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Optimal Design and Analysis of Integrating Solar Energy in Off-Grid Telecommunication Sites

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***Abstract*—** In the last decade, the number of mobile subscription all over the world growing at a magnificent pace and providing connectivity to everyone around the globe is indispensable, which led to an increasing number of mobile base stations (BSs). In urban community mobile operator has easy access to grid electricity and they can easily installed BTS in these locations in a cost-effective way. But the rural areas face huge problem of electricity and grid electricity is not spread out in all the region, so, mobile operator face a huge problem while deploying BTS. Most of the rural region of Pakistan facing the problem of load shedding, power failure and no grid electricity access, so, mobile operator usually employed diesel generator to cater these issues, but due to escalating price of diesel oil and global warming it's very costly in term of energy production and is environmentally unfriendly too. So, mobile operator needs some alternative ways of energy production in these locations. To power up BTS in remote areas, renewable energy sources are the best solution and incorporation with diesel generator make the system further efficient and reliable. This study furnishes the design and simulation of stand-alone HRES along with their feasibility report and economic analysis using HOMER. Another aim of this work is the comparison of the existing system and the proposed hybrid system for the telecommunication site. A sensitivity analysis is also carried out to observe and analyze the effect of variation in different parameter on the COE and NPC. It is evident from the optimization results that the integration of solar energy along with battery bank is the most optimum. Furthermore, due to the integration of renewable energy emission of greenhouses gases get abated.

***Keywords*—** Base Transceiver Station (BTS), Net Present Cost (NPC), Cost of Energy (COE), HRES

I. INTRODUCTION

All over the world energy is the most influential pre-requisite, which play a major role in countries economic development, industrialization and improving quality of life. In developing countries sustainability of energy is very important for sustainable economic growth, so continuous supply of electricity appeared as a backbone and play a paramount role in economic development and quality of life. According to[1] in developing countries, electrified regions are more developed than the non-electrified regions in spite of having great electric power growth. Despite having appreciable development in the technical field, the world couldn't even solve the global warming issue, but it is increasing very rapidly due to increasing energy demand around the globe. Most of the energy around the globe is generated from the fossil fuels and in late 1960 almost 94% of the global power was generated from the fossil fuels and in 2014 it is reduced to 80%. Nevertheless, the energy generated by fossil fuels has still a great share and also heating up the globe[2].

According to[3] Pakistan has limited conventional resources and is laboriously relying on the import of fossil fuels and every year greater than 20% earnings gain through the foreign exchange is used upon oil imports. Pakistan is confronting huge energy crises right now, and the energy gap between supply and demand is shooting up. The domestic and commercial consumer confronting too many problems, so policymakers and energy planners must take a step for several auxiliary sources of energy which are economically viable and practically feasible. Folks living in the rural areas of five provinces in Pakistan are about 63.623% of the total population of Pakistan in compliance with Pakistan economic survey 2017-2018. Global Energy Systems (GESs) is too much relying on conventional energy sources but now there is a global shift towards the clean energy. The total global investment was $62 billion in 2004 and raised to $333.5 billion in 2017[4].

Nowadays, a great percentage of world energy consumption met through conventional energy sources. However, these sources cannot overcome the demand of future electricity requirement due to their economic and environmental problem. Also for electrification of remote and scattered populated areas, more reliable, robust and less maintenance system is need to design because in these areas consistent maintenance and replacement is not practicable due their geographical locations.

So, renewable energy sources in these remote and scattered populated areas are the best way to overcome the energy demand but there are several problems associated with these sources when they are used to supply the local community load discretely, such as high capital cost and little security of supply due to their intermittent and undetermined nature[2]. Also, a single renewable source cannot provide a reliable system so, a new notion, namely Hybrid Renewable Energy Systems (HRESs) has unfolded which can solve the above mention problems[5]. HRES is an integration of renewable sources with each other and with other conventional sources e.g. fossil fuels which can supply a local load either in grid annexed mode or in a stand-alone fashion. HRES divide the energy demand among these resources and provide a reliable, economical and secure system. The world is moving with a great pace towards a hybrid renewable energy system due to several advantages and because of the great innovation in power electronics devices and renewable energy technologies[6]. A lot of improvement and innovation in technology have made it possible to control several generating units at the same time to meet the demand of consumers in a more economical, secure and reliable way.

