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Optimization of off Grid Solar-Gas Generator Hybrid Power System for Rural Area of District Karak, Pakistan

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***Abstract*—** The environmental impact of using conventional thermal energy sources for generating electricity and fossil fuel's depletion fear are two major factor pushing world towards alternative energy resources. Pakistan is blessed with high potential of solar energy but hight initial cost and unpredictable nature of solar energy makes it uneconomical. Because of the shortfall and due to the bad geographical location, most of the rural areas in Pakistan have no access to central grid.Although some of the remote community is served by the local fuel generator for just a couple of hour at night, but increasing rate of fuel is issue which makes this system non-economical and also have harmful effect on the surrounding to emit carbon dioxide and carbon mono oxide gases. To decrease dependency on hydrocarbon base generator and cope the unpredictable nature of Photovoltaic (PV) system, an off grid hybrid solar-gas generator with battery storage is presented in this research work for the electrification of rural areas of Pakistan. Purpose of this research work is to model optimize and stable system with minimum net present cost and low cost of electricity using HOMER software.

***Keywords*—** Solar PV, Gas Generator, Hybrid Power System, HOMER, Net Present Cost.

I. Introduction

Energy particularly electricity plays an important role in the economic growth of any country. Electricity has become so important that life without electric energy is difficult to imagine, because it is used to run everything in our everyday life, i.e. light, appliances, cooling and heating for homes and business. No one thinks about electricity as long as it is available. But when outage happens in power system, the importance of electricity is realized. However, lots of people around the world do not have access to reliable electrical energy.

In many developing countries, the access to the central power grid is problematic due to the bad geographical location or location with less community. Solution for such problem is either installation of decentralized local generating units based on conventional energy sources or on renewable resource such as hydro, solar wind etc. The need to improve the performance of these systems generates an interest in hybrid generating power system that comprises many power generating sources. Such systems are good, technically and economically to provide reliable power supply for independent consumers.

In Pakistan, the urban community has access to electricity while rural areas are affected badly. Out of total population round about 27% population have no access to electricity [1]. As electricity is an important tool in every field of life such as health care, education, transportation, communication, high standard of life and economic growth. Unfortunately, in Pakistan so many remote areas have no access to main grid station to get benefit from the use of electricity. That area which has access to electricity is facing high load shedding or electricity is served irregularly. The main hurdle in developing remote and rural areas is the non availability of electricity. Reason behind this problem is low population in remote areas where grid extension proves very expensive. Therefore these areas remain out from grid extension.

Because of increase in population day by day and increase in the need of energy, its demand is increasing. In Pakistan, demand for electrical energy is increasing drastically. The total installed capacity is 25,000MW and shortfall is between 5,000MW-6,000MW [2]. In Pakistan, energy is generated generally from the conventional source like fossil fuels 14,635 MW (64.2%) of total out of which form oil (35.2%) and gas (29%), hydro 6611 MW of total (29%) and nuclear 1322 MW of total (5.8%) [2].These figures clearly show that, in Pakistan, major part of energy is generated from fossil fuels. The excessive use of fossil fuels will finally cause the depletion of these resources one day due to which it is necessary to search for alternative sources of energy to fulfill the energy demand of the world. [3].

One of the major harms with Pakistan's power system is ineffective operational system and high losses in transmission and distribution network. To solve this problem, it is requisite to generate electricity near the community without using complex network of transmission and distribution system [4]. There are some remote and rural areas which have great renewable resources potential [5]. In Pakistan rural area are blessed with renewable energy resources like biomass, hydro, solar and wind [6]. Now a days the renewable energy which is catching the attention in the world is mostly the solar energy

[7], as it can be catch easily, economical to generate electrical energy from solar energy and every where available [8].

