Comparative analysis of different hybrid energy system for sustainable power supply: A case study

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Abstract. Hybrid Power System (HPS) is an energy system with combination of different regenerative energy sources like Solar, Wind, Geo-Thermal, Biomass and several others to achieve energy sustainability. This paper investigates the feasibility of grid connected and stand-alone hybrid energy system to meet electric load requirement of a community or organization, by utilizing the available resources. Potentiality of different energy sources like solar, wind, biogas, etc. along with currently used energy sources is studied thoroughly by taking a case study of Kathmandu University central campus, located at Dhulikhel, Nepal. Technical and economic analysis of on-grid and off-grid hybrid system is performed to get optimum model that supply continuous energy to the end user. Furthermore, the possibility of net metering with national utility has been analysed. The main objective of this study is to identify the suitable energy mixed model, that provide the sustainable energy supply to the university, and recommend the possible energy generators to be added for fulfilling the continuously increasing load demand. The load profile of several years of the University is taken into consideration for forecasting the power demand. The findings of the research show that system when adopted to hybrid system can meet up to 55% of the load by renewable resources. Maximum renewable fraction is found to be 0.603 and maximum renewable penetration of 812%.

Keywords: Hybrid Power System, Hybrid Energy System, Net-metering, Technical and economic analysis, energy generators

1 Introduction

With the increasing energy demand, taking environmental concern as a crucial factor: use of renewable energy along with hydropower has escalated to a good number. From Key World Statistics, it is noted that out of total world energy supplies(13,761 Mtoe): 1.7% has been supplied by geothermal, solar, wind, tide/wave/ocean, 2.5% by Hydro, 9.8% by Biofuels and waste [1]. The use of renewable energy is practiced almost everywhere in the world. They are mostly used as mini/micro grid power supply in the places where either grid power supply is lacking or it might not sound economically good to install grid supply. This kind of scenario mostly occurs in distant islands or rural hilly places far from the city area where population density is low [2]. The 2030 Agenda for Sustainable Development positions...
access to affordable, reliable, sustainable and modern energy as a key pillar of Sustainable Development Goal 7 (SDG 7) (UN, 2018). IRENA published that the number of people served by off-grid renewables globally has expanded six-fold since 2011, reaching nearly 133 million people in 2016. Off-grid renewable energy capacity has witnessed a spectacular three-fold increase from under 2 gigawatts (GW) in 2008 to over 6.5 GW in 2017 [3]. Consequently, for the system reliability, more than one renewable energy source must be combined and in turn, it is essential to model the energy system before implementing the project for decision making and feasibility analysis [4]. According to a study reported in [5], the worldwide market for hybrid power systems is expected to grow at a CAGR of roughly 5.7% over the next five years, will reach 58000 million US$ in 2023 from 41600 million US$ in 2017. Though installation of alternative hybrid systems provide reliability and reduce operating cost in a system, the analysis must be done in order to find the optimum mixture of hybrid system for the system to be technically and economically viable.

There are different computer tools that can be used to analyze the integration of renewable energy sources, according to the review [6], out of 37 software reviewed, RETScreen, HOMER, LEAP, BCHP Screening Tool and energyPro were found to be mostly used software for energy system optimization. Hybrid Optimization Model for Electric Renewable (HOMER) is a software tool designed by National Renewable Energy Laboratory (NREL) in the USA. HOMER simulates and optimizes stand-alone and grid-connected power systems with any combination of wind turbines, PV arrays, run-off-river hydropower, biomass power, internal combustion engine generators, microturbines, fuel cells, batteries, and hydrogen storage, serving both electric and thermal loads [7]. According to studies [4, 8] done using HOMER and RETScreen, taking parameters like Levelized cost of electricity, emission, equity payback: between Solar PV/Diesel Generator and Wind/ Diesel Generator, the former one was selected with lesser payback period as well as CoE. Parameters like Levelized CoE, emission, equity payback can be considered to model hybrid power system. Additionally, the energy-storing device being one of the major components for hybrid power system, choosing best alternatives among different choices might be proven economical. An analysis cost performed in [9], the hybrid system based on PV and battery represents the cheapest configuration, whereas PV and hydrogen system is the most expensive configuration.

The main objective of this study is to identify reliable and sustainable optimized energy system for a university complex. In this study every possible energy sources in the campus area is studied and finally a multi-hybrid system is identified which is technically and economically viable.