Solar energy percentage around the globe is in excessive amount that other renewable sources but all the energy resources are exploited in a balanced and appropriate ways for the stability of natural resources[7]. Each renewable energy source has a crucial role in power sector in regards to cost, output and nature dependency. In[8] author witnessed that load demand of 24 hours cannot be satisfied by the existence of mammoth amount of solar/wind energy when these resources are used in standalone mode so that there should be hybrid system composed renewable energy sources with DG or battery storage systems. Additionally, in[9] authors discussed Wind/PV/ DG hybrid system and witness that by using this combination power system is more reliable.

Intermittent nature of solar radiation and wind speed resulting in variable and uncertain output that cannot be able to meet the load demand, consequently, a battery storage technology is presented for stable output and to mitigate the intermittent nature of the renewable sources. Maintenance of hybrid system is also possible with the addition of batteries[10]. The solar, and diesel hybrid power system is best for decreasing consumption of diesel as well as eliminating power outages. Additionally, Economic and environmental aspects are in favors of using renewable sources but cost of the renewable energy system are too high. Nowadays, cost of renewable energy sources is minimized by exploiting latest techniques. In[11] authors defined the reputation of photovoltaic (PV) technology around the globe thousands of PV based stand-alone and hybrid power systems are installed and many of them are under working process.

Solar photovoltaic (PV) has enormous potential around the globe and solar irradiance in different locations of Pakistan are available lavishly which makes solar energy the most probable and likely among all the renewable energy sources[12]. Additionally, nearly all base transceiver stations (BTS) are mounted and operated in open and high places that are visible to direct sunlight and make it easier for energy production in telecom sites from solar energy. In[13] the author suggested a model comprising of solar photovoltaic (PV) and fuel cell (FC) hybrid power system for the operation of telecom network operators. Furthermore, in[14] the author discoursed about hybrid system and came across numerous techniques for optimization such as wind turbine size can be minimized by integrating of other renewable resources such as the addition of solar energy along with batteries backup[15].

Reliable and economically feasible diversification of the telecommunication system in rural and remote areas has initiated a very tough and challenging issue. Grid extension in these areas are either not practically possible or their extension can be tremendously costly. As most of the rural areas of Pakistan facing the issue of load shedding, power failure and even no grid-electricity approach, so these issues create a huge problem for telecommunication companies, they do not work properly under these circumstances because for the proper functioning of BTS they need a continuous supply of electricity. Mostly, Diesel Generators (DGs) are employed for the proper functioning of these BTS, although the initial cost of DG is less but the running cost of DG is high. Escalating fuel prices and delivery cost of fuels to these remote locations and also global warming associated with the use of DG drive the mobile operator to implement some other ways for the production energy. So, Renewable Energy Sources (RESs) are the best alternative for energy production in these telecommunication sites, and the system could be either on-grid or off-grid depending on the location of BTS. In this research, we are only considering off-grid locations, and a renewable energy source such as solar PV is used for energy production in these locations to power up BTS. If solar PV is integrated with diesel generator than the system becomes more reliable, robust and economical with less Net Present Cost (NPC) value and COE.

In all the above work the authors has employed HOMER for simulation of the hybrid model after inserting all the required data. The optimization results of the HOMER can be easily interpreted and the optimized system among different system can be obtained. In this paper same software is employed for designing and optimization of off-grid hybrid power system comprising of solar PV, Diesel generator and battery backup. This study contrast the above mentioned related studies in terms of approach, application, load demand, climatic data, and location of the area. In this paper, we shall see technical, economic and financial grounds for SCO to use alternative energy resources instead of fossil energy sources. After that, we consider a typical case of BTS in Skardu, one of the districts of Gilgit Baltistan (GB), Pakistan performing an economic evaluation of its Installation and operations, and calculating the NPC of the project over an operating period of twenty five years along with sensitivity analysis by taking fuel price as the sensitivity variable.

II. RESEARCH METHODOLOGY

The methodology of this research work comprised of several most important steps for the design of optimal and economically viable hybrid stand-alone system for the selected off-grid telecom site. The steps carried out for the completion of this research work are the following

i. Collection of load data site description

ii. Meteorological data collection i.e. solar/ Resource assessment or estimation

iii. Component assessment

iv. Hybrid energy system design

v. System optimization through HOMER

vi. Optimization results

The most influential requirement for this analysis is load data and we need peak and average load demand for the selected site for the whole year which can be obtained by visiting the selected site, it's a pre-design preparation. After getting load data the next step is the assessment of resources available at the selected site, as this research is about the hybrid system of PV-diesel so the solar resource assessment is important. Solar irradiance changes with the location and is dependent on weather condition so for every specific site solar irradiance will change which in turn change the component requirement. The information about the solar irradiation is acquired from the National Aeronautics and Space Administration (NASA) website. After getting this information put this information in HOMER software and design a model, the HOMER simulates the design model and shows the optimized model and compare it with other models.