The southern parts of KPK, rural sindh and Baluchistan have highly solar potential [6]. Solar energy is a gift of energy

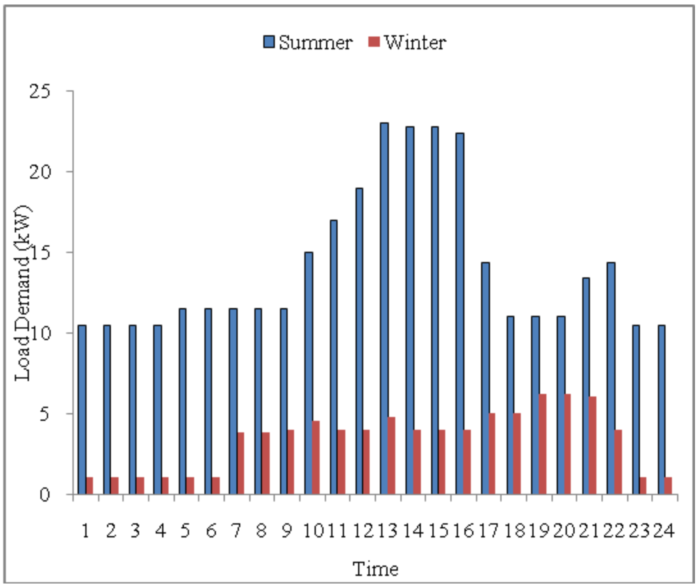

Figure 1. Seasonal Load Profile of Study Area

source because it is free available. Utilization of solar has become significantly attractive and cost effective [3]. However one drawback in getting solar energy is its unpredictable nature, dependency on weather and non availability at night. It is practical that a standalone Photovoltaic system is not able to provide a constant supply of power as it changes seasonally and periodically [9].

To solve the problem of load shedding people are using hydrocarbon based generators (natural gas) which is non-economical due to increasing rate of hydrocarbon fuels and also have harmful effect on the surrounding to emit carbon dioxide and carbon mono oxide gases. To decrease the dependency on hydrocarbon based generator, people are using standalone photovoltaic system in homes and irrigation. But the problem with PV system is its dependency on weather. On the basis of availability of solar potential and the trend of gas engine usage in karak, a hybrid system of PV/gas generator can be used for continuous and sustainable generation.

II. PROPOSED LOCATION

In Pakistan the rural areas are badly affected by load shedding. District karak is one of those affected areas. It is in between Peshawar and D.I.Khan on main Indus highway 140 Km from Peshawar. The latitude and longitude of karak is 33.1105° N, 71.0914° E repectively [10]. The total population of karak counted in the 1998 census was 431,000 [11] that increased to 706,299 by census 2017 [12]. In district karak several natural resources have been discovered such as oil, gas, and uranium. According to a report the average daily production of gas is 80 million cubic feet and oil is 7000 barrels [13]. Being very important for the economy of Pakistan, the people of karak are facing 20-22 hours daily load shedding [14].

III. METHODOLOGY

This portion discusses in detail the method followed in this research work. To know about the load, a survey was conducted to collect the data. The resource potential of study area has been collected from different sources. Finally HOMER pro software is used to modle the optimized solar-gas generator hybrid power system.

A. *Load Assessment*

The electric loads in villages are mostly consisting of lights, fans, TV, water pumps and school loads [15]. The study area has 80 households with an average 8 members per family, 4 general stores, 4 mosques and 2 schools.

During winter season and some part of spring season, fans and freezer are not used . Since fans and freezer add major loads in the system, therefore the load profile is separated into two seasons i.e. winter and summer as shown in fig.1. To know about the load, a survey was conducted to collect the data. The load of mosques consists of fans and lights which are used five times a day during prayer times. During summer the fajar prayer timing is 05:00 a.m to 06:00 a.m, zuhar prayer timing is 01:00 p.m to 03:00 p.m, while asar, Maghrib and isha timing are 05:00 p.m to 08:00 p.m. The load of houses consists of fans, lights, freezers and iron. In summer the peak load (23 kW) is in mid of the day where mostly all fans are used along with freezers. In summer school timing is from 07:00 a.m to 12:00 noon. These are primary school which consists of 4 rooms. In every room there are fans and lights. . Fans are use during day time while lights are used during night time. In general stores the fans are on during day time from 09:00 a.m to 01:00 p.m and 03:00 p.m to 05:00 p.m. The whole load of the village combine together give peak hour at mid of the day.

In winter the load is very low because the fans and freezers are not used. Whole night only few security lights are on. During day time there is no need of lights in homes, mosques, general stores and schools.

