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Optimum Sizing of Hybrid Renewable Energy Sources for a Rural Microgrid

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Abstract: *Microgrid are being formed by interconnection of renewable energy sources and thus there is a need to find an optimal solution for the rural electrical demand. The paper presents an optimal solution to form a hybrid microgrid using renewable energy sources like wind turbines, photovoltaic systems and micro hydro power plants. HOMER software is used to get an optimal size and configuration for the site considering the resource availability and cost of components.*

Keywords: *Microgrid, hybrid, renewable energy sources, HOMER, optimization*

I. Introduction

With growth of electrical load demand the need of larger power sources has increased in the rural comunities of developing countries which are out of reah of the national grid. Diesel generators or renewable energy sources like wind turbines (WT), photovoltaics (PV), micro hydro power plants (MHP), etc. are being used to fullfill the rural electric demand. The rural parts of Nepal get electrical power mostly from microhydro power plants, solar photovolatic systems and wind turbines [1,2,3,4,5]. There are there are 329849 numbers of solar home systems with total installed capacity of 8.43MWp, 22605 numbers of small solar home systems (>10Wp) with total installed capacity of 113kWp, 2155 numbers of institutional solar PV systems with total installed capacity of 2949.35kWp, and 111 numbers of solar photovoltaic water pumping systems fullfilling the rural electricity demand in Nepal [1]. There are 1287 numbers of MHP with installed capacity of 24.606MW, 1634 numbers of pico hydro power plant with installed capacity of 3.703MW, and 24 numbers of small WT with installed capacity of 26.7kW for rural electrification in Nepal [1].

These small generating sources like wind turbines (WT), photovoltaics (PV), micro hydro power plants (MHP), diesel generators, etc. can be interconnected to form a Microgrids and serve larger rural communitiy loads[2-11]. For developing countries like Nepal where fossil fuels like diesel, petrol, coal etc. are to be imported, clean green renewable energy sources are the major sources for hybrid microgrid[5]. In Nepal there are prospects and possibilities to interconnect these green energy sources like MHP, WT or PV systems to supply a larger electrical load demand of the rural villages[2,3,4,5]. Micrograds are to be formed by optimal sizing of the renewable energy sources and battertries. The cost of the components, the availability of the sizes of the components and the availability of the resources for electricity generation are to be considered to get a optimal solution to form a hybrid microgrid.

II. System Details

The optimum sizing of renewable energy sources is determined using Hybrid Optimization of Multiple Energy Resources (HOMER) simulation tool developed by National Renewable Energy Laboratory (NREL) [6,7]. Depending on the availability of resources, the load requirements and the cost of all the components to be connected in the hybrid microgrid, HOMER indentifies the best options and also helps in analyzing effect of different variables of the resources, system components and costs [6,7].

At various site of rural Nepal there are possibilities of having a renewable energy sources like micro-hydro power (MHP) plant, wind turbine (WT) and photovoltaic (PV) systems. There are many rural sites where sufficient resources of water, wind and solar are available abundantly and can be used for small, local, community based power plants. Thus to select the optimum combination of energy sources for a rural site will all these resources HOMER software has been used. The system under study consists of a micro-hydro power (MHP) plant, wind turbine (WT) and photovoltaic (PV) systems, battery and converter as shown in Fig.1.

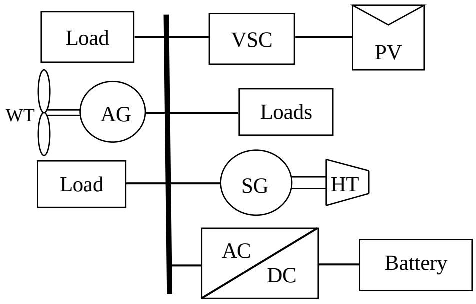
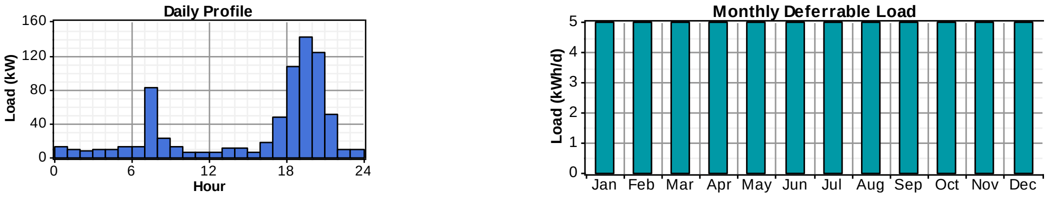


