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OPTIMUM USE OF RENEWABLE ENERGY RESOURCES TO GENERATE ELECTRICITY VIA HYBRID SYSTEM

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ABSTRACT

The necessity of hybrid energy system is gaining more importance day by day as it incorporates two or more than two renewable energy resources that when integrated overcome limitations inherent in either. Hybrid energy system has been seen as an excellent solution for electrification of rural place where the grid extension is difficult and economically not feasible. Such system may consist of several renewable resources such as solar PV, wind, biomass, micro-hydro, geothermal and other conventional generator for back-up where the deficiency of one system can be compensated by others. This paper depicts the different system components and their optimal combination for the efficient generation of electrical energy exploiting locally available resources. The model discussed in paper compromises of micro-hydro, solar PV and biomass for the rural village in Nepal known as Kalikhola which is used as a case study. The optimized hybrid system shows a unit cost of $0.088/KWh which is obtained after the simulation considering contribution of individual renewable resources participating in the system.

Keywords: Renewable Energy Resources, Hybrid system, Micro-hydro, Solar PV, Biomass, Renewable Energy Technologies, Electrification.

INTRODUCTION

Nepal is not rich in fossil fuel resources but it has plenty of renewable energy resources, in particular water that is running down from the vast Himalayan mountain ranges in over 6,000 rivers. With 300 sunny days a year, the sun's freely available solar energy can also be converted into electricity. Nepal is presently facing an energy crisis of unprecedented proportions. The 706 MW total installed capacity of Nepal Electricity Authority, supplemented by net purchases from India, is inadequate to meet demand [1]. Load shedding has thus become the rule of the day. In this context renewable energy development continues to be a high priority program of government as it provides a least cost solution to remote, sparsely populated areas unviable considered for the hybrid system. A case study was done in Kalikhola of Nepal. The main task is to find the suitable being component size and operation strategy for system which results would lead to the design and planning of optimal hybrid energy system. The compulsion to access electricity via national grid at higher cost due to geographical structure would be eliminated by the establishment of hybrid systems where people of such region can experience a reliable, affordable and continual supply of power by exploiting the locally available renewable resources. Nepal Electricity Authority is only the organization responsible for the generation, transmission and distribution of electrical energy in Nepal. The major of population in Nepal are deprived of electricity only due to their geographical locations where the extension of national grid line is economically not feasible, thus dependence upon traditional sources of energy has been a compulsion to fulfill energy needs. The current energy crisis in Nepal clearly indicates that the future energy- demand cannot be met by traditional energy-sources. In coming years it would be a necessity as well as requirement to switch from conventional sources to renewable energy resources to fulfill the energy demand.

Table 1: Composition of NEA's Installed Capacity [2]

Source	**MW**	**% of Total**
Major Hydro (NEA) - grid connected	472.99	67.0
Small hydro (NEA) – isolated	4.54	0.7
Total hydro (NEA)	**477.53**	**67.7**
Hydro (IPP)	174.53	24.7
Total hydro (Nepal)	**652.06**	**92.4**
Thermal (NEA)	53.41	7.6
Solar (NEA)	0.10	0.0
Total capacity including private and others	**705.57**	**100.0**

This paper attempts to develop the general model to find an optimal hybrid system combination of renewable energy resources for rural village ensuring the reliability of power supply. Micro-hydro, Solar PV and biomass with battery and converter are considered for the hybrid system. A case study was done in Kalikhola of Nepal. The main task is to find the suitable component size and operation strategy for system which results would lead to the design and planning of optimal hybrid energy system.

MATERIALS AND METHODS

The individual scheme participating in the hybrid system depending upon the availability can be integrated into various renewable combinations of micro-hydro, solar PV and biomass for the required output of electrical energy. In general, there can be 2^n-1 combinations where 'n' represents the number of available renewable energy resources [3]. The parallel configuration of these individual schemes in hybrid system in used in this approach with the battery and converters for additional back-up especially for the output from solar panels. Flexibility, efficiency, reliability and economics are the factors held responsible for selecting the most optimum hybrid system combination of the proposed site. Depending upon the coast comparison of each hybrid system combinations obtained from the simulation the most economical system will be selected which also ensures the continuity of power supply to the locality. Basic power modules considered for rural community in Kalikhola are micro-hydro, solar PV and biomass with battery and converter for additional backup during the period of night.