B. *Resource Assessment*

Anything that has the ability to generate electric or thermal power is term as resource. Recourse may be renewable energy resource that includes (solar energy, wind energy, hydro and biomass) or any generator that make use of any fuel to run and generator electrical power. Renewable energy resources are mostly depending on the geographical location and weather condition. The solar energy depends strongly on the latitude and climate condition. The wind energy depends on atmospheric and geographic condition. The hydro energy depends on the pattern of rainfall and topography of that location, and the biomass energy resource mainly depends on biological productivity of the location. Moreover, the renewable energy resources have the nature of seasonal unevenness. These unpredictable natures of renewable energy resources effect the cost of renewable power system. Therefore it is very important to model the renewable energy resources carefully. The main focus is on solar energy, therefore in this paper, solar resource along with gas potential is discussed.

1) Solar potential of study area

For modeling a power system comprising a PV array, it is necessary to provide the solar data of that location. The solar data includes the solar radiations and clearness index. Solar radiation may be the direct radiation or indirect radiations. The solar data can either be in the form of hourly average solar radiation (Kw/m2) or monthly or yearly average solar radiation.

The clearness index is defined as the ratio of the solar radiation that strikes the surface of earth to the solar radiation that strikes the top of the atmosphere. It defines how clear the atmosphere and this constant number are ranging between 0 and 1.

Solar data obtained from NASA surface meteorology and solar energy database as shown in fig. 2.

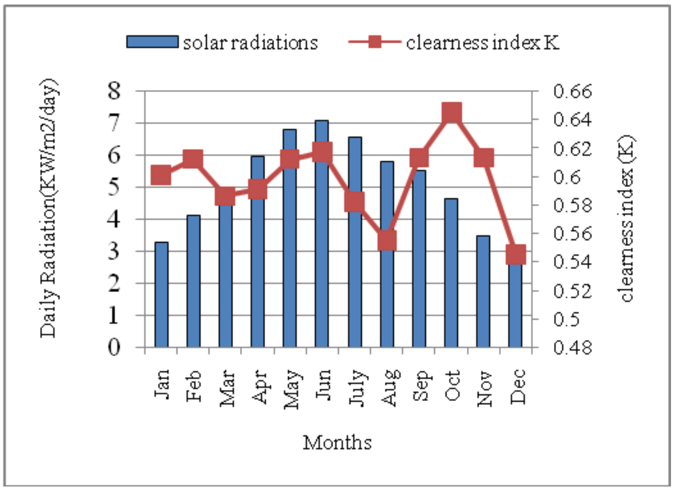

Figure 2. Average Solar Radaition and Clearness Index of Study Area

2) Gas Potential of Study Area

District karak is blessed with so many natural resources. Recently oil and gas reservoir has been found in different location of district karak such as makori, nashpa banda, and gurguri and lachi circle. Many national and international companies and Oil and Gas Development Company Limited (OGDCL) are exploring gas and oil in different areas of karak. Until now, the area of nashpa and gurguri are explored whereas other areas are on the way to be explored. In nashpa banda karak, 8 wells have been explored by OGDCL where as well number 9 is under process. Recently (in 2018) well number 8 has been explored and tested by the production department of OGDCL. According to the daily morning report (DMR) generate every day by the production department of nashpa oil field karak; the average gas production of nashpa from all 8 wells is 80 million cubic feet per day which varies day by day. Besides natural gas, there is also LPG reservoir mix with natural gas. To extract LPG from natural gas, LPG recovery plant has been installed recently which is inaugurated by ex prime minister of Pakistan Shahid Khaqan Abbasi on March 8, 2018.

C. Components Assessment

In HOMER software, components mean anything that can generate, convert or having the ability to story energy. There are different built-in components in HOMER software. There are renewable energy resources components that include PV, wind turbine, hydro and biomass. It has the option of generators that run on different fuels, grid which is dispatchable energy source component, converter and electrolyzer. Converters are an electrical component that can convert alternating current (ac) to direct current (dc) or dc to ac. Electrolyzer is used to converts electricity into hydrogen. This is done through a chemical process called the electrolysis of water. Another component is a reformer, which is used to generate hydrogen gas from natural gas by reforming process. The hydrogen gas produce during the process of electrolyzer and reforming can be stored and used as a fuel when needed in the system. To store energy for future use, there are components i.e. batteries and hydrogen storage tank. Since the performance of each component and their costs has an important role in the cost optimization and designing of a system, therefore the different data related to the component used in the system is carefully selected. HOMER software use different set of performance and cost parameters in order to characterize each component. The component of interest has been covered in the given section.