Figure 1 A hybrid microgrid with MHP, PV, Wind turbine, battery bank and converters

2.1 Load Assumptions of the site

The daily electrical load profile of the site is assumed to be as presented in Figure 2 (a). The peak load is 142.48kW and the total energy consumed at the site is 754kWh/day. The daily random variability in the load is assumed to be 15% and the hourly variability is 10%.



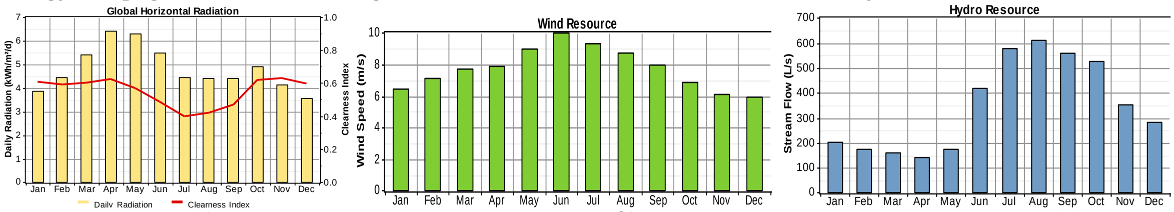
(a) (b)

Figure 2 (a) The daily electrical load profile for the community, (b) Monthly dump load profile

The dump load is assumed to be a constant deferrable load and the monthly dump load profile is depicted in Figure 2 (b). This load is to be activated during the off-peak hours of the primary load profile.

2.2 Resources assumption for the site

The solar, wind and water resources are assumed as per the rural site case in Nepal. Figure 3 (a) presents the solar radiation of the site for one year at a rural site. The data is obtained from the NASA surface meteorology solar energy webpage. The annual average solar radiation of the site is 4.82kWh/m^2/day.



(a) (b) (c)

Figure 3 (a) Solar radiation profile, and (b) Wind speed profile and (c) Water flow profile in a small river, at a rural community in Nepal

The wind speed profile is assumed as recorded at a rural site and is presented in Figure 3 (b). The annual average wind speed of the site is 7.5m/s. One year wind profile is show in Figure 3(b). The monthly water flow profile of the rural site is as shown in Figure 3(c). The water flow is low during March, April and May and high during July, August, September and October. The annual average water flow is 349L/s.

2.3 Size and cost assumptions of the components to be used

The hybrid microgrid is assumed to have a project life of 25 years and the annual interest rest is considered to be 10%. Table I presents system components, their costs and their sizes assumed for optimization using HOMER.

Table I Input data on costs and size

Components	Capital ($)	Replacement ($)	O&M ($/yr)	Life (yrs)	Sizes and number options
PV (kW)	1000	0	0	25	0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300,330, 360, 390, 420, 450, 480, 510, 540, 570, 600, 630, 660
WT (3kW)	3900	3900	50	15	0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300
MHP (161kW)	322000	0	20000	25	140L/s flow rate
Battery	300	300	10	5	strings nos 1,2,4,8,12,16,24, 32, 40, 48, 56, 64, 72, 80, 88, 96, 106, 212, 424, 848,(with 1 string of 10 batteries)
Converter (kW)	145	145	0	5	1, 2,4, 8, 16, 32, 64, 128, 156, 312, 624

III. Optimization using HOMER

The optimization of the hybrid microgrid presents six cases for comparison. Case-I considers PV and battery based system, Case-II considers WT and battery based system, Case-III considers WT, MHP and batter based system, Case-IV considers MHP, PV and battery based system, Case-V considers PV, WT and battery based system, and Case-VI considers MHP, PV, WT and battery based system. All these six cases are depicted in Figure 4.