2 Current Status of Hybrid System in Nepal

Under the Government of Nepal, Alternative Energy Promotion Centre (AEPC) has done installation and research of different renewable energy: solar PV system for electrification (off/on-grid plant) and water pumping system, solar thermal, biomass, biogas (small, urban domestic and large), wind. AEPC reported that 77 companies work for installation and promotion of Solar PV systems [10]. Saral Urja Nepal Pvt. Ltd. has been making their continual effort for the installation of rooftop solar in order to provide continuous power supply and reduce electricity consumption from grid supply at offices, organizations and commercial complexes; the company have installed 50 kW solar rooftop at NMB Bank, Kathmandu, Nepal, 27.6 kW at a commercial complex situated at Thapathali, Kathmandu; and 25kW at Shaligram Hotel, Kathmandu, 75 kW at City cinema, Biratnagar as ongoing projects [11]. Dhulikhel Hospital operated by Kathmandu University consist of 161 kW of Solar for the sustainability of power supply [12]. This shows that to prevent unexpected power cut off, different organization are putting their efforts in to promote renewable energy and, solar PV system as a major one. The addition of renewable energy sources alone cannot provide the desired level of system reliability but they may significantly lower system operating costs [13].

Nepal’s largest wind-solar hybrid power system serving 83 rural houses in the Hariharpuradgi village of Sinduli district was constructed with a total cost of $16.2 million, consists of 20kWp of wind turbines and 15 kWp of solar PV panels producing 110 kWh of energy per day[14]. Similarly, supported by the Asian Development Bank, a hybrid system of 10 KW wind turbines and 2 kW of Solar has been
implemented in Nawalparasi, Dhaubadi VDC [15]. In Nepal, the hybrid system implemented so far is on small scale, however, in collaboration with Alternative Energy Promotion Center, many private organizations are making initiatives for the development of Hybrid Power System [16]. Regardless of Solar and wind, many rural places of Nepal are utilizing biomass for electrification and cooking, yearly more than 16000 biogas plants are installed in order to utilizes daily wastages produced in a house, in the year 2015 it was reported that 31,512 biogas plants were installed marking largest number of biogas installed in a year [17]. This shows that biogas can be proven to be one of the energy sources for the hybrid power system in case of Nepal.

3 Description of the case study

Kathmandu University is an autonomous, not-for-profit, non-government institution dedicated to maintain high standards of academic excellence. It is committed to develop leaders in professional areas through quality education [18]. The central campus is located at Dhulikhel municipality, Kavrepalanchok, Nepal at 27.6196°N and 85.5386°E with an altitude of 1473.79 meters above sea level. The central campus covers different administrative buildings, research labs, student hostel, faculty quarters and all fundamental laboratory, classes and other things of School of Engineering and School of Science. Figure 1 shows the top view of central campus from Google earth.

3.1 Load Profile of Campus

The load profile of campus for whole year is shown in figure 2. From this curve it is shown that the load demand is not same for all months and each instant of time. Comparatively, the peak power demand is occurred in day time and evening time of a day. Similarly, the overall energy demand is high in exam time and significantly reduced in vacation period. For the load profile, the electricity bills of Kathmandu University complex from Nepal Electricity Authority (NEA) of years 2016, 2017, 2018 and the records of internal Time of Day (TOD) metering were analysed. The average monthly curve of the campus is not same throughout the year. Maximum demands are seen in certain months due to exams and student project period in the campus and lower demands are observed during the vacation period.

4 Potentiality of different energy sources

The resources available in the campus area are Solar Resource, Biomass, Diesel, Wood and grid power. Two sets of diesel generators are available in the campus along with biomass gasification project proposed to be running in the campus province. A 50kW solar PV panel are installed in the block 08
and 09 of the campus. The solid waste generation is calculated with the help of number of students living in the campus provinces and the average amount of waste produced from the people in campus. The generator size for the solid waste is calculated to be 64kW [19]. The detailed resources are given below in this section.

4.1 Solar Resources
From the global horizontal radiation, the campus area campus area receives an average of 4.758 kWh/m²/day as shown in Figure 3. A total of 50kW solar PV panel providing 120V DC output is installed in the Block 08 and Block 09 of the campus.

4.2 Diesel Generators
Two set of diesel generators are available in the university of 40kVA and 200kVA. The diesel price at Nepal is $0.85 per litre [20].