III. SITE ELUCIDATION AND LOAD ESTIMATION

A. Site Elucidation

The selected site is located in Skardu one of the districts of Gilgit Baltistan, Pakistan. The network operator working there is the Special Communication Organization (SCO). The selected areas have both on-grid and off-grid communication sites but this research focuses on the prototype of a hybrid stand-alone system for the off-grid site. The geographical location of Skardu GB is 35oN 74oE with time zone (UTC + 05:00) Islamabad, Karachi.

B. Load Estimation

The most significant element of the research is electrical load estimation for simulation and optimization of the system. In fact, load estimation is a paramount task in other power generation units too in all around the world. Figure 4.3 portrays the daily electrical load profile for the selected site. The load data of each site is congregated from the nearest SCO exchange. The load data portray that average load at the selected site is about 3.5 kW with 4.06 kW peak load. Almost 84kWh is the average energy utilization on a daily basis. As the average load is 3.5 kW and by adding random variability to the load the peak of the load is changed. Real load data have some variability so HOMER offers the functionality of adding the random variability which will make the load data more realistic. So by the inclusion of random variability to the average load of 3.5 kW, the peak load goes to 4.06 kW with a load factor of 0.86. Figure 1 manifest average load of each month for the whole year.

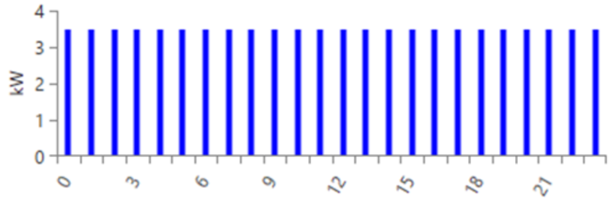


Figure 1. Daily Average Load

Manual calculation of the total energy load (EloadTotal) is

$$E_{\text{Load Total}} = \frac{E_{\text{load}}}{\eta_{\text{BOS}}} \quad (1)$$

E_{load} narrate daily load for the selected site and η_{BOS} narrate balance of system efficiency and its approximated value is about 70%. Now the power needed to accommodate the energy demand of fewer peak hours is calculated using the relation below

$$P_{PV} = \frac{E_{\text{load Total}}}{\text{PSH}.\eta_{\text{nonStc}}} \quad (2)$$

IV. SOLAR RESOURCE POTENTIAL

Solar irradiance statistics are obtainable on the NASA Surface Meteorology and Solar Energy website. They provide information about the solar irradiance at a specific location over a 22-year period (July1983-June2005). So at the selected site solar irradiance statistics are collected from the NASA website. Solar irradiance can be downloaded from National Renewable Energy Lab (NREL) too. Figure 2 shows the monthly average Global Horizontal Irradiance (GHI) and clearness index data for the selected site. Solar irradiance is maximum in summer and in winter it is less. The maximum solar irradiance occurs in the month of June.

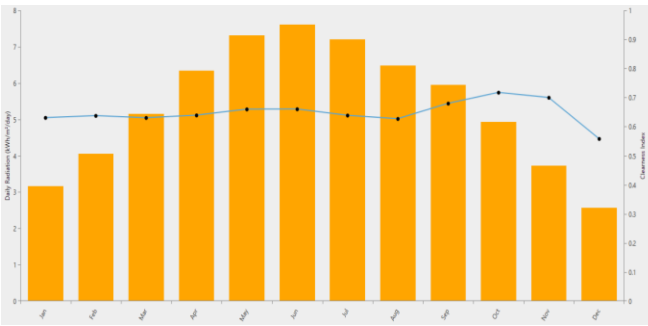


Figure 2. Monthly Average Global Horizontal Irradiance and Clearness Index Data

Table I shows the average monthly GHI of Skardu, GB. Annual average solar irradiation is 5.38 kWh/m2/day. HOMER calculate clearness index using the below formula

$$k_T = \frac{H_{\text{ave}}}{H_{\text{o,ave}}} \quad (3)$$

H_{ave} represents the average radiation on monthly basis falling on the earth surface horizontally in kWh/m2/day.