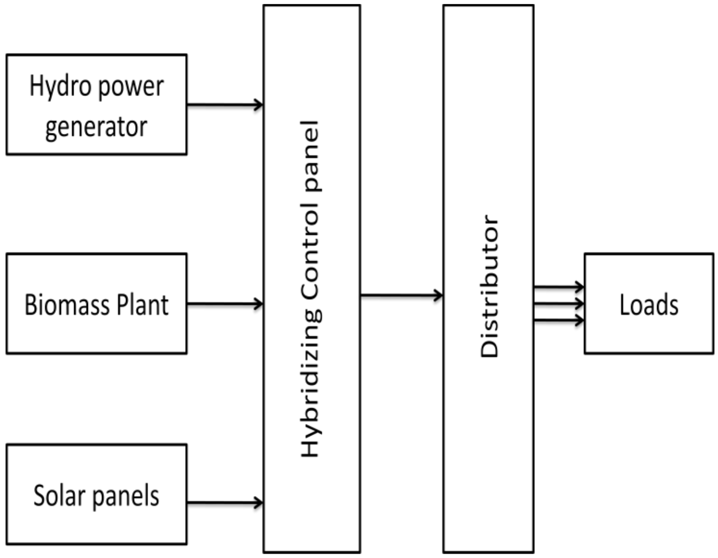

Figure 1 Block diagram of a proposed hydro/Solar PV/biomass hybrid energy system.

HYBRID ENERGY SYSTEM

The design of a optimal hybrid system is complex as the renewable energy supplies are not fixed it fluctuates depending upon the seasonal and geographical factor. The fixed output from each scheme participating in system is not uniform. The call for optimized hybrid system while guaranteeing reliable operation is dependent upon component size and its characteristics with the optimal operation strategy.

Optimal Sizing

Repeated number of numerical iteration is carried out to find the optimal system. Availability of timely energy, load-demand curve, operating cycle of units are the criteria for optimized system. The energy density of micro-hydro is very much greater than that of solar PV and biomass thus the number of PV modules and biomass generator capacity are incremented step by step until the desired system is achieved. The entire procedure is repeated for all seven combinations and the system with higher reliability and lowest cost of energy per unit (KWh) is chosen as the optimal hybrid system. The minimum total capital cost C_c for the micro hydro-solar PV-biomass is given as,

$$C_c = \sum_{h=1}^{N_h} C_h + \sum_{s=1}^{N_s} C_S + \sum_{b=1}^{N_b} C_b + \sum_{bt=1}^{N_{bt}} C_{bt} + \sum_{c0=1}^{N_{co}} C_{co} \quad (1)$$

Where N_h, N_s, N_b, N_{bt}, N_{co} are the total of micro-hydro, solar PV, biomass, battery, converter units respectively and C_h, C_s, C_b, C_{bt}, C_{co} are corresponding capital costs respectively.
The electrical power generated by micro-hydro unit with design flow rate of 570 l/s with head of 4m is given by,

$$P_{hyd} = \eta \rho g Q H \quad (2)$$

Where η, ρ, g, Q, H represents efficiency, density of water, gravity, flow rate and head respectively.
The hourly output of solar PV array is,

$$P_{pv} = \eta_{pv} * N_{pvp*} N_{pvs} * V_{pv} * I_{pv} \quad (3)$$

Where η_{pv} represents conversion efficiency of PV module, V_{pv} the module operating voltage, I_{pv} the module operating current and $N_{pvp,}$ N_{pvs}represents the number of parallel and series connected solar cells.

The use of biomass generator in the hybrid system ensures the reliable operation in case of failure of any other scheme or the decrease in output density from other scheme than biomass participating in the system. For an interval the rate of fuel F, consumed by biomass generator producing power P is given by,

$$F= aP^2+bP+c \tag{4}$$

Where a, b and c are coefficients for generator.