Solar PV is a renewable source component used in this paper. The derating factor of PV, which is the real output of PV as compare to the rated output, is considered 80%. This is because in real world when PV is operating then temperature, dust and many other factors affect the output. The solar panels are fixed with the slope of 350. The capital cost of solar panel is considered 1,06,000/- Pakistani Rupees (PKR/kW) while operating and maintenance cost is 6000 PKR/kW.

Next power generating component is gas generator. The initial capital cost, maintenance cost and fuel cost of generator play important role in the designing of hybrid system and cost optimization, therefore all the parameters related with generator should be specified carefully. The initial capital cost is 91,500 PKR for 5kW generator while operating and maintenance cost is 10,000 PKR.

Battery is used to store energy from PV system. It is cheaper to use batteries than generator for long term, although it needs regular maintenance. HOMER analyzes different combination of system and consider batteries when need. In this work 60 Ah, 12 V Lead Acid batteries with initial cost of 34,500 PKR/battery and replacement cost of 30,000 PKR/battery are used.

Another component used is converter. It converts ac to dc or dc to ac. To convert ac to dc is rectification while dc to ac is inversion. In modeling electrical power system, the size of converter needs to be defined. The converter size is either inverter capacity or rectifier capacity which is the maximum power produce by converting ac or dc. So the important parameters are these efficiencies that are constant. We consider converter as an inverter in this work. The initial capital cost of inverter is 38000 PKR/kW with 90% efficiency.

The price of gas varies with the passage of time therefore sensitivity variables are added on gas price and they are 27 PKR/m3 and 29.7 PKR/m3 to inspect the cost with each gas price.

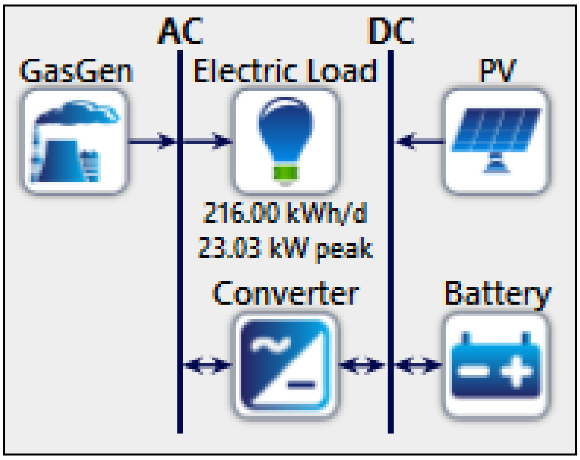

Figure 3. Schematic Diagram of Hybrid System

IV. Simulations and Results

We have simulated our model using HOMER software. Our model consists of Solar PV, Gas Generator, Batteries and converter and the peak demand is 23.03 kW with average energy demand of 216 kWh/day as shown in fig. 3. The HOMER software performs simulation for the whole year (8,760 hours). The simulation results comprise different combinations of each source, with net present and initial cost of each of them, cost of energy (COE), and carbon di oxide (CO2) emission in each combination. Since the price of gas changes with time due to which the net present cost, cost of energy and other costs changes. As discussed earlier, HOMER can do sensitivity analysis on the bases of which a sensitivity variable is added for gas price. It is assumed that a 10% increase in gas price occurs, so sensitivity variable Rs. 27 and Rs. 29.7 is added. On the basis of gas prices, we discuss two cases each with different scinarios.

A. Case #1

In this case we simulated our system with gas price 27 PKR/m^3 and obtained different combinations. Two most expensive and two most optimal system are being discussed, the detail of which are given below.

1) Scenario 1(PV, Batteries, Inverter)

In this scenario, the total demand is met by the combination of PV's with batteries in backup. During day time, there is solar radiation and PV directly met the demand to some extent. As there no sunlight during nights, so batteries will be needed to charge in day time from PV. In order to meet demand at day time and charge batteries to use in night, a very huge PV system will be needed. Therefore in this scenario 125 kW PV, string of 312 batteries and 49.4 kW converter is used.

This system generates 2, 08,235 kWh/year. Throughput of batteries is 38,566 kWh/year while the losses in batteries are 8618 kWh/year. The minimum power production is 0Kw while maximum power production is 127 kW.

Although there is no CO2 in this system, but the costs are too high to make this system the most expensive one.

The initial capital cost, which is the combination of cost of PV, Batteries and inverter is 25.9 million PKR. The operation and maintenance cost is 9.7 million PKR. The replacement cost is 7 million PKR. As a result the net present cost of whole system is 40.6 million PKR as shown in fig. 4.