$H_{o.ave}$ narrate radiation on the straight surface at the summit of the earth atmosphere in kWh/m2/day, it's also called extraterrestrial horizontal radiation. For calculating the intensity of solar radiation HOMER use equation 4, it gives the intensity at the top of the Earth's atmosphere.

$$G_{on} = G_{sc}(1 + 0.033.cos\frac{360n}{365} \quad (4)$$

G_{sc} in the above formula represents the solar constant, which have a value of 1.367 kW/m2 and n narrate 1 to 365 days for the whole year. For calculation of extraterrestrial radiation from the sun's rays which are normal to the horizontal facet, HOMER uses the subsequent equation.

$$G_o = G_{on}cos\theta_z \quad (5)$$

Where 〖 θ 〗_z represents zenith angle in degrees. The table below shows the average monthly global horizontal irradiance (GHI) at Skardu, Gilgit Baltistan.

TABLE I. AVERAGE MONTHLY GHI OF SKARDU, GB

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.630	3.170
February	0.637	4.052
March	0.630	5.154
April	0.638	6.344
May	0.659	7.315
June	0.660	7.614
July	0.638	7.204
August	0.626	6.474
September	0.679	5.950
October	0.717	4.936
November	0.699	3.719
December	0.588	2.575

V. COMPONENT SIZING AND COST ESTIMATION

The main components for the design and implementation of the described hybrid system are PV array, Diesel generator, Battery and converter. The subsequent section briefly explains different characteristics of each component as well as the cost of each component such as Capital, replacement and O&M cost. These all are necessary for the optimization process and finding the best-optimized system.

A. Solar Photovoltaic Panels

Solar energy is transformed into electrical energy with the aid of solar PV cells and the effect is known as the photovoltaic effect. For generation and load demand to be balanced it is necessary to install enough solar panels for the generation of electricity. The output of the PV array is DC in nature and is directly proportional to the solar irradiance. In this research work Canadian Solar Dymond 285watt, 60 cell and double glass PV array having the efficiency of 17.3% are used. It can tolerate snow load up to 6000 Pascal (pa), and wind load up to 4000 Pascal. Solar panels output decreases with several factors with the passage of time such as temperature, dust, tilting and shading so here we consider derating factor of 80% for each solar panel. Table II demonstrate different parameters and properties of the solar PV panels.

TABLE II. SPECIFICATION OF SOLAR PV PANEL

Monocrystalline Silicon PV Module	
Capital Cost (Rs), 1kW	60,000
Replacement Cost (Rs)	0
O&M Cost/Year (Rs)	16,000
Derating Factor (%)	80
Lifetime Span (Year)	25
Efficiency	17.33
Rated Capacity	285 W
Operating Temperature (°C)	45
Tracking System	No Tracking System

B. Battery Storage

Battery is exploited for storing electrical energy and it is necessary for the reliable operation of the grid. Batteries provide backup power during night hours and when diesel generator power is not available due to maintenance. The battery exploited in the proposed model is the lead acid battery (Surrette S-500EX). Capital cost, replacement cost and physical properties of the selected battery is mentioned in the below table III.

TABLE III. COST AND PROPERTIES OF BATTERY

Physical Specification of Lead Acid Battery	
Model	Surrette S-500EX
Capital Cost (Rs) of 1 battery	104,000
Replacement Cost (Rs)	104,000
O&M Cost/Year (Rs)	10,000
Nominal Voltage (V)	6
Lifetime Span (Year)	12
Roundtrip Efficiency (%)	80
Maximum Capacity (Ah)	517
Throughput (kWh)	3693.50
Maximum Charge Current (A)	121
Maximum Discharge Current (A)	121

The battery storage for the electrical load is calculated by the mathematical relation given below

$$E_{Battery} = \frac{E_{load}.n}{DOD.\eta_{BBOS}} \quad (6)$$

DOD in the above formula flaunt the depth of discharge, E_{load} appeared as a day-to-day load profile, the number of self-sufficiency/autonomy days is depicted through n and η_{BBOS} is the efficiency balance of system to compensate the inverter losses.

