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Homer based Techno-Economic Comparison of Solar PV, Micro Hydro and Biomass Renewable Energy System with and without Battery Storage

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***Abstract*—**Almost all developing countries are facing severe energy crisis, which is affecting their economy from several years. Most of remote areas have no access or limited access to grid, while grid extension is expensive and time consuming option. Generation from renewable sources at load center is a viable option, but huge investment and intermittency are the main constraints in implementing renewable base projects. By integrating different renewables can minimize cost and enhance reliability of distributed renewable systems. This paper mainly emphasizes on the optimization of hybrid renewable power systems having solar PV, biomass and micro-hydro with and without energy storage for a village in district Mardan, KP, Pakistan using Homer. Solar irradiance data is taken from National Aeronautics and Space Administration (NASA), hydro resource data from local irrigation department and biomass resource data from world bank biomass atlas. We have performed the techno-economic analysis of two different hybrid renewable power systems with unidirectional and bidirectional three phase converters. We have compared net present cost (NPC) and levelized cost of electricity (LCOE) of two models which justifies that system consist of PV, micro-hydro and biomass with battery storage is more economical and reliable.

***Keywords*—** Solar PV, Micro Hydro, Biomass, Net Present Cost, Cost of Electricity, Homer

I. Introduction

Electrical energy is basic need of modern life. Increase in population in developing countries causes high rise in energy demand which directly or indirectly affect both environment and GDP of countries. In Pakistan electrical energy demand is 85.9bn kWh which was 51.5bn kWh in 2000 while total generation from fossil fuels, hydro, nuclear and renewable resources are 61.8%, 31.8%, 3% and 5.7% respectively [1]. Population of Pakistan touches figure of 200 million in 2017 census report in which 51 million people has no access to electricity which includes 10% of urban areas and 37% of rural areas of country [2]. Using conventional sources for generation of power required imported fuels which would increase the import prices as import and export are linked with GDP ultimately GDP will shrink while using renewable sources for power generation decreases imports and as a result GDP increases [5]. Global warming and depletion of fossil fuels are some other issues related to use of conventional sources. A healthy solution to tackle the problem of global warming and depletion of fossil fuel is use of renewable resources [6]. Geographically southern part of country is blessed with good wind speed and massive solar energy potential, center being an agriculture part of country has high potential of biomass and solar while northern areas are blessed with tremendous hydro potential. To overcome energy crisis and attract investors to invest in renewable energies different surveys and assessments are done. To assess the technical potential of renewable energies in Pakistan study was carried out in [3] which showed that estimated solar potential was 149GW, energy generation from wind has capacity 13 GW, potential from biomass was 5GW in 2010. Potential of 41.7GW power from hydro resources are available [4]. To electrify rural areas where there is no or limited access to grid, distributed generation using renewable sources is a suitable option if its inconsistent nature and high cost issues are overcome.

Numerous hybrid renewable systems are proposed by researchers to decrease cost of the system and overcome unpredictable nature of renewables using different modelling and optimization tools. Hybrid2, iHOGA, RETScreen, HOMER and sixteen other software tools are discussed in [7] in which Homer is selected as a user friendly and fast processing widely used software for pre-feasibility studies of hybrid renewable energy projects. A study for residential buildings in Saudi Arabia is done in [8] using Homer for modelling a wind-diesel hybrid system for 3512 MWh annual load demand and comparing its cost & carbon emissions with stand-alone diesel generating system. For electrification of remote areas in Ethiopia feasibility study of a hybrid system consist of PV, wind and fuel cell is carried out in [9] using Homer software and its results are compared with previously studied model's (PV, wind and genset) cost and carbon emissions. A control system is designed for PV and battery energy storage system using MATLAB to reduce peak load shaving of underwater tunnel in Canada and further simulated in Homer to find the economic benefits of this control design [10]. To electrify a remote village of Karnataka, India, a hybrid