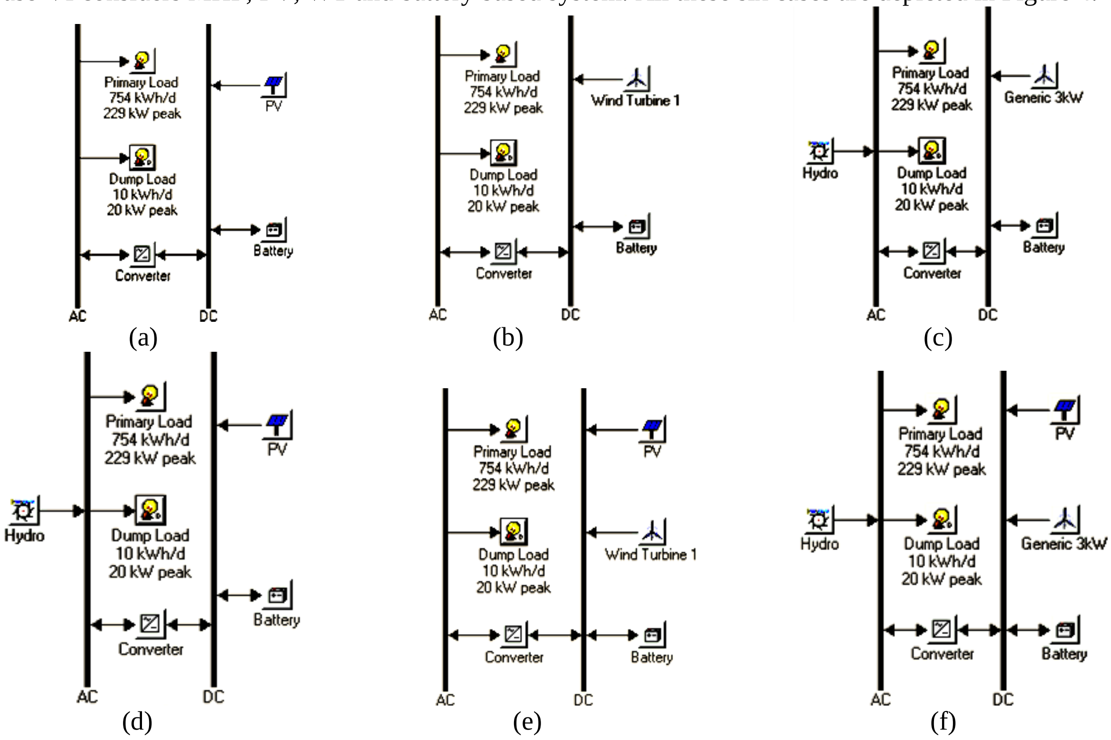


Figure 4 (a) Case-I: PV and battery system, (b) Case-II: WT and battery system, (c) Case-III: MHP, WT and battery system, (d) Case-IV: MHP, PV and battery system, (e) Case-V: PV, WT and battery system, (f) Case-VI: MHP, PV, WT and battery system

IV. Results and Discussions

As per the six different cases stated in section-3, optimization is done using the HOMER software and the results are compared. The details of the optimal microgrid plans for all the six cases are given in Table II. As seen in Table II for case-1 630kW of PV and 880 numbers of battery are selected, for case-2 540kW wind turbines and 880 numbers of battery are selected, for case-3 161kW of MHP, 180kW of WT and 640 numbers of battery are selected, for case-4 161kW of MHP, 300kW of PV and 480 numbers of battery are selected, for case-5 360kW of PV, 60kW of WT and 640 numbers of battery are selected, and for case-6 150kW of PV, 60kW of WT, 161kW of MHP and 400 numbers of battery are selected.