C. Converter

Converter is very important in the design of PV-Diesel hybrid system. Converter is a device exploited to convert Alternating (AC) into Direct Current (DC) and DC into AC according to the demand. It turns DC, which we acquire from the solar PV into AC to meet the load demand, it also converts AC into DC to power the telecom equipment's. In the proposed model the converter is used between AC and DC bus. Table 4.4

shows the cost and other parameters of the converter used in this research work.

TABLE IV. COST AND PROPERTIES OF CONVERTER

Specification of Converter	
Capital Cost (Rs) of 8 kW	150,000
Replacement Cost (Rs)	150,000
O&M Cost/Year (Rs)	0
Lifetime Span (Year)	15
Efficiency (%)	95
Relative Capacity (%)	100

D. Diesel Generator

DG is employed to dispense electrical energy to the load in night hours and during daytime when no PV power is available due to extreme weather conditions. It is also used for charging the batteries when PV supply is not enough. Generic 10kW fixed capacity generator is used for the selected site. Capital cost, maintenance cost and other peculiarities of the selected DG are shown in the table below.

TABLE V. COST AND OTHER PROPERTIES OF DG

Specification of 10kW DG	
Capital Cost (Rs)	500,000
Replacement Cost (Rs)	300,000
O&M Cost/Year (Rs/hr.)	20
Capacity (kW)	10
Lifetime Span (Hours)	30,000
Minimum Load Ratio (%)	25
Fuel Consumption (L/hr.)	0.480
CO Emission (g/L)	19.76

VI. EXISTING AND PROPOSED HYBRID SYSTEM

In this section simulation model of the existing power system and proposed system for the off-grid sites are presented. HOMER analyze these model and provides a better, genuine and cost-effective way of powering the BTS and remote areas.

A. Existing Power System

The existing system at the BTS for the selected site consists of diesel generator and battery backup shown in figure 3. The DG provides the necessary power to BTS all the time but due to some maintenance work of DG battery backup provide the necessary power to the BTS for the continuous and reliable operation.

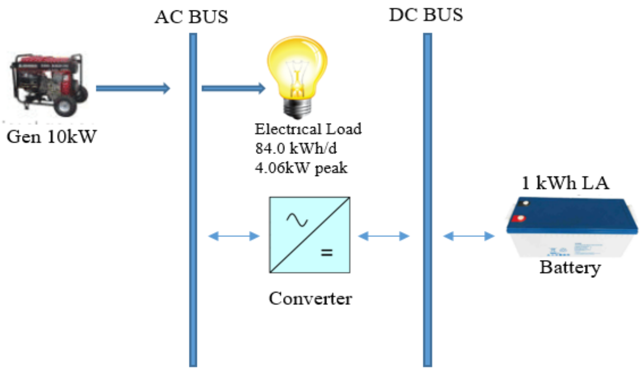


Figure 3. Model of Existing Power System for Off-Grid Site

B. Proposed Hybrid Power System

The suggested or recommended hybrid system for the off-grid sites comprise of diesel generator, PV and battery backup. In the proposed system HOMER perform analysis on different configuration such as PV/DG/Battery/Converter, PV/DG/Converter and DG/Battery/Converter and gives their NPC and COE, on the basis of these parameters the best-optimized system can be selected for the proposed site. Figure 4 shows the hybrid system for the off-grid telecommunication site.

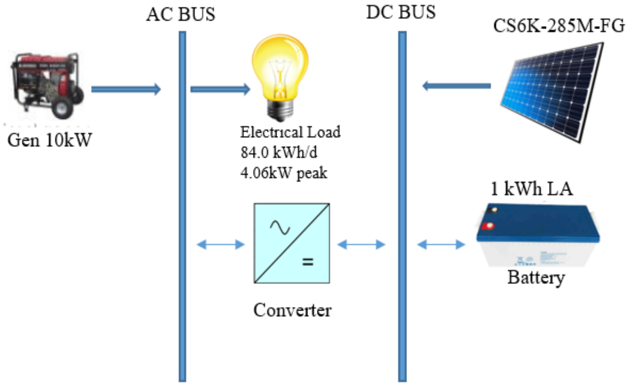


Figure 4. Model of Proposed Hybrid Power System for Off-Grid Site

The specific objective of proposed power systems are as follows:

• To minimize the cost of existing systems by integration of solar energy.

• Load shedding and power outages issues are resolved.

• Reduction in DG running time minimizes net present cost (NPC) and cost of energy (COE) of the system and environmental pollution can be mitigated.