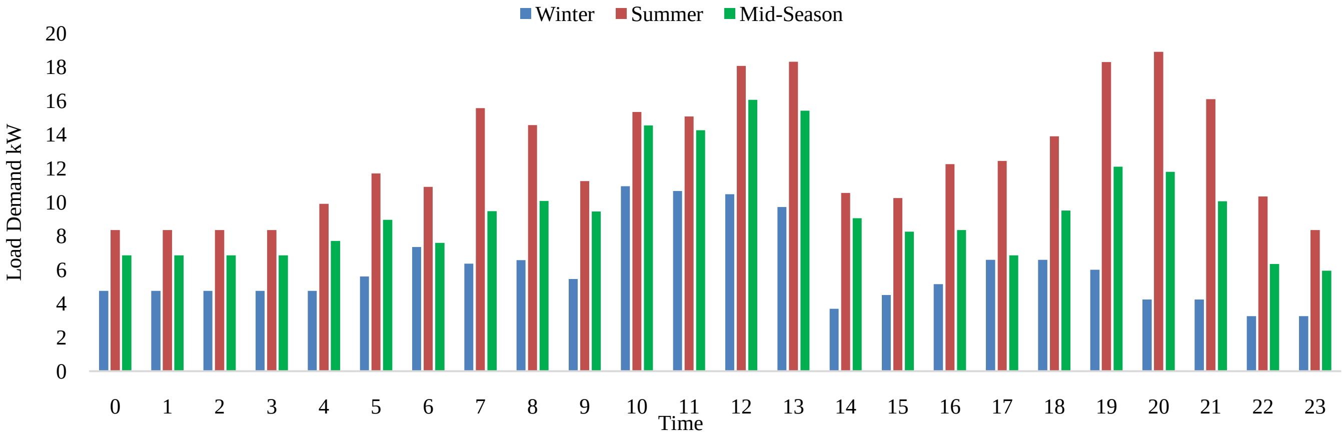


Figure 1. Seasonal Daily Load Profile

power system consists of solar, wind and diesel is simulated in [11] to find the impact of intermittent variables on renewable energy system and propose an optimum design to provide electrical energy at low cost. A hybrid energy system comprising of PV, wind, diesel and battery is simulated in [12] to find optimized models for electrification of commercial, public and residential buildings under diverse climatic environments of Iran. Six different cities of Turkey (Karaman, Kirklareli, Sinop, Konya, Gelibolu and Belen) were selected in [13] to find levelized cost of electricity of grid connected and stand-alone PV system, designed for 2500 kWh annual energy demand, which shows that grid connected PV system is more economical than stand-alone off grid system. A hybrid energy system consist of solar PV, battery and biodiesel was designed in [14] for newly established university in North of Ghana and its price was compared with grid prices using Homer, results in simulation showed that price per unit of electricity from hybrid system is 2% less than grid electricity prices. Socio-economic benefits and potential of hybrid PV, wind, diesel and battery system was designed in [15] for a community of peak demand=51.52kW and daily energy demand=242.56kWh, in northern region of Bangladesh using Homer. An optimized and economical design for electrification of residential community and agriculture farm of small village of district Layyah, Pakistan, using hybrid energy source biomass and PV was proposed in [16], Homer simulated results showed that the combination of 12kW convertor, 32 batteries, 8 kW biogas generator and 10 kW PV modules was optimized solution.

Literature review shows that Homer is recently widely used for modelling and optimization of hybrid renewable energy system. For pre-feasibility studies and economic analysis, it is preferred. Available renewable energy generators in Homer are hydro-turbines, solar PV, wind turbines, fuel cells and biomass generators. Energy storages available in Homer are batteries and hydrogen tanks while loads are primary and deferrable load (AC or DC). This tool is enough smart to recognize the appropriate timings of power supplied to the loads and when the generator should be functioned and when the batteries get charged.

II. Proposed Location

A small remote village of tehsil Dargai, Malakand agency of Khyber Pakhtunkhwa (KP) province is selected for this study. Geography of location is 71.54° east longitudes and 34.27° north latitudes. Locals are farmers by profession as land of this area is agriculture land and sources of irrigation are canals of river Swat. This area being in north of country is blessed with hydro, solar and biomass potential. Majority of rural areas of Pakistan are facing worst load shedding i.e. 18 to 22 hours because of gap between demand and supply, line losses and electricity theft issues. 37% of rural areas of country have no access to national grid. To electrify these areas distributed generations at load center is feasible solution.