The fuels consumed by biomass generator are mainly agricultural waste, firewood, animal manure, cattle dung, human waste etc.The state of charge of battery can be calculated from the following equations[4],
Battery discharging,

$$P_b(t)= P_b(t-1)*(1-\sigma)-(P_h(t)/ \eta_i-P_l(t)) \tag{5}$$

Battery charging,

$$P_b(t)= P_b(t-1)*(1-\sigma)+(P_h(t) -P_l(t) / \eta_i)*\eta_b \tag{6}$$

Where $P_b(t-1)$, $P_b(t)$ the battery energy at beginning and end of the interval t, $P_l(t)$ the load demand at time t, $P_h(t)$ total energy generated by PV array, σ the self discharge factor, η_i, η_b the inverter and battery efficiency obtained from the manufacturers data. Thus the total power generated from hybrid system at any time t is,

$$P(t) = \sum_{h=1}^{N_h} P_h+\sum_{s=1}^{N_s} P_s + \sum_{b=1}^{N_b} P_b \tag{7}$$

Optimal Operation

The operation of hybrid system signifying the most economical, reliable, efficient parameters would be chosen as the strategy for the required operation of modeled hybrid system. It is important that the chosen operating actions are beneficial to the systems in its long-term performance and long-term cost efficiency [5]. A very good short-term operating decision might not be optimal in the long-term perspective of achieving low cost and satisfying system performance. Different operation strategies can be implemented upon the various combinations. The energy stored in battery can be utilized during the time of night ensuring the optimal operation of system. The goal of optimal operation is to minimize cost and operating a system to yield best possible system performance where performance and cost are interlinked by each other. This is due to the fact that the sizing of components is related to the operation strategy adopted for the system.