Table II Optimal microgrid plan for the six cases

Components	**Case-1**	**Case-2**	**Case-3**	**Case-4**	**Case-5**	**Case-6**
PV (kW)	630	0	0	300	360	150
Battery (strings numbers)	880	880	640	480	640	400
WT (kW)	0	540	180	0	60	60
MHP (kW)	0	0	161	161	0	161

4.1 Cost Comparisons

Table III shows that for the existing load the most economical option is case-5 with PV, WT and battery. Case-2 with WT and battery is the most expensive option for the site. Figure 5 presents the cost components for all the six cases. In case-1 the cost of battery and PV are almost same, for case-2 the cost of wind turbine and battery are almost equal. For case-3 the cost off MHP and battery are almost equal while that of wind turbine are almost half of the two costs. For case-4 the cost of the MHP is the highest while for case-5 the cost of the battery is highest. For case-6 the cost of MHP is the highest and is followed by the cost of the battery.

Table III Comparisons of costs for the six cases

Items	**Case-1**	**Case-2**	**Case-3**	**Case-4**	**Case-5**	**Case-6**
Total net present cost ($)	1,450,353	1,750,503	1,439,755	1,300,246	1,089,514	1,188,866
Levelized cost of energy ($/kWh)	0.573	0.692	0.569	0.514	0.431	0.47
Operating cost ($/year)	56,308	81,443	71,225	53,873	45,640	52,178

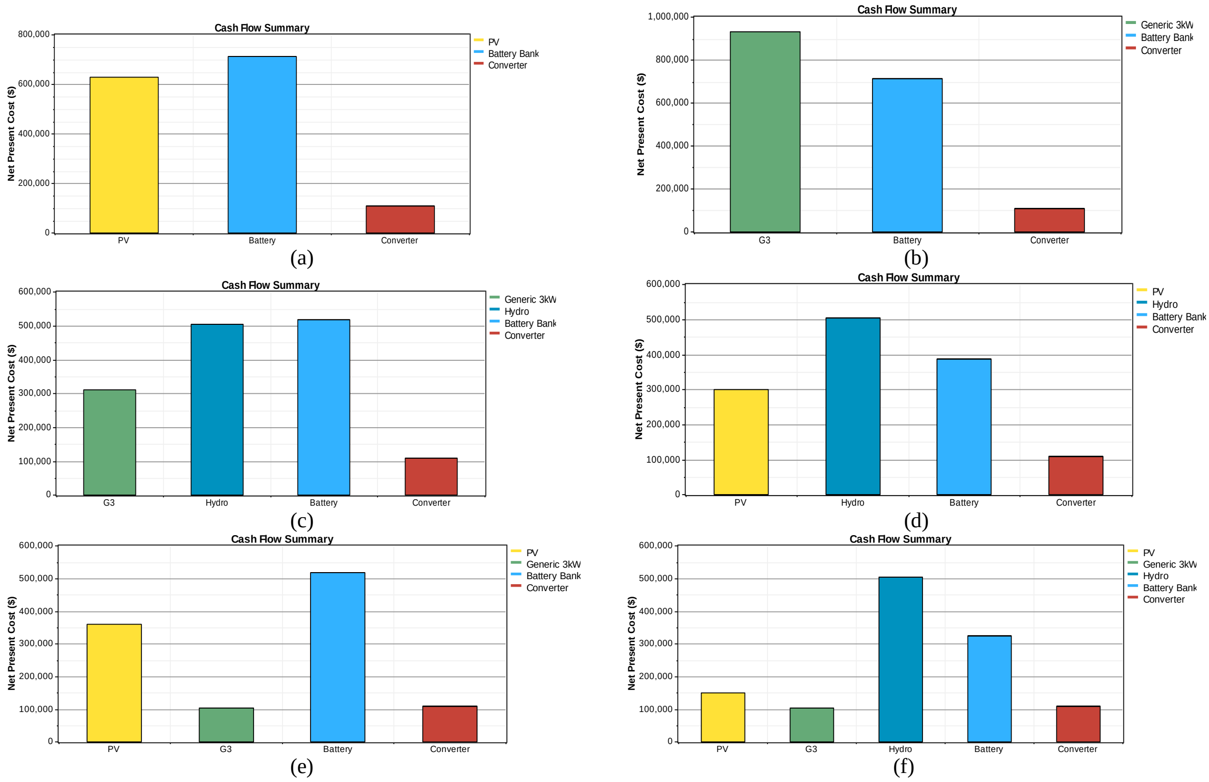


Figure 5 Cost components for (a) case-1, (b) case-2, (c) case-3, (d) case-4, (e) case-5, and (f) case-6

Fiigure-6 presents the annual cash flow for all the six cases. For case-2 the replacement cost is higher than the capital cost of the system. For all other case the capital cost is higher followed by the replacement cost which is distributed periodically throughout the system life span.