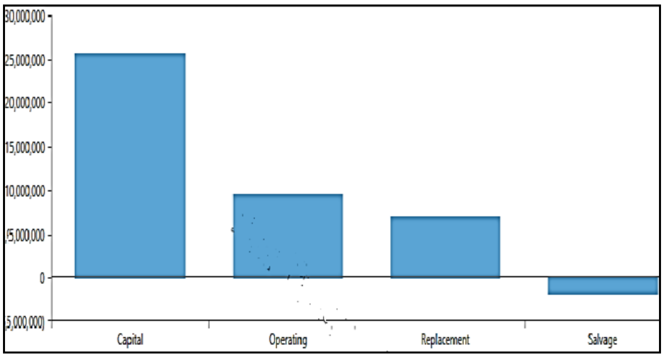

Figure 4. Cost Summary of PV System

2) Scenario 2 (Gas Generator only)

In this scenario, the total demand is met by gas generator only. The generator is to run day and night to meet demand load. The minimum electrical output is 2.6 kW and maximum output is 23 kW as shown in fig. 5.

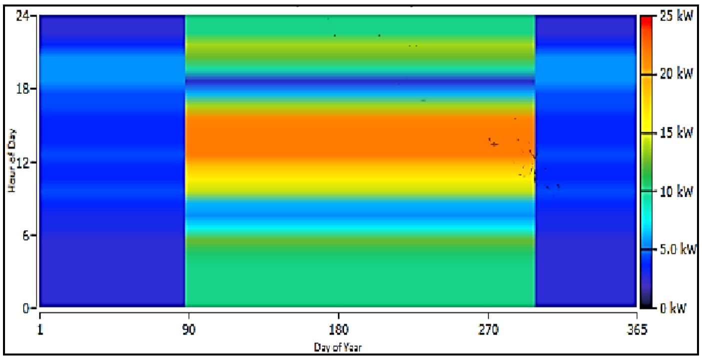

Figure 5. Gas Generator Power Output

Average of 95.5 m3/day gas is consumed as result 80,942 kwh/year energy is generated. The energy cost and net present cost in this case is almost three time less than first scenario.

The initial capital cost is this case is Rs. 475,800. Operation and maintenance cost is Rs. 136,656/year and fuel cost is Rs.941, 252/year. The operating cost which is the maintenance cost plus fuel cost is Rs. 1.08 million. Cost of energy in this case is Rs. 14.14.But still this case is considered as the second most expensive system due to constant usage of gas.

3) Scenario 3 (PV, Gas Generator and Inverter)

This is the second most optimal system. In this scenario, there is no battery to be charged, therefore at night time gas generator will meet the demand. At day time PV is

contributing in power production, since there is no battery the contribution of PV is very small. The rated capacity of PV is 0.657 kW and Gas generator is 25 kW. Out of total energy, 1.35% of energy is generated by PV and 98.65% is by Gas generator.

4) Scenario 4 (PV, Gas Generator, Batteries, Inverter)

This scenario consists of 11.3 kW PV and 19 kW gas generators with 16 batteries and 6.47 kW converters. In this case 23.2 % of total energy is generated by PV (orange color) system while 76.8% is generated by gas generator (green color) as shown in fig .6.

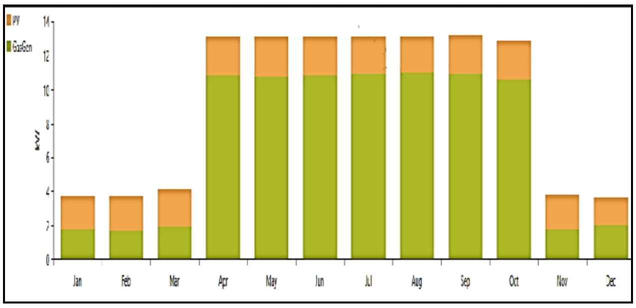

Figure 6. Monthly Average Production of PV and Gas Generator

When demand is low at day time, PV will charge batteries until they get fully charged. These batteries will meet the demand at night time or at peak. When they get discharge, gas generator will meet the demand. The initial capital cost of this system is highest of all because of PV system, but net present cost and operating & maintenance cost is lowest of all.