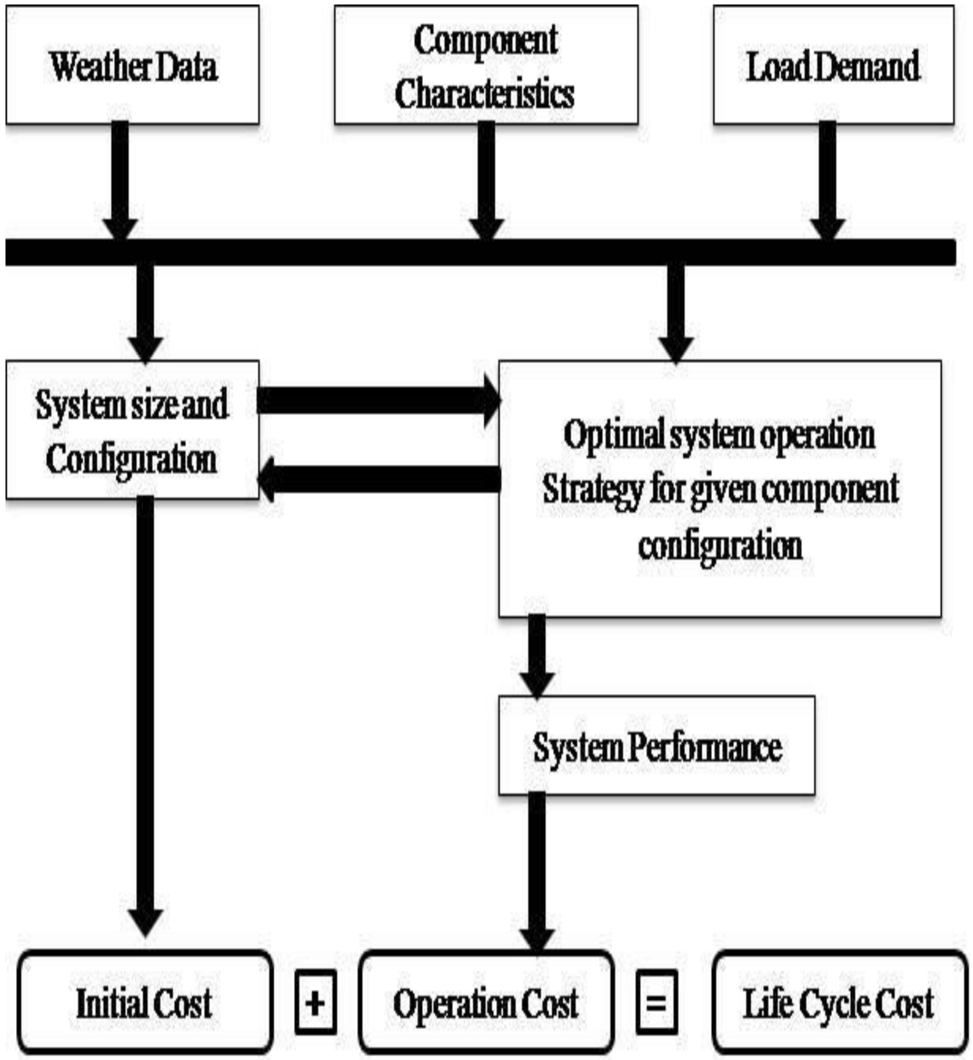

Figure 2 Interdependence between system sizing and operation [6]

Total annualized life cycle cost of system considering both capital and operating cost is given by,

$$C_{annual} = (C_c R + C_o) \quad (8)$$

Unit cost of electricity for hybrid system is,

$$C_{coe} = \frac{C_{annual}}{E} \quad (9)$$

Where E is the load served in KWh/yr and R is the capital recovery factor for the system.
The procedure for finding the optimal hybrid system is given in Figure 3 where the operation of hybrid system is shown consisting of micro-hydro, Solar PV and biomass with possibilities of different combination of hybrid operation results in the most economical and higher performance system ensuring the reliability.