4.3 Solid Waste Generators
A 64kW generator can be run in the campus area using solid waste. The number of students, staffs and faculty member living in the campus vicinity are studied thoroughly and based on average waste production per person, 64kW of energy can be generated through solid waste.

4.4 Grid Input
Kathmandu University is connected to grid with three transformers of 200kVA, 50kVA and 500kVA. Energy consumed from each transformers is monitored by a TOD (Time of Day) meter installed by the Nepal Electricity Authority, the sole distributor of electricity company in Nepal. The tariff rate for the energy consumption is given in Table 1 [21].

| Time       | T1          | T2          | T3          |
|------------|-------------|-------------|-------------|
| 05:00 to 17:00 | $0.112      | $0.057      | $0.102      |
| 23:00 to 05:00 |             |             |             |
| 17:00 to 23:00 |             |             |             |

4.5 Biomass Resource
A biomass generator of 12.5kW is proposed to be built at the university premises. Biomass available is considered to be 0.5 tons per day for the whole year and at $70 per ton [22].

4.6 Wind Resources
Figure 4 shows weather station residing at campus premises, it consists of anemometer which measures wind velocity at particular instant. Data obtained from this device shows that maximum wind speed of 1.7m/s is obtained in the month of June as shown in Figure 5. An average of 6-8 m/s wind speed is required for wind turbine to be economically viable [23]. Thus wind energy is not considered in this system.

4.7 Pump Storage
In the campus premises, there are two reservoirs, with lower reservoir capacity of 300m³ and upper reservoir of 100m³. The natural head for this resource is 30m and pump head of 150m. This resource is used for testing of turbines by Turbine Testing Lab (TTL). TTL has a testing capacity of 300 kW [24].
Through detail calculation it is found that 10kW of electricity can be generated for a period of 32 minutes. Thus this resource is not taken as a system component in this hybrid system.

5 Simulation and Results

The optimization of the hybrid system is done using HOMER software. Solar energy, wind energy, diesel generators, biomass generators, solid waste generators and grid power are taken as input for meeting the load of the campus. The campus has two generators of 40 kVA and 200 kVA available and biomass gasification project already proposed. Maximum usage of available resources is considered during optimization. The system has an AC bus bar of voltage level 220V and is fed from Biomass generator, solid waste generators, and DG 1 and DG 2. The DC bus bar voltage level is 220V DC which is fed from solar PV system, excess energy generated from PV system is stored in battery. The DC and AC bus are interlinked by means of converter (Inverter/Rectifier) for power exchange between AC and DC links. All the load in campus are fed from AC bus. The annual peak load and energy demand are 384kW and 2.629MWh/day respectively. The hybrid system for the campus is simulated for optimization in HOMER software is shown in Figure 6.

Considering the available resources and the hybrid system, the simulation model has the following inputs as shown in Table 2. For the optimized hybrid system, all the resources available at the campus are taken into account. Two cases are taken for the study one with net metering considered and the other without considering net metering.

| S.N | Component            | Capital Cost ($/kW) | Replacement Cost ($/kW) | O & M Cost ($/hr) | Sizes Considered (kW) | Quantity Considered | Life (Hours) |
|-----|----------------------|---------------------|-------------------------|------------------|------------------------|---------------------|--------------|
| 1   | Solar PV             | 1200                | 200                     | 0.10             | 12.5                   | 1                   | 25 years     |
| 2   | Biomass Generator    | 1200                | 200                     | 0.1              | 12.5                   | 1                   | 1500000     |
| 3   | Solid Waste Generator| 780                 | 50                      | 0.050            | 64                     | 1                   | 105120      |
| 4   | DG1                  | 375                 | 100                     | 0.150            | 0, 32                  | 1                   | 2000000     |
5.1 Case I: Without net metering

In this case, all the resources available in the campus are taken for study along with the grid purchase from NEA. Based on the load of the campus, when net metering is not considered the campus gets its 45% of the load from the national grid. The campus has potential for meeting 55% of its load by generating from different energy sources available in the vicinity. The renewable fraction is found to be 0.532 and maximum renewable penetration as 325%. Monthly average electricity produced is shown in Figure 7. Table 3 shows result of optimized hybrid system of case I.