The initial capital cost is 2.34 PKR million, operation and maintenance cost is 142,540 PKR/year, fuel cost is 655,599PKR/year and replacement cost is 480,000 PKR twice in year, which is the cost of batteries to be replaced. At the end of project the salvages is 434, 003 PKR which is the price of batteries to be sold. The cost of energy of this system is lowest which is 12.65 PKR. The CO2 emission is lowest i.e.46,873 kg/year expect in the case when there is only PV system which is the most expensive one.

Hence this system is considered as the most optimal system.

B. Case # 2

In this case we simulated our system with 10% increase in gas price and obtained different combinations. The detail of different scenarios are given below.

1) Scenario 1 (PV, Batteries and Inverter)

Since this scenario has no gas generator, therefore the sensitivity variable has no effect on the cost of energy, net present cost and other costs. This scenario is same as the one discuss in case #1 scenario 1. This is the expensive one.

2) Scenario 2 (Gas Generator only)

In this scenario, the total demand is met by gas generator only. The generator is to run day and night to meet demand load. The CO2 emission is same as in case 2 scenarios 2, because in both cases only generator is used to meet the load. Due to increase in gas price the operating cost, net present cost and cost of energy increased as shown in fig. 7.

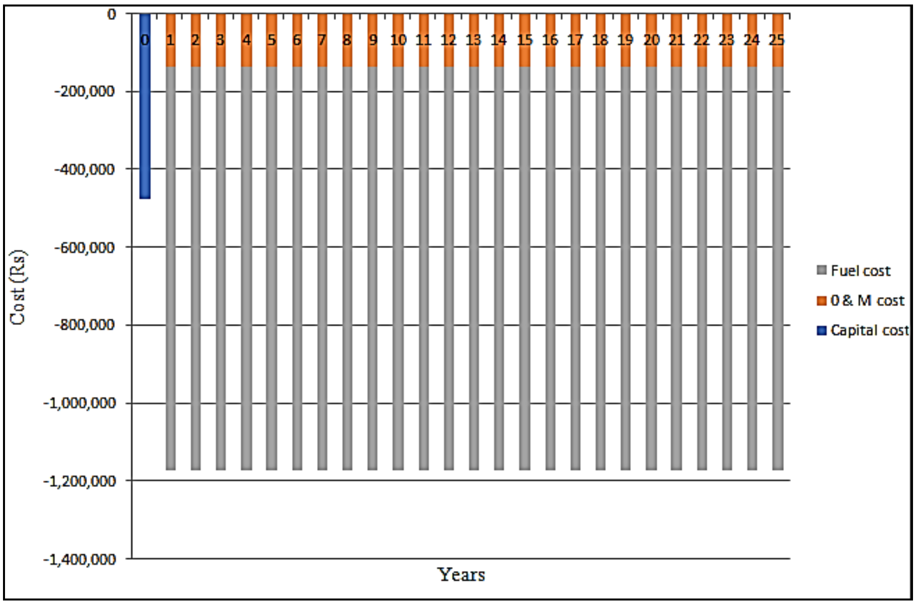

Figure 7. Cash flow of Gas Generator System

The initial capital cost is this case is 475,800 PKR while Operation and maintenance cost is 136,656 PKR/year. These costs are same as in the system discussed in case 1 scenario 2. Fuel cost is 1,035,378 PKR/year which is increased by 94,000 PKR as compare to case 1 scenario 2. The operating cost which is the maintenance cost plus fuel cost is 1.17 million PKR. Cost of energy in this case is 15.33 PKR.

Average of 95.5 m3/day gas is consumed as result 80,942 kwh/year energy is generated. The minimum electrical output is 2.6 kW and maximum output is 23 kW.

The fuel consumed and energy generated remain the same in both cases when only generated is used.

3) Scenario 3 (PV, Gas Generator and Inverter)

This is the second most optimal system. Compare to the scenario 3 of case 2 the initial capital cost is same because both scenarios has same PV and gas generator. The rated capacity of PV is 0.657 kW and Gas generator is 25 kW. Out of total energy, 1.35% of energy is generated by PV and 98.65% is by Gas generator. But due to change in gas price the net present cost increased by 1.2 million PKR, cost of energy is increased by 1.17 PKR and operating cost increased by 90,000 PKR.

4) Scenario 4 (PV, Gas Generator, Batteries, Inverter)

This scenario consists of 11.3 kW PV and 19 kW gas generators with 13 batteries and 6.33 kW converters. In this case 23.2 % of total energy is generated by PV system while 76.8% is generated by gas generator.