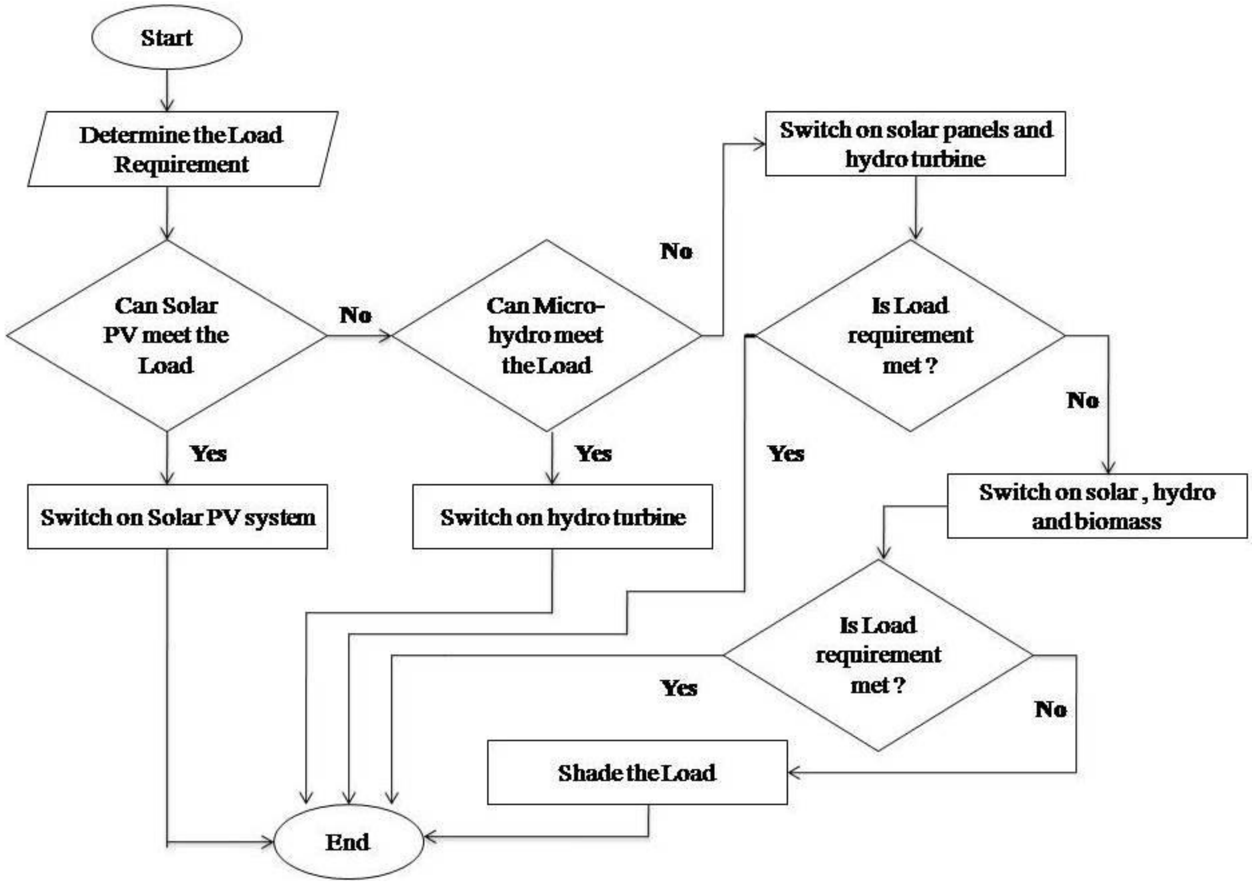

Figure 3 Flowchart to find optimal hybrid system

CASE STUDY

The thesis work is based on a typical farming village situated in Middle Hilly region located in Udayapur district of Nepal. It is about 15km away from the nearest local town known as Gaighat and distance to the existing grid line is around 7km. It is expensive and complex to extend the grid due to hilly terrain nature of landscape. The village has 57 families with a population of over 350. As the maximum population of this village depends on farming for their livelihood their economical background is not so sound. Thus many of them does not have any access to electricity but roughly about 25% of people partially fulfills their electricity needs by the means of individually installed solar panels although it does not provide the reliable means of supply of electricity since it depends upon the sun hours and a day. About 75% people are deprived of electricity. The principal demand for electricity is lighting, heating (in winter) and for entertainment purpose (radio and television). In this study we estimated the electricity need for each family as approximately 375Watt peak where it includes five fluorescent lamp each having rating of 20W, three fan having rating of 60W, a radio set having rating of 35W and a television having rating of 40W. Thus in total there is necessity of continuous supply of power about 20.235KW.

Proposed Scheme

Even though the potential of renewable sources are high, the application of renewable generators as standalone units will not be sufficient to provide a continuous power supply due to seasonal and non-linear variation of renewable resources. To ensure a balance and stable power output, different renewable generators might be installed and integrated to form a hybrid energy system. An optimal combination of a decentralized hybrid energy system will eliminate the resource fluctuations, increase overall energy output and reduce energy storage. The design flow for the micro-hydro scheme is 570 l/s. The lowest recorded flow measured is 432 l/s. The average daily solar radiation based on annual measurement is 4.68626Kw/m^2 /day with average sunshine hour of 5.8hours/day of about 300 days of sun a year is available in this region.

From the load profile of the village given in Figure 4, total electrical energy required is 119KWh/day with 15.8KW peak demand.