III. Methodology:

This section describes the procedure implemented throughout this study. An investigation was done to asses the load of diverse consumers of selected area by visiting locals. Resource potential of different renewable energy resources were collected from different sources. HOMER Pro software is used to do the techno-economic comparison of two different models.

A. Load Assessment:

To model an electrical system for any area, it is recommended to find load demand of that area in first step. For this purpose, a survey was done and load demand of area was found by visiting twenty houses, a mosque and a primary school. Questions asked during survey were about water pumps, lights, fans, PCs and television etc. Questions about fans, water pumps and television usage timings were asked during load survey. One 6kW flour mill machine (industrial load) is also added in load profile which operates daily from 10:00 a.m to 02:00 p.m. Keeping in mind the climatic conditions of the selected area, load profile for three different seasons i.e. summer, mid-season and winter, were made as shown in Fig.1. In winters peak load demand is 11kW which occurs in noon time when industrial load is added to the system. In mid season there are two peaks one in noon time which is 16kW which includes industrial load, mosque and residential and other peak of 11kW is noted in evening time which is purely residential load. In summer season there are three peaks, two are because of residential load demand, i.e. in morning (15.5kW) and in evening time (18.9kW) while one is in noon time (18.3kW) which includes 6kW industrial load.

B. Solar Resource Assessment:

Southern and center part of country is blessed with enormous amount of solar potential as Pakistan is in a region with excellent solar insolation. To electrify southern and western deserts and northern hilly areas electrical power can be generated form this solar energy using off-grid and on-grid systems to tackle the crisis of energy in the country. According to NASA surface meteorology and solar energy database, monthly average clearness index is 0.633 and daily average global horizontal radiation is 5.31 kWh/m2/day for the proposed site as shown in Fig. 2.

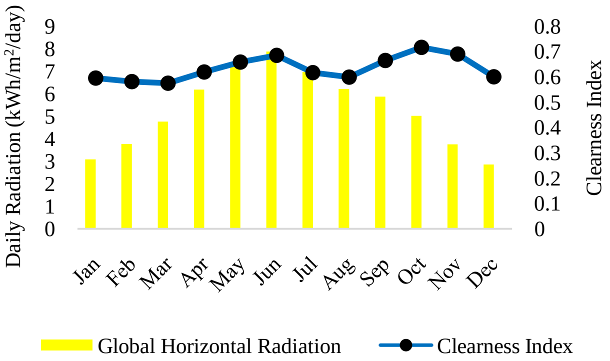


Figure 2. Solar Radiation & Clearness Index Data

The maximum solar radiation is 7.680 kwh/m2/day in month of June and minimum GHI is 2.880kwh/m2/day in month of December. From April to October GHI is higher than 5 kwh/m2/day.

C. Hydro Resource Assessment:

There is massive hydro power potential present in northern part of Pakistan. To meet the growing energy demand, energy can be produced from these hydro resources which include large network of canals with small heads and high stream flow and natural waterfalls in hilly areas. Electric power generation from mini and micro hydro is one of the feasible and economical option for distributed generation. According to Alternate Energy Development Board (AEDB) 128 sites for small micro hydro on natural falls and flow are identified having potential of 0.2 to 32MW with total potential of 750MW only in KP. The average potential hydro at the planned site i.e. at Jalala Disty canal in Dargai, Malakand agency of KP measured is approximately 89 cusecs and available head is 1.2 m. figure shows flow rate of canal for 2013, 2014 and its average.

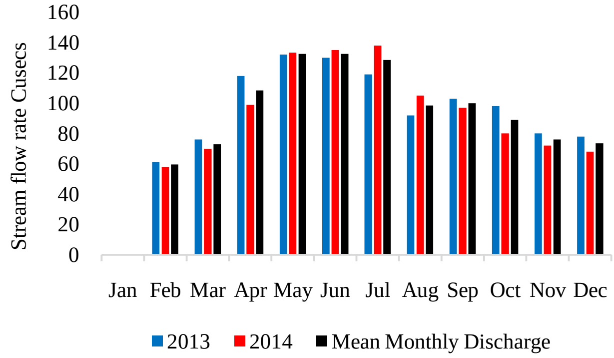


Figure 3. Average Monthly canal flow rate

In month of January every year irrigation department close canals for desilting purpose to improve canals condition and maintain depth of canal. From month of February to June and July canal flow increases when weather changes during winters flow again decreases.