The average monthly production of this system is same as the one discussed in case 1 scenario 4. When demand is low at day time, PV will charge batteries until they get fully charged

Table 1 summary of Scenarios

		PV kW	Gas Generator kW	Batteries	Inverter kW	Initial capital cost (PKR)	NPC (PKR)	COE (PKR)	CO_2 (kg/Year)	Remarks
Case1	1	125	--	312	49.4	25.9m	40.6m	39.85	0	Most expensive scenario
	2	--	26	--	--	475,800	14.4m	14.14	67,306	Second expensice scenario
	3	0.654	25	--	0.467	544,602	14.2m	13.92	65,803	Second optimal scenario
	4	11.3	19	16	6.47	2.34m	12.9m	12.68	46,813	Most optimal scenario
Case2	1	125	--	312	49.4	25.9m	40.6m	39.85	0	Most expensive scenario
	2	--	26	--	--	475,800	15.6m	15.33	67,306	Second expensive scenario
	3	0.654	25	--	0.467	544,602	15.4m	15.09	65,803	Second optimal scenario
	4	13.3	19	13	6.33	2.24m	13.8m	13.52	47,219	Most optimal scenario

These batteries will meet the demand at night time or at peak. Compare to case 1 scenario 4, the number of batteries and converter size is decreased due to which initial capital cost is decreased.

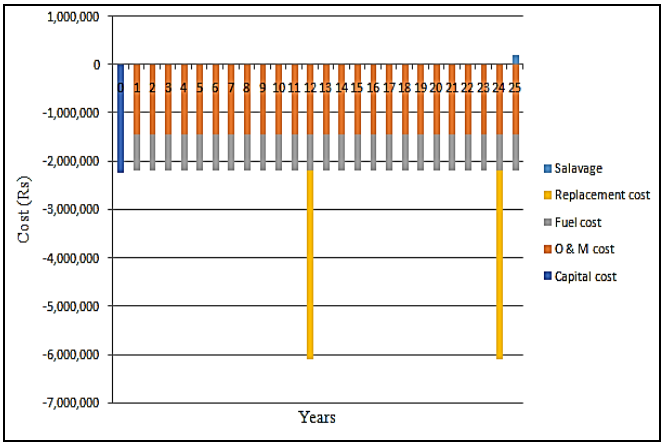

Figure 8. Cash flow of Hybrid Powe System

Fig. 8 shows that initial capital cost is 2.34 million PKR, operation and maintenance cost is 142,540 PKR/year, fuel cost is 726,371 PKR/year and replacement cost is 390,000 PKR twice in year, which is the cost of batteries to be replaced. At the end of project the salvages is 200, 058 PKR which is the price of batteries to be sold. The cost of energy of this system is lowest which is 13.52 PKR. The CO2 emission is lowest i.e. 47,219 kg/year expect in the case when there is only PV system which is the most expensive one.

The detail of both cases along with different scenario is given in table 1, which shows that in each case the scenario which consist of hybrid system i.e. Solar PV, Gas Generator, Batteries and Inverter is the most optimal system for rural areas.

CONCLUSTION

The objective of this project is to give an idea that renewable energy is very important to provide electricity to remote areas. Making a hybrid system of renewable energy sources and other power sources is economical and decrease the cost of energy rather than investing in only hydrocarbon base generator.

Load changes whole day in locality. More power is needed during evening and mid of the day. During day time solar irradiance is quite enough to meet the demand. Since there is no sunlight during night or evening to generate electricity, solutions are needed to fulfill the demand. First is to use battery bank in the system. During peak sun hours, batteries will get charge from solar system when solar energy is more than the demand. These batteries can meet the demand at night because at night time the demand is usually low. This option can decrease the cost per kWh because gas generator is not use to run. The second option is to run gas generator when load is high. This project is designed and simulated for different scenarios using all the components of different combinations. These scenarios are compared in order to get the best and optimal system. By comparing the net present cost and cost of energy it is concluded that the most optimal system is hybrid power system consisting PV, gas generator, string of batteries and inverter. This system reduces the carbon emission to the environment.

The results of this study show that a standalone hybrid power system is cheaper and good for remote areas. It encourages the private investors and local community members, especially in Pakistan, to make use of renewable energy because it is sustainable energy.

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