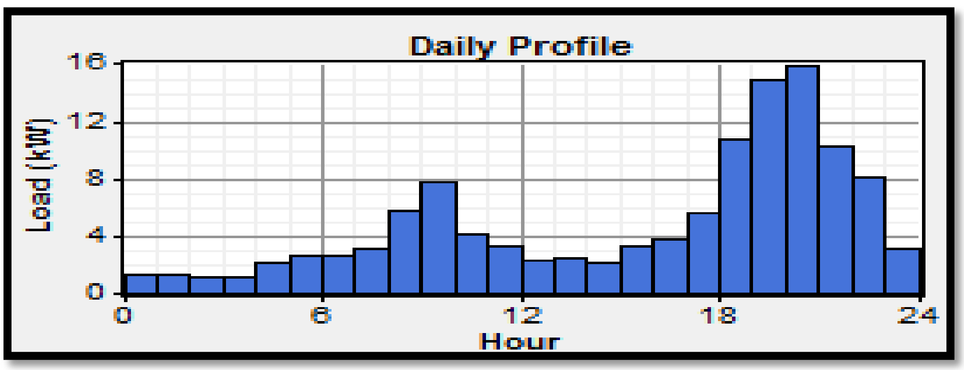

Figure 4 Daily load profile of the village

The micro-hydro scheme participating in the hybrid system is modeled to give output of 17.89KW, solar PV contributes 3KW to the hybrid system for which 24 panels are used each of 125W$_p$ thereby producing7KWh energy from the solar panels, biomass generator accounts for 5KW in hybrid system, battery was used for the storage purpose with nominal capacity of 1900Ah with nominal voltage of 4V having maximum charge current of 67.5A, also converter was used for the conversion of dc output of solar panels to ac output since only the ac loads are considered for the proposed hybrid system.

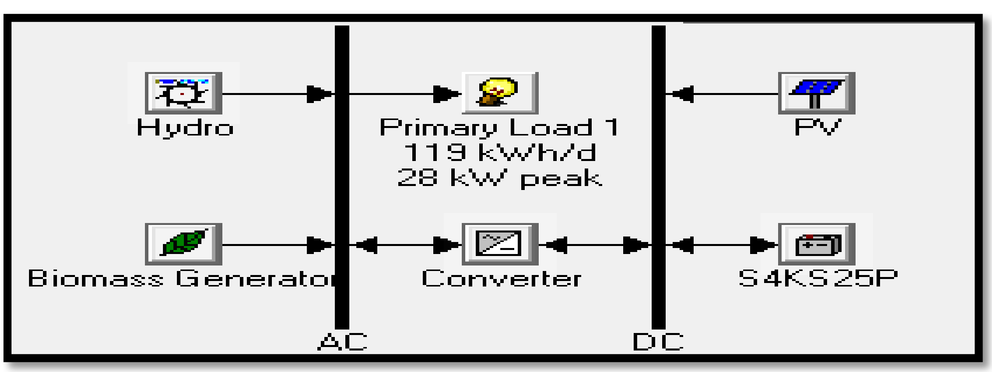

Figure 5 Proposed hybrid system

RESULTS AND DISCUSSION

Three renewable energy resources are considered for the hybrid system where after different results obtained from iteration of each possible combination, the optimum result compromising of all three individual schemes was selected. The solar PV system contributes 3% to hybrid system with rated capacity of 3KW having maximum and minimum output of 2.99KW and 0KW respectively. The electrical production of solar PV system is 4518KWh/yr operating 4383 hour per year. The levelized cost for solar PV scheme is 0.0640$/KWh.

The micro-hydro system contributes 96% to the hybrid system with rated capacity of 17.9KW having maximum and minimum output of 15.8KW and 12.2KW respectively. The electrical production of micro-hydro system is 131348KWh/yr operating 8760 hour per year. The levelized cost for micro-hydro system is $0.00917/KWh. The biomass system contributes 1% to hybrid system with rated capacity of 5KW having maximum and minimum output of 4.5KW and 1.35KW respectively. The electrical production of biomass system is 972KWh/yr operating 337 hour per year. The levelized cost for the biomass system is $0.0654/KWh.

Thus, the hybrid system integrating all of the individual system has rated capacity of 23KW with maximum and minimum output of 23KW and 13.55KW respectively. The total electrical production of the hybrid system is 136839KWh/yr operating for 8760 hour per year. The cost of energy obtained from the hybrid system is $0.088/KWh. The proposed hybrid system can supply the entire village population 24 hour reliable power supplies throughout the year. The monthly average electric production from hybrid system is given in Figure 6