D. Biomass Resource Assessment:

Being an agricultural country Pakistan is blessed with high biomass fuel stock. Energy crisis can be overcome using latest technology to convert biomass in useful fuel for power generation. To fulfill energy demands of a society most of developing countries are showing interest to bio fuels to tackle problem of variation in fuel prices, energy security and global warming associated with conventional fossil fuels. This is a clean source of renewable energy that has positive impact on energy security, economy and environment. As compared to fossil fuels biomass carbon emission is very less. It can be characterized roughly as animal wastes (animal husbandry), crop residues (bagasse, husks, straw and leaves etc.) and domestic wastes (sewage, rubbish and food). Under Energy Sector Management Assistance Program (ESMAP), World bank and AEDB has developed biomass atlas for Pakistan [17]. As our selected site is located at the boarder of district Mardan and Malakand agency therefore biomass potential of both areas is shown in Fig. 4.

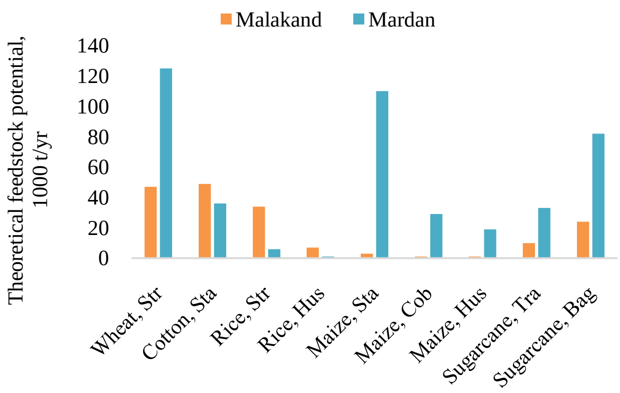


Figure 4. Available Biomass resources

E. Systems Components and Configuration

Hybrid renewable energy systems are more efficient, stable and reliable which practices various resources to attain an economical system and boost the system lifetime. We configure two systems to compare the technical and economic effect of both systems. Solar PV is the first power generating unit in both systems, we put a derating factor of 80% which means that the generation from PV declines by 20% to take in considerations of soiling effect and temperature. The PV module capital cost is 102,500 PKR/kW and operating & maintenance cost is 6000 PKR/year.

Equation (1) is used by Homer to calculate PV array's output power at each time step.

$$P_{pv} = f_{pv} \; Y_{pv} \; \frac{G_T}{G_{T,stc}} [1 + \alpha_p (\; T_c \; - \; T_{stc} \;)] \quad (1)$$

Where,
Ypv = under standard test conditions (STC) output power of PV array i.e. rated capacity (kW)
f_{PV} = derating factor of PV module (%)
G_T = incident solar radiation in current time step over PV array (kW/m^2)
$G_{T,stc}$ = at STC, incident solar radiation ($1kW/m^2$)
α_p = temperature coefficient of power (%/°C)
T_C = in current time step PV cell temperature (°C)
$T_{C,stc}$ = under STC PV cell temperature (25°C)

Next important power source of our hybrid system is micro-hydro in which cross flow turbine and 3 phase synchronous generator with automatic voltage regulator (AVR) is used. As we cannot divert all water towards turbine due some restrictions and rules of irrigation department, turbine is design for 40 cusecs though minimum flow is 60 cusecs. Total initial capital cost of micro-hydro system is 1200,000 PKR and operating & maintenance cost is 80,000 PKR/year. 80% efficiency of complete micro-hydro system is considered.