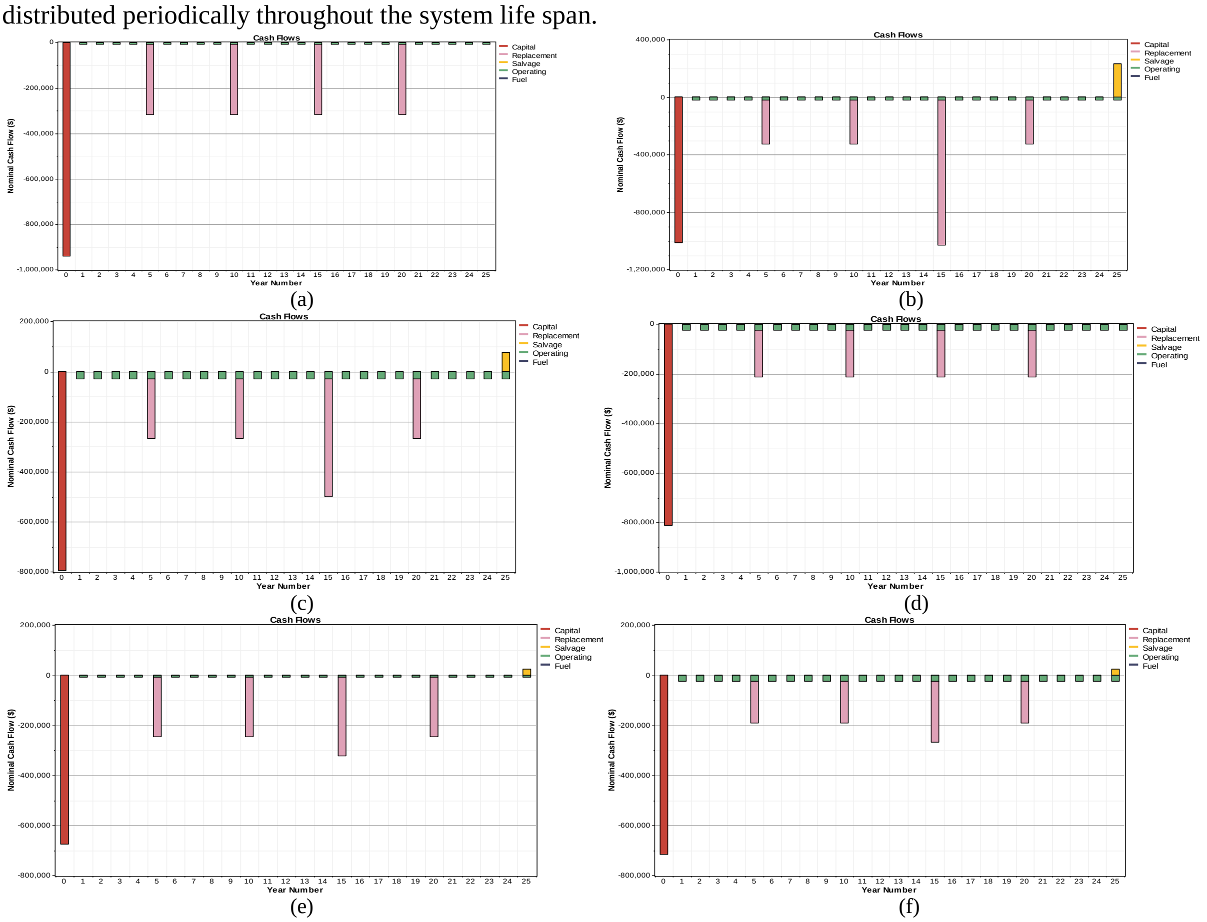


Figure 6 Cash flow for (a) case-1, (b) case-2, (c) case-3, (d) case-4, (e) case-5, and (f) case-6

4.2 Comparison of electric production

Figure 7 presents the monthly average power production for all the six cases. For case-1 the total production is from PV and for case-2 all is from wind turbine. For case-3 and case-4 the major proportion of electricity production is from MHP. For case-5 PV has a larger contribution than WT and for case-6 MHP is the highest power producer PV and WT are very less compared to MHP.