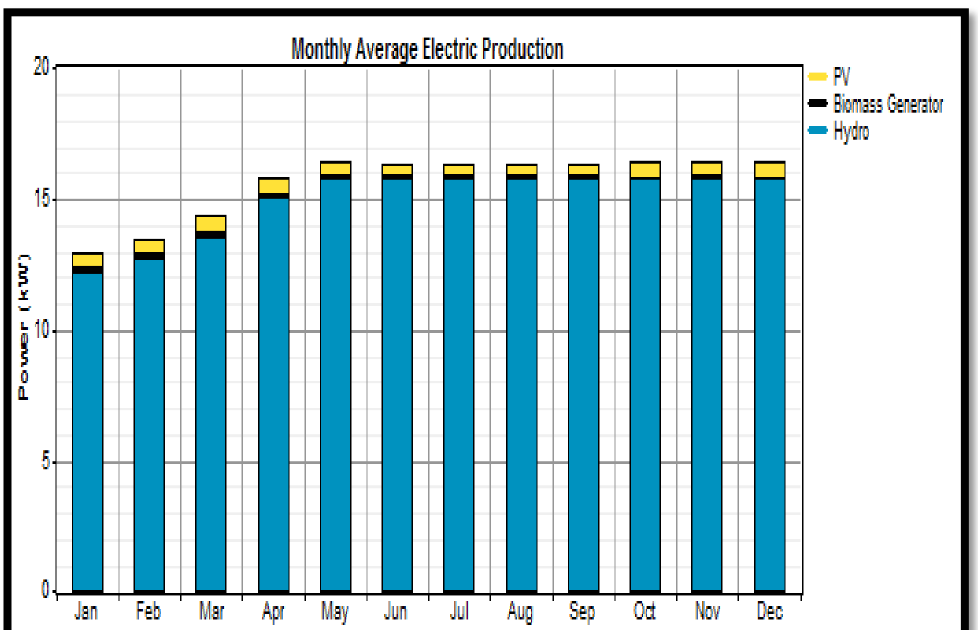

Figure 6 Monthly average electric production of Hybrid System

The contribution of individual system participating in hybrid system is shown in Figure 7.

Production	kWh/yr	%
PV array	4,518	3
Hydro turbine	131,348	96
Biomass Generator	972	1
Total	136,839	100

Figure 7 Production of energy by individual scheme in hybrid system

The biomass generator mainly operates during the period of night where day light is not available and solar PV is out of the system although the battery is used as the storage device to store excess energy which can be utilized later. The micro-hydro operates continuously throughout the year hence it is considered as the base load which accounts for the major portion of hybrid system. The output of each system of hybrid configuration for various months throughout the year during different time period is shown in Figure 8.