Equation (2) is used by Homer to calculate output power of micro hydro in each time step

$$P_{hyd} = \frac{\eta_{hyd} \cdot \rho_{water} . Q_{turbine} \cdot g . h_{net}}{1000} (kW) \quad (2)$$

Where,
P_{hyd} = hydro turbine output power (kW)
η_{hyd} = efficiency of hydro turbine (%)
ρ_{water} = water density (1000 kg/m3)
g = gravitational acceleration (9.81 m/s2)
h_{net} = effective head (m)
$Q_{turbine}$ = flow rate of hydro turbine (m3/s)

3rd source in our hybrid system is biomass system, which consist of gasifier and three phase synchronous generator. Gasifier used in this system is downdraft gasifier while three phase generator has AVR and governor to maintain voltage and frequency stability. Initial capital cost of biomass system is 1.3m PKR, operating & maintenance cost is 80 PKR/hr and biomass fuel cost is 6500 PKR/ton. Biomass output power can be find using steam flow rate, while steam flow rate depends on temperature and pressure [18] as shown in (3)

$$P = \frac{F}{5} * 1000(kWh) \quad (3)$$

$$F = 1.841 \left(\frac{C}{K}\right) t/h \quad (4)$$

$$K = \frac{0.00471a + 1.286}{0.0102b + 1.032} - (0.0097 - 0.0000132a) \quad (5)$$

Where,
P = output power of biomass system
F = actual steam flow rate of biomass gasifier
C = the output reading of transmitter flow
a = the temperature reading of transmitter output
b = the pressure reading of the transmitter output

4th component used in our systems is converter. As we have designed two different models, in first model we have used 10kW unidirectional converter (SolaX X-10) as shown in Fig. 5(a). Capital cost of this inverter is 380,000 PKR while operating & maintenance cost is 5000 PKR/year. In second model we have used three 4kW bidirectional converters(Schneider) as shown in Fig. 5(b). This converter is both grid following and grid forming battery dedicated converter whose capital cost is 180,000 PKR while operating & maintenance cost is considered as 2000 PKR per converter in second model.

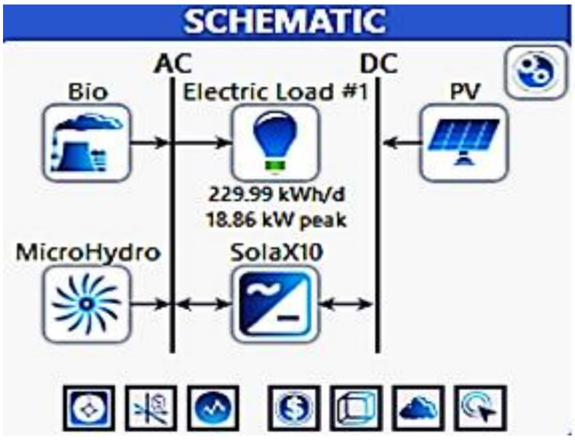
Battery is another important component which we have used in second model to find its economic and technical impact on the system. In this model 12V, 214Ah deep cycle lead acid batteries (Power Sonic) are used whose capital cost is 43000 PKR/battery, replacement cost is 38000 PKR/battery while operating & maintenance cost is 500 PKR/battery/year. Important parameter of battery is state of charge (SoC) of battery which is shown in (6).

$$SoC = \frac{E_{batt}}{C_{batt} \cdot V_{batt}} \quad (6)$$

Where,

SoC = capacity of battery available for further discharging
E_{batt} = Energy capacity of battery (Wh)
C_{batt} = Capacity of battery (Ah)
V_{batt} = rated voltage of a single battery

Other components of the system includes electronic load controller (ELC) which is used to keep the frequency of micro hydro stable, Synch-modules (Deep Sea) for synchronization purpose, energy analyzer (Janitza) to analyze demand and supply of the system, programmable logic control (PLC) unit to take decision about load dispatach and other protection equipments such as breakers and relays etc.