| Component               | Optimizing Rate | Production (kW/year) | Levelized COE ($/kWh) | Initial Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total NPC ($) |
|-------------------------|-----------------|----------------------|-----------------------|---------------------|----------------|---------|---------|-------------|---------------|
| Solar PV                | 100 kW          | 162340               | 0.0740                | 100,000             | 0              | 9,077   | 0       | 0           | 109,077       |
| Solid Waste Generator   | 64 kW           | 373642               | 0.00625               | 49,920              | 630            | 179,130 | 28,361  | -158        | 257,884       |
| Biomass Generator       | 12.5 kW         | 1570                 | 0.07                  | 15,000              | 0              | 1,441   | 1,300   | -226        | 17,515        |
| DG1                     | 32 kW           | 1324                 | 0.213                 | 12,000              | 0              | 5,054   | 4,845   | -291        | 21,608        |
| DG2                     | 160 kW          | 4028                 | 0.213                 | 40,000              | 0              | 14,233  | 14,682  | -1,460      | 67,456        |
| Battery Bank            | 10 batteries    | -                    | -                     | 3,000               | 4,184          | 908     | 0       | 0           | 8,091         |
| Converter               | 64 kW           | -                    | -                     | 9,280               | 12,941         | 0       | 0       | 0           | 22,221        |
| Grid                    | -               | 440200               | 0                     | 0                   | 414,654        | 0       | 0       | 0           | 414,654       |

5.2 Case II: With net metering

In this case, when net-metering is adopted with the resources available, there is no excess energy that could be sold at the rate the national grid is buying. It is seen that, using the energy in the campus vicinity is economically more feasible than selling it. Thus a different case with more renewable penetration factor is taken for study. In this case, only 36% of the electricity is purchased from the grid, while
renewable sources: PV array contributes to 38% of the load and solid waste to 26% of the load. The renewable fraction is found to be 0.603 and maximum renewable penetration to be 812%. The levelized COE in this case is found to be $0.111/kWh and operating cost as $66,244 per annum. Figure 8 shows the monthly average electricity production for this case. Table 4 shows result of optimized hybrid system for Case II.

![Monthly Average Electric production](image)

**Table 4** Result of Case II (with net metering)

| Component         | Optimizing Rate | Production (kWh/year) | Levelized COE ($/kWh) | Initial Capital ($) | Replacement ($) | O&M ($)   | Fuel ($) | Salvage ($) | Total NPC ($) |
|-------------------|-----------------|-----------------------|-----------------------|---------------------|----------------|-----------|----------|------------|----------------|
| Solar PV          | 250 kW          | 405850                | 0.0740                | 250,000             | 0              | 22,693    | 0        | 0          | 272,693        |
| Solid Waste       | 64 kW           | 278081                | 0.00625               | 49,920              | 362            | 133,614   | 21,120   | -268       | 204,749        |
| Biomass Generator | 12.5 kW         | 325                   | 0.07                  | 15,000              | 0              | 295       | 268      | -230       | 15,334         |
| DG1               | 32 kW           | -                     | -                     | -                   | -              | -         | -        | -          | -              |
| DG2               | 160 kW          | -                     | -                     | -                   | -              | -         | -        | -          | -              |
| Battery Bank      | 80 batteries    | -                     | -                     | 24,000              | 33,468         | 7,262     | 0        | 0          | 64,730         |
| Converter         | 156 kW          | -                     | -                     | 22,620              | 31,544         | 0         | 0        | 0          | 54,164         |
| Grid              | -               | 379740                | 0                     | 0                   | 351,174        | 0         | 0        | 0          | 351,174        |

6 Discussion and Conclusion

In this study, a hybrid system was designed from different available resources at the campus. Potential resources that can be added as energy source in the campus is studied as well. Solar PV, Diesel generators, Biomass gasifier, solid waste generators, battery bank, converter and grid were used as the resources in the campus. Two case were taken for study, one with net metering and other without net metering. The optimum case was found to be hybrid system with 100 kW solar, 64 kW from solid waste, 12.5 kW of Biomass generator, 32 kW and 160 kW of existing diesel generators, 10 batteries, convertor of 64 kW and remaining load supplied through the grid connection. With these resources the campus gets its optimized hybrid system. When considering net-metering, the optimized system does not have any significance change in the system, which means that the energy produced are consumed in the campus. No excess energy seems to be sold at the power per unit price of the government. Thus, it is suggested that the campus only needs to increase the solar PV system from 50kW to 100kW and does not need to add any more energy resources at present time. With increasing demand, the campus may add more renewable resources considering technical and economic variables. Also, a case study with no diesel generators running is taken for study, in which 250kW of solar PV system is considered. But it
does not show any significant reduction in O&M cost. Moreover, taking this system leads to adding more batteries, which significantly increases the capital and replacement costs. Renewable energy resources are widely accepted resources and increasing globally. For a large scale organization or industry, it can be a cost cutting strategy and going environmentally green by using hybrid system. This also leads to utilization of locally available resources. Similar model of hybrid energy system can be implemented by other organizations of Nepal and abroad, where resources like solar, biomass, solid waste, wind, etcetera are available abundantly.