VII. RESULTS AND DISCUSSION

This section presents the optimized result of the existing power system and proposed hybrid power system along with their techno-economic analysis. Optimized results of both system e.g. current power system having DG/Converter and battery backup and proposed hybrid system having

PV/DG/Converter and battery backup are compared. After that sensitivity analysis is performed using different fuel prices. HOMER needs different input parameter for the system designing and optimization process. The diagram below shows the general structure of HOMER modelling.

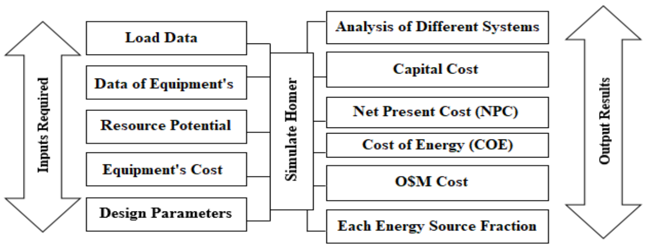
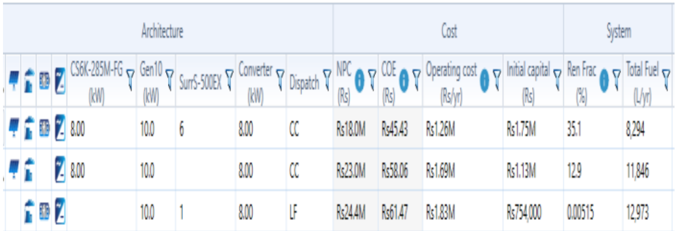


Figure 5. HOMER Modeling with Several Input Parameters

A. *Optimized Results (considering fuel price 120Rs/L)*

HRES consist of different components, search space provides a way where we can define the size of these components such as inverter size, PV size etc. HOMER simulates all the feasible combinations and find out the most reliable and cost-effective combination. In this section, we simulate our proposed system with pre-defined values and get the results on the basis of which we can select the most efficient configuration. From the figure, it can be seen that component sizing for HRES is 8kW PV, converter size is 8kW, 21 batteries and 10kW diesel generator which is installed to satisfy energy requirement during emergency and cloudy weather situations, for the recommended hybrid power system, but for the existing system generator size is 10kw along with the 8 batteries for backup and 8kW converter. Here the fuel price is considered 120Rs/L.



Architecture					Cost				System	
CS6K-285M-FG (kW)	Gen10 (kW)	SurrS-500EX	Converter (kW)	Dispatch	NPC (Rs)	COE (Rs)	Operating cost (Rs/yr)	Initial capital (Rs)	Ren Frac (%)	Total Fuel (L/yr)
8.00	10.0	6	8.00	CC	Rs18.0M	Rs45.43	Rs1.26M	Rs1.75M	35.1	8,294
8.00	10.0		8.00	CC	Rs23.0M	Rs58.06	Rs1.69M	Rs1.13M	12.9	11,846
	10.0	1	8.00	LF	Rs24.4M	Rs61.47	Rs1.83M	Rs754,000	0.00515	12,973

Figure 6. Simulation Results for Off-Grid Site

The simulation results depict that, the NPC and COE of the proposed hybrid system are less than the existing system and other configuration. For the proposed hybrid system NPC is 18M and COE is 45.43/kWh which is less compared with the existing system with NPC 23M and COE 58.06, so, COE and NPC are much higher than the proposed system. Although the initial capital cost of the proposed system is higher than other configurations but operating cost, NPC and COE is very less compared to other, so, it is the most efficient and optimized system for the selected site. Greenhouse gases emission get reduced by the addition of 35.1% renewable fraction.

TABLE VI. ELECTRICITY PRODUCTION AND CONSUMPTION SUMMARY

Production	kWh/yr	%	Consumption	kWh/yr	%
Canadian Solar Dymond (CS6K-285M-FG)	15,179	43.3	AC Primary Load	30,660	100
Generic 10kW Genset	19,909	56.7	DC Primary Load	0	0
Total	35,088	100	Total	30,660	100

The above table explicitly summarize the energy production and consumption phenomenon, as total energy generated together from PV and generator is 35,088 kWh/yr, nearly 42.7% of the total energy is generated for solar panels which is 15,179kWh/yr, on the other hand, DG generate 29,909 kWh/yr which is nearly 56.7 % of the total energy generated. Energy generation is higher than consumption and almost 3,288 kWh/yr energy is in excess amount, which is almost 9.37% of the total energy production, which can be fed to the grid in case of the grid-connected system. Figure 7 portray average energy production scenario on a monthly basis.