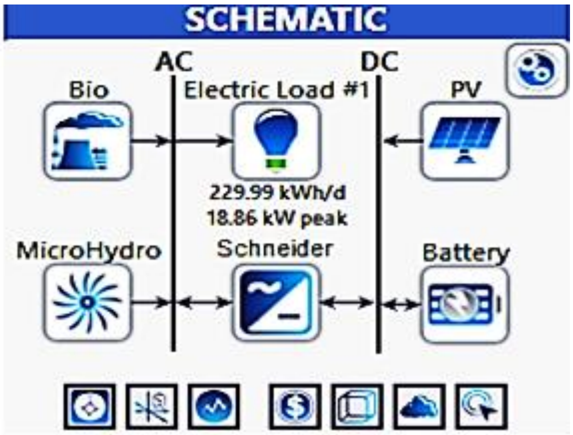


Figure 5. (a) Schematic of First Model (b) Schematic of Second Model

F. Cost Functions

Homer uses different functions to calculate annualized cost, levelized cost of electricity and net present cost.

Equation (7), (8) and (9) shows cost and energy functions which is used to obtain an optimized hybrid renewable energy model.

$$NPC = \sum_{t=1}^{T} C_{O\&M} + C_C - C_{sal} + (C_{rep} * N) \qquad (7)$$

Where
Cc = initial capital cost invested at start of project
$C_{O\&M}$ = annual operating and maintenance cost of system
C_{sal} = at end of project life salvage value of components
C_{rep} = cost required for replacement of components in system
N = number of replacements in project lifetime
T = Life time of project in years

$$E_{sys} = ((P_{sys} - P_{loss}) * T_{sys})) \qquad (8)$$

Where,
E_{sys} = and energy used by the consumer (kWh)
P_{sys} = total power generated by system (kW)
P_{loss} = Power that is used by system itself or losses (kW)
Tsys = the time for which system generates power throughout project life (h)

$$COE = \frac{((P_{sys} - P_{loss}) * T_{sys}))}{NPC} \qquad (8)$$

Where
COE = cost of electricity (PKR/kWh)
NPC = total net present cost of the system

To provide electrical energy at low cost to customers the NPC of the system should be reduced to minimalize the COE.

IV. SIMULATIONS & RESULTS

We simulated two different models, first model is consist of solar PV, micro hydro and biomas with unidirectional inverter, while in second model there is addition of battery bank and bi-directional converter is used.

A. First Model (Unidirectional Converter)

As discussed earlier our first hybrid system is consist of 10kW solar PV, 10.8kW micro hydro and 10kW biomass with unidirectional converter as shown in Fig. 5(a). Solar PV and micro hydro act as primary sources, when load demand rises then biomass start generating power and it continues its generation until load demand falls again to certain level that can be fulfill by solar PV and micro hydro. Monthly average electric production of our first model is shown in Fig. 6.

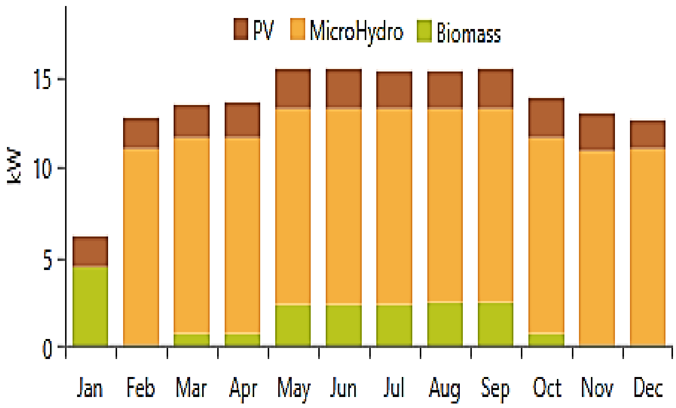


Figure 6. Monthly Average Electric Production

In the absecnce of micro hydro during month of January maximum power is produced by biomass system. In other three months of winter season, biomass is used for very small time during noon time when industrial load is connected to the system and PV generation is low. While in mid-season biomass operates in noon and evening time to meet peak load demand. While in summer peaks occur during morning noon and evening, in noon PV provide some support to fulfill load demand while in evening time when solar generation is zero biomass operates at its maximum. Micro hydro generation remains same for whole year (except January) because turbine is design for 40 cusecs which less than minimum flow of water in whole year. Daily mean output of solar PV is

47.8kWh and it operates for 4,385hrs/yr. Total share of PV in the system is 14.8%. Micro hydro operates for 8016 hrs/yr and produce 86,815kWh. The micro-hydro contribution is 73.5% of total electric power generation in the system. Biomass operates for 4,106hrs/yr and produce 13,924 kWh/yr which is 11.8% of total power.