References

[1] IEA, "Key World Energy Statistics," 2018.
[2] A. Shrestha et al., "Comparative Study of Different Approaches for Islanding Detection of Distributed Generation Systems," Applied System Innovation, vol. 2, no. 3, p. 25, 2019.
[3] IRENA, "Off-Grid Renewable Energy Solution," 2018.
[4] S. Salehin, M. T. Ferdaous, R. M. Chowdhury, S. S. Shithi, M. B. Roﬁ, and M. A. Mohammed, "Assessment of renewable energy systems combining techno-economic optimization with energy scenario analysis," Energy, vol. 112, pp. 729-741, 2016.
[5] REUTERS. (2018). Hybrid Power Systems Market-Global Statistics. Available: https://www.reuters.com/brandfeatures/venture-capital/article?id=59087
[6] D. Connolly, H. Lund, B. V. Mathiesen, and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," Applied energy, vol. 87, no. 4, pp. 1059-1082, 2010.
[7] F. A. Farret and M. G. Simoes, Integration of alternative sources of energy. John Wiley & Sons, 2006.
[8] S. Sah, A. Shrestha, and A. Papadakis, "Cost Effective and Reliable Energy System for Kathmandu University Complex," in 11th International Conference on Deregulated Engineering Market Issues in South Eastern Europe, Nicosia, Cyprus, 2018.
[9] M. Castaneda, A. Cano, F. Jurado, H. Sanchez, and L. M. Fernandez, "Sizing optimization, dynamic modeling and energy management strategies of a stand-alone PV/hydrogen/battery-based hybrid system," International journal of hydrogen energy, vol. 38, no. 10, pp. 3830-3845, 2013.
[10] AEPC. (2019). Renewables. Available: https://www.aepc.gov.np/
[11] SUN. (2019). Roof Top Solar PV. Available: https://www.facebook.com/saralurja/
[12] S. M. Shrestha, "Status of installed Roof top Solar at Dhulikhel Hospital," ed, 2017.
[13] R. Karki and R. Billinton, "Reliability/cost implications of PV and wind energy utilization in small isolated power systems," IEEE Transactions on Energy Conversion, vol. 16, no. 4, pp. 368-373, 2001.
[14] ADB. (2017, May 29). Nepal's Largest Wind-Solar Hybrid Power System Switched on to Connect a Small Village to the World.
[15] AEPC. (2019). Acheivement.
[16] A. Shrestha et al., "Peer-to-Peer Energy Trading in Micro/Mini-Grids for Local Energy Communities: A Review and Case Study of Nepal," IEEE Access, vol. 7, pp. 131911-131928, 2019.
[17] AEPC. (2019). Biogas-Plant Statistic. Available: https://www.aepc.gov.np/statistic/biogas-plant
[18] KU. (2019, May 26). About Kathmandu University. Available: http://ku.edu.np/university/
[19] A. Shrestha, A. Singh, K. Khanal, and R. Maskey, "Potentiality of off-grid hybrid systems for sustainable power supply at Kathmandu University campus," in 2016 IEEE 6th International Conference on Power Systems (ICPS), 2016, pp. 1-6: IEEE.
[20] NOC. Retail Price of Diesel [Online]. Available: http://noc.org.np/retailprice
[21] N. E. Authority, "Annual Report 2018/19," 2018/19.
[22] S. R. Bhandari, N. Sapkota, A. Wagle, and A. Shrestha, "Assessment of Biomass Energy and Electric Potential from Bio-degradable Waste as a Renewable Source of Energy."
[23] H. C. I. First, W. S. W. T. Do, I. Need, and C. I. G. Off-Grid, "Small Wind Guidebook."
[24] TTL. (2019). Turbine Testing Lab(TTL) Lab Overview. Available: http://ttl.ku.edu.np/lab-overview/

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