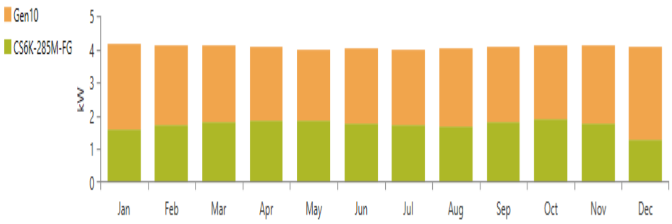
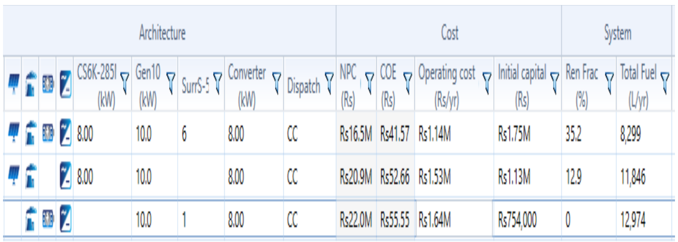


Figure 7. Monthly Average Electric Production

Above figure explicitly portray power production from solar PV and DG during different months for the whole year. It can also comprehend that from the diagram, solar PV share is highest during summer and in the winter it declines drastically. In the month of December production from solar PV is very less compared to other months. As mentioned in the previous section it's a hybrid system some of the energy portion is generated from solar PV during day time, which is directly fed to the load after conversion and some energy is used for charging of batteries, during night time and cloudy weather condition if battery backup is not available DG come into play in that case.

B. *Optimized Results (considering fuel price 106Rs/L)*

Analysis of the proposed hybrid system is carried out for the fuel price of 106Rs/L to get optimized results. Fuel price is a variable quantity so its value varies over the passage of time, so it is a sensitivity variable here. Figure 8 below shows that HOMER optimization result for several configurations.



Architecture					Cost				System	
CS6K-285I (kW)	Gen10 (kW)	SurrS-5	Converter (kW)	Dispatch	NPC (Rs)	COE (Rs)	Operating cost (Rs/yr)	Initial capital (Rs)	Ren Frac (%)	Total Fuel (L/yr)
8.00	10.0	6	8.00	CC	Rs16.5M	Rs41.57	Rs1.14M	Rs1.75M	35.2	8,299
8.00	10.0		8.00	CC	Rs20.9M	Rs52.66	Rs1.53M	Rs1.13M	12.9	11,846
	10.0	1	8.00	CC	Rs22.0M	Rs55.55	Rs1.64M	Rs754,000	0	12,974

Figure 8. Simulation Results for Off-Grid Site

The results show different configuration such as PV/DG/Battery/Converter, PV/Battery/Converter, DG/Battery/Converter, only DG and PV/DG/Converter. These are the different feasible architecture for the proposed site. In the figure above the first combination of PV/DG/Battery/Converter consist of 8kW PV, 21 batteries with 11.2 autonomy hours, 10 kW diesel generator and converter size 8 kW. This combination is the most optimal one as HOMER determine the best-optimized system on the basis of less NPC and less COE. The NPC of the first combination is 16.5M and COE is 41.57/kWh, which is less as compared to other combinations. But the initial capital cost of the system is high due to 8 kW PV system and 21 batteries but COE and NPC are less compared to other combinations. Renewable fraction in this combination is 35.2% so, which in turn reduces greenhouses gases emission. Comparison with the existing system shows that NPC of the existing system which comprises of DG/Battery/Inverter, is 22.0M and COE is 55.5/kWh which is too much high, although the initial capital cost is low. In this case, the renewable fraction is zero.

From the above debate, it is concluded that the first layout which is comprised of PV/DG/Converter/Battery is the most economical system for the off-grid site. The cost of energy is less as compared with the existing power system composed of DG/Battery/Converter.

