Science & Engineering published by the Society of Chemical Industry and John Wiley & Sons Ltd. pp 271-285.

[8] Ayodele T.R, Ogunjuyigbe A.S.O and Babatunde J.B 2016 Sustainable electricity generation in rural communities using hybrid energy system: The case study of Ojataye Village International Journal of Renewable Energy Vol. 11 No. 1 pp 43-56.

[9] V.A. Ani and B. Abubakar 2015 Feasibility Analysis and Simulation of Integrated Renewable Energy System for Power Generation: A Hypothetical Study of Rural Health Clinic Journal of Energy.

[10] Geem, Z. W. 2012 Size optimization for a hybrid photovoltaic–wind energy system International Journal of Electrical Power & Energy Systems42 (1): 448–51.