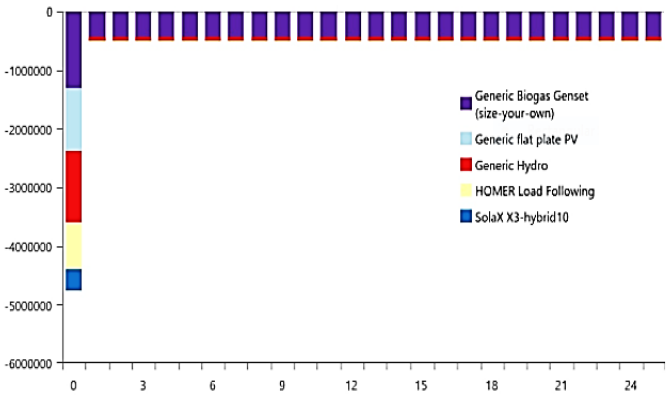


Figure 7. First Model Cash Flow by Components

Cash flow by component of the whole system through out the project litfetime is shown in Fig. 7. First long line shows the capital cost which is invested at the start of the project. Biomass fuel cost is 259,627 PKR/yr, initial capital cost 4.77m PKR while operating and maintenance cost of whole system is 520,867 PKR/yr. Net present cost of system is 11.5m PKR while cost of electricity is 10.6 PKR.

B. Second Model (Bidirectional Converter)

Schematic diagram of 2nd model which we simulated in Homer is shown in Fig. 5(b), which is consist of 10kW solar PV, 10.8kW micro hydro, 10kW biomass and 8 batteries with bi-directional converter. In this model solar PV and micro hydro act as primary source as discussed in first model but when load demand increase or generation from these two primary sources is not enough then system look at the battery SoC, if SoC of battery is higher than minimum, then battery start discharging and until it reaches its minimum SoC or load demand decreases enough that can be fulfill by primary sources. In other case, when SoC of battery is at its minimum and load demand is high which cannot be satisfy by primary sources then biomass start generation to balance demand and supply.

Monthly average electric production of all three sources is shown in Fig. 8. During month of January there is no micro-hydro that's why biomass operation is shown in month of January where biomass generate most of power to meet load demand. In peak months, i.e. summer season biomass generate electricity at its full capacity during evening time when PV cannot generate power. In morning and noon times (peak load) battery provide support and therefore no need to start biomass system. Micro-hydro generation remains constant throughout the year except January.

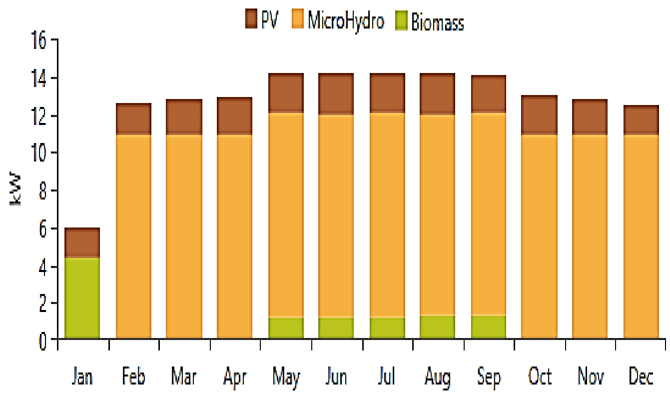


Figure 8. Monthly Average Electric Production

With injection of battery bank in this system biomass operation is reduced. Battery bank get charged mostly during night time when load demand is low and power generation from hydro is still high. Solar PV produces 17,447 kWh/yr and it operates for 4,385hrs/yr. Total share of PV in the system is 15.6%. Micro hydro operates for 8016 hrs/yr and produce 86,815kWh. The micro-hydro contribution is 77.6% of total electric power generation in the system. Biomass operates for 1,279 hrs/yr and produce 7,681 kWh/yr which is 6.86% of total power, while battery bank provides 1,724 kWh/yr. If we compare the biomass operating hours in second model it is reduced by more than 50%.