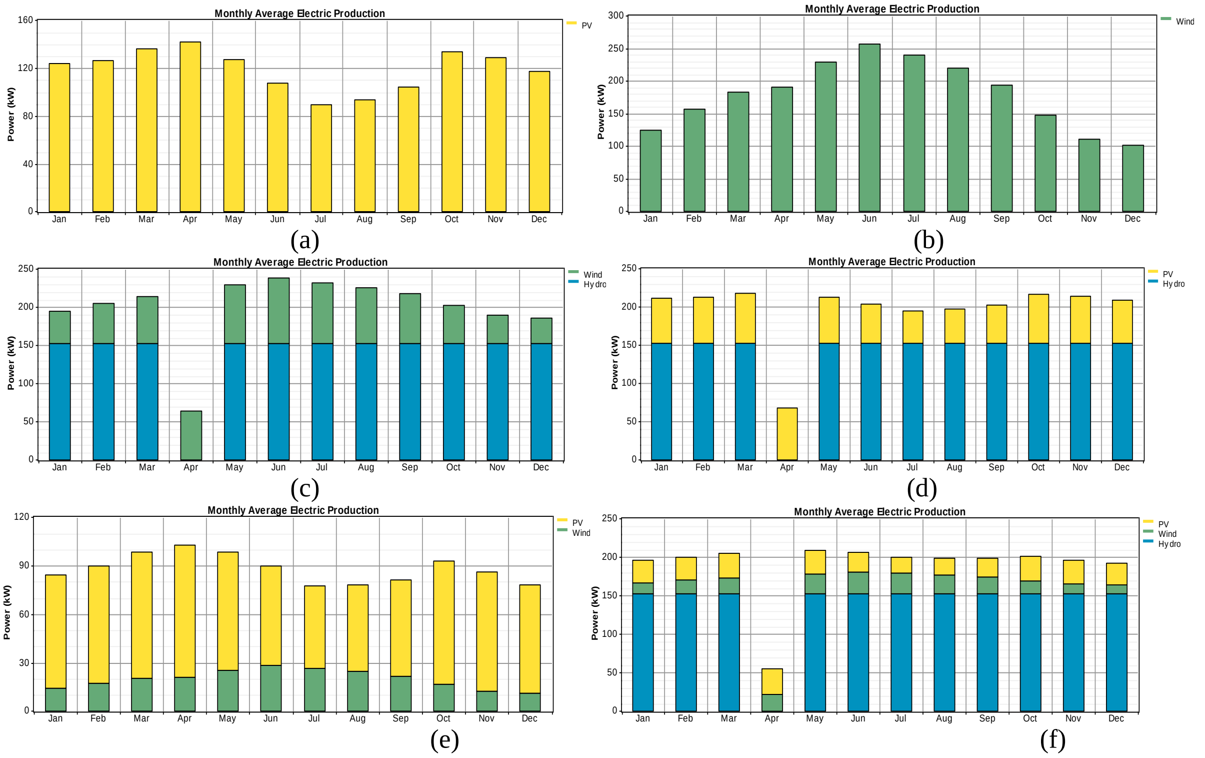


Figure 7 Cash flow for (a) case-1, (b) case-2, (c) case-3, (d) case-4, (e) case-5, and (f) case-6

V. Conclusion

This paper presents an optimal sizing and comparative study of different configurations of hybrid microgrids using renewable energy sources like photovoltaic, wind turbine and micro hydro power plant. HOMER software has been used to find the optimal sizing of components in the different configuration. The simulation results depicts that the Net Present Cost of system of case-5 with PV and WT and battery is very less and is the most economical for the site. The paper presented the analysis for the optimal solution of a hybrid microgrid for a rural site.

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