C. Sensitivity Analysis

In this research work, a sensitivity analysis is carried out by entering different values for a certain variable which alters the result. HOMER carry out the optimization process for different values of the sensitivity variable and the results obtained tell us about how different values affect the results. Here fuel cost is considered a sensitivity variable. One value for fuel cost is 120/L and other value is 106/L. HOMER perform optimization process on these two values and tells us how fuel cost effects the system cost as this variable only affects NPC, COE and operating cost etc. Below detail of every scenario is presented.

TABLE VII. EFFECT OF SENSITIVITY VARIABLE ON DIFFERENT PARAMETERS

Parameters	Fuel price 120Rs/L	Fuel price 106Rs/L
NPC (Rs)	18.0M	16.5M
COE (Rs)	45.3	41.57
Operating Cost (Rs)	1.26M	1.14M

The above table represents the effect of varying fuel price on the different parameter for the proposed hybrid system only. It can be easily seen from the above table that with the change of fuel price it also affects different parameters such as NPC, COE and operating cost.

D. Gases Emission

This section compares the emission of greenhouses gases for both systems i.e. existing system and the proposed hybrid system for the off-grid site. Table VIII depicts the ejection of greenhouse gases for the proposed hybrid system.

TABLE VIII. POLLUTANT EMISSION OF PROPOSED HYBRID SYSTEM

Quantity	Value	Units
Carbon Dioxide	21,681	Kg/yr
Carbon Monoxide	164	Kg/yr
Unburned Hydrocarbons	5.98	Kg/yr
Particulate Matter	9.94	Kg/yr
Sulfur Dioxide	53.2	Kg/yr
Nitrogen Oxides	186	Kg/yr

The table depicts emission of several gases from the hybrid system in term of their weights for the period of one year. Table IX depicts the case of an existing system composed of DG/Converter/Battery storage.

TABLE IX. POLLUTANT EMISSION OF EXISTING HYBRID SYSTEM

Quantity	Value	Units
Carbon Dioxide	33,893	Kg/yr
Carbon Monoxide	256	Kg/yr
Unburned Hydrocarbons	9.34	Kg/yr
Particulate Matter	15.5	Kg/yr
Sulfur Dioxide	83.2	Kg/yr
Nitrogen Oxides	291	Kg/yr

From the tables above it can be concluded that the emission of carbon dioxide is 18,924 kg/yr and carbon monoxide is 143 kg/yr. For the existing system as shown in the above figure CO2 emission is 32,915kg/yr and carbon monoxide is 249 kg/yr. When these results are compared with each other than it is clear from the results that emission of greenhouses gases reduced with the incorporation of solar PV in the existing system. The inclusion of the solar PV in the current system has reduced the emission of CO2 to a great extent.

CONCLUSION

Mobile operator in rural areas facing the problem of power outage and load shedding due to unreliable grid power supply. Most of the mobile BTS are operating in a standalone diesel generator and battery backup hybrid power system due to no access to grid electricity. The considered area for this research work is Skardu, Gilgit Baltistan, Pakistan. The layout of the stand-alone hybrid system along with the economic analysis is presented in this chapter for the off-grid SCO telecommunication site. The suggested hybrid system comprises of solar PV, diesel generator, converter and battery backup where the current power system consists of DG, converter and battery backup.

HOMER software is employed for economic analysis and design purpose of the stand-alone hybrid renewable energy system. For the complete economic analysis HOMER need s several inputs for analysis purpose, the inputs are load data, data of equipment's, resources potential at the selected site such is solar PV, equipment's costs and other design parameters. HOMER perform an economic analysis of the designed system on the basis of these inputs and most optimized system with less NPC and COE are obtained among different configurations. The evaluation standards for this research work are capital cost, operating cost, net present cost, and cost of energy. These are the main factors on the basis of which HOMER declared the most optimized system among several configurations.

In the above section, HOMER performs optimization through HOMER search space. For the first scenario the fuel price of 120Rs/L and 106Rs/L for the second scenario is selected, different values of fuel are taken for sensitivity analysis to be performed. The results depict that the most optimized system is DG/PV/Converter/battery having less NPC and COE. But the existing system has very large COE, NPC and operating cost although the initial capital cost of the system is less compared to the proposed system.

Greenhouse gases emission is an important factor for the selection of power system among different configurations shown by HOMER. Greenhouses gases emission get reduced to a huge extent with the penetration of solar energy, this is a very important factor for environmental stability because these harmful gases emission causes global warming which is very dangerous for the whole world. So our proposed system is best, efficient and most economic for the BTS sites in rural areas and also discharge less CO_2.

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