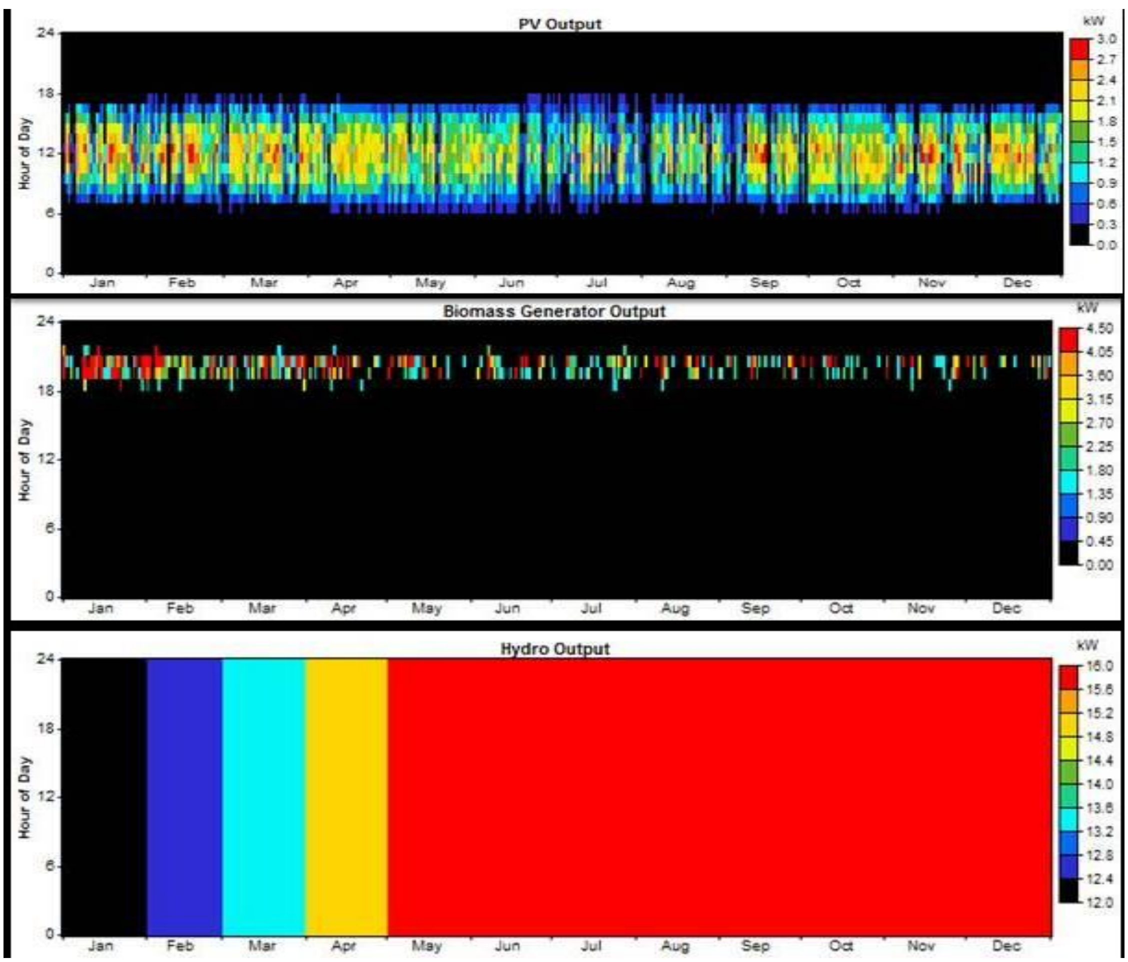

Figure 8 Output of Solar PV, Biomass and Micro-hydro

CONCLUSION AND FURUREWORK

Hybrid energy system is an excellent solution for electrification of remote rural areas like Kalikhola where the grid extension is difficult and not economical. The compulsion to access electricity via national grid at higher cost due to geographical structure would be eliminated by the establishment of hybrid systems where people of such region can experience a reliable, affordable and continual supply of power by exploiting the locally available renewable resources. HOMER Micro power Optimization Model provides the easy way to design the hybrid power system. The hybrid system with battery backup provides 24 hour electric supply to every household of the village at unit cost of $0.088/KWh. The total renewable energy fraction for the hybrid system is 100% which also eliminates the need of any conventional diesel generator. In future, we would like to work on implementation of hybrid system in Kalikhola based on the results obtained from simulation if funding is available for the project. Furthermore, most of the region in Nepal is deprived of electricity only due to their geographical structure. Thus, we would like to encourage every rural community of remote hilly places to exploit their own renewable resources so that the practice can be developed among the community to fulfill their energy needs by their own locally available resources.

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REFERENCES

[1] Annual Report of 2004 of Ministry of Population and Environment, Govt. of Nepal.

[2] Nepal Electricity Authority, Kathmandu, Nepal "*Annual Report 2009-2010*"

[3] S Ashok, "Optimized model for community based hybrid system", Renewable Energy 32(2007) 1155.

[4] Elhadidy MA, Shahid SM, "*Optimum sizing of battery storage for hybrid (wind+diesel)",* Renewable Energy;18(1)(1999)77.

[5] Kruangpradit P, Tayati W, "*Hybrid renewable energy system development in Thailand*", Renewable Energy 8(1-4) (1996;)514.

[6] Gabriele Seeling- Hochmuth, "*Optimization of hybrid energy systems sizing and operation control*", A dissertation presented to the University of Kassel in Candidacy for the degree of Dr.-Ing, October 1998.