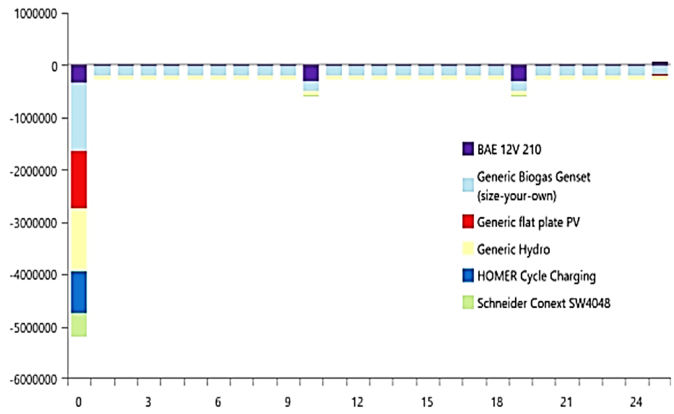


Figure 9. Second Model Cash Flow by Components

Cash flow by component of the of second models for whole project litfetime is shown in Fig. 9. First long bar at left side of image shows the initial investment which is invested at the time of commissioning. Biomass fuel cost is 135,209 PKR/yr, initial capital cost 5.19m PKR while operating and maintenance cost of whole system is 307,549 PKR/yr. Net present cost of system is 9.16m PKR while cost of electricity is 8.44 PKR. Batteries are replaced twice as shown while at the end of project salvage value of batteries is shown. Although initial capital cost is high in this case but operating & maintenance and biomass fuel cost is low, that's the reason of low cost of electricity.

TABLE I. SUMMARY OF BOTH MODEL OF HYBRID RENEWABLE ENERGY SYSTEMS

Model	Biomass				Initial Capital Cost	Annual O&M Cost	Net Present Cost	Cost of Electricity
	Annual Operating Hours	Annual kWh	Total Share	Annual Fuel Cost				
First	4,106	13,924	11.8%	259,627	4.77m	520,867	11.5m	10.60
Second	1,279	7,681	6.86%	135,209	5.19m	307,549	9.16m	8.44

Summary of both models are shown in Table 1. This is clearly shown that operation hours of biomass in first model is more than double as compared to second model. In second model biomass operation is reduced by introducing batteries to the system. Increase in biomass operation causes rise in annual fuel consumption for which extra money is required and ulitimately annual fuel cost and operating and maintenance cost rises.

CONCUSLION

In this paper we have discussed two different models of solar PV, micro hydro and biomass with and without battery storage. In first model solar PV is connected to AC bus using unidirectional converter that converts DC power generated by solar PV to AC power and feed AC load demand. In second model solar PV and battery bank is connected to AC bus using bidirectional converter. Battery bank get charged from micro hydro during night time when power demand is less and production is more. initial capital cost of first model is less as compared to second model and there is no replacement cost in first model, while in second model initial capital cost is high but NPC and COE of this model is less than 1st model. Second model is more complex because of additional component (battery bank) and bidirectional converter, but if we analyse the system technically, battery bank increases system stability and reliability. In first system when load increases than generation of primary sources, immediate operation of biomass system is required in this scenario, if biomass system doesn't react in given time there will be mismatch in system's demand and supply, as a result system stability and reliability will be at risk. While in second model if load demand increases than primary source's generation, battery is there to provide support to the system. When SoC of battery approaches its minimum limit before touching its minimum SoC, system sends signal to biomass system to start generation, if biomass system takes some time battery is still there to provide because we apply minimum 50% of SoC. Another benefit of battery bank in system is that, when peaks occur in systems, these peak are oftenly for very short intervals, therefore no need of starting biomass system again and again because battery bank can fullfil this demand. Second model is designed in such away that, when demand is less than supply of primary sources then battery bank start charging from these primary sources and when demand increases than primary sources battery bank start discharging. In this manner biomass operation is reduced in second model, which reduces its operation & maintenance and fuel consumption and ultimately we get electricity at low price as compared to first model.

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