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Comparative Analysis of Techno-Economic Feasibility of Different Hybrid Renewable Systems for Remote Area Electrification of Pakistan

Abdul Majid Khan[1], Muhammad Mohsin Nawaz[2], Muhammad Ahmad Khan[3]
[1,2,3]Department of Electrical Engineering, University of Engineering and Technology Peshawar, Pakistan
majidkhan2124@gmail.com[1], mohsinawaz18@gmail.com[2]
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Abstract— Pakistan energy problems are complex and deep and are posing far reaching serious threats to its feeble economy and fugitive national security. Pakistan population is increasing rapidly but the power generation and transmission to cope with the population remains overlooked, despite having huge renewable resources like solar, wind, biogas and hydro-power plant sites. This study is about the comparative analysis of techno-economic feasibility of different hybrid renewable systems for remotely located off-grid communities of Pakistan. In this research two different sites that are rich in renewable resources are selected. The sites considered for modelling and optimization are located in Khyber district and Swat District of Khyber Pakhtunkhwa, Pakistan. At these sites different hybrid systems are designed using renewable and non-renewable resources like Solar, Wind, Micro-hydro, Batteries and Diesel generator using a software called Homer pro. Homer Pro is a designing software that combine the resources, components and economic calculations alongside different realistic constraints. The Homer Pro performs techno-economic feasibility analysis and study the performance of systems for their lifetime. As a result of the simulation, it provides an output solutions like total net present cost (NPC) and cost of electricity (COE), yearly energy produced and consumed, operating cost, losses, renewable fraction, life time of model and excess electricity produced. Based on all of these variables a most suitable solution for the desired location is selected.

Keywords— Renewable Energy, Hybrid system, Techno-Economic feasibility, Optimization, Homer Pro.

I. Introduction

Energy is a cardinal part and parcel of life. It is because of the perks of the availability of huge amount of energy that we have shorter working days, larger industrial productions and higher agricultural yields. For the economic development and prosperity of a country, it is very essential that it has a cheap and continuous supply of electrical energy to all of its users especially its remote area users as they play an integral role in country economic progression. Remote areas of Pakistan are very distant from the national grid hence providing electricity to such area is a key bottle neck in country economic and social development. As per one report presented before the United Nations (UN) in 2014, around 17.8% of the total world population has no access to electricity [1]. Amongst those who don't have access to electricity around 80% of them lives in the remote areas [1]. As remote areas main source of income is agriculture and agriculture is mostly dependent upon underground water resources. Providing electricity to remote areas for water extraction is thus very important. As a consequence of not providing sufficient electricity to remote areas, Pakistan Gross Domestic Product (GDP) has dropped from 8% to 2% because almost 20% of the country relies on agriculture and agricultural farms [2]. Pakistan is the 6th largest country and has a growth rate of 2%. Pakistan total electrical energy production by April 2019 was 33,972 Megawatts (MW) and was showing a growth rate of 7%. Amongst this hydropower generation was about 25.8%, thermal was 63.0%, nuclear was 3% and renewable was just 8.2% [3]. Despite with huge potential of renewable energy, Pakistan usually relies on conventional resources of energy like thermal power plant whose production is 63% of its total production. In order to shift from convential resources to renewable energy, recently government has announced attractive incentives like enchanting tariff, low import duties on equipment etc. and is providing full facilitation in this regard through Alternative Energy Development Board (AEDB) Pakistan. Wind, solar power and micro hydro plants stand as an inexpensive, competitive, brisk, swift and pristine source of electricity that will transfigure Pakistan energy sector and will change it from energy deficit country to a one that has energy in abundance. As per the reports of Alternative Energy Development Board (AEDB) Pakistan, 1000 watts per square meter of solar power is extensively at the disposal in different parts of the country [4]. All of these solar power resources can be used and utilized.

A. *Problem Statement*

Pakistan far-flung remote areas are either detached from National Grid or are facing low voltages that are not able to support electrical equipment's. According to one report round two third population of the country lives in rustic far flung areas and they are bereft of electricity from the National Grid [5]. Currently, in Pakistan the difference in demand and supply of electricity is met through load curtailments, due to this shortage, people are facing severe load shedding (8 to 12 hours/day) in rural areas. Independent power plants (IPP'S) and Rental power plants (RPP'S) were considered as an early solution to all such problems because of their quick installation setup but they depend on oil for electricity production which is causing environmental hazards and thus national disasters like floods dry spells, rising of the standard, inundation, extreme weather, soil erosion and loss of wild life and species are direct impact of climate change [6]. We are amongst those countries that is worst effected by global warming. Secondly, the increase in prices of oil in international market as well as the Pakistani currency depreciation makes it a very expensive solution for energy crisis which is financially not viable. So, providing electricity to remote area is very challenging job considering the fact that our transmission system is already not supporting our generation and load. Remote areas users mostly use solar energy or diesel generator in order to fulfill their needs but these systems are uneconomical and has feasibility and reliability issues. Solar energy on one hand is not available at night time while diesel generator on the other hand needs fuel and produce lot of noise and air pollution.

To overcome the critical energy crisis situation, we need to move from conventional energy sources to renewable energy sources to get independent from foreign oil price hikes and also play our part in reducing environmental pollution. For this purpose, we will discuss in our thesis that economical hybrid system of renewable resources, for remote areas having no electricity, is economical and feasible. In an off-grid standalone system, the factor that plat key roles are the price value, life span of components and the accessibility of components. To reduce the entanglement and intricacy of the control, pertinent maintenance and effective working, unbroken and sustained power flow, elegant and spruce control mechanism and inexpensive cost plays an important role. For solving different problems like these for the electrification of remote areas of Khyber Pakhtunkhwa (Pakistan) in a sagacious way, it is very essential that the renewable resources of the province are utilized at their maximum. So, for this purpose, a standalone off-grid system will be designed for isolated and secluded parts.

B. *Objectives*

The sole purpose of this paper is to present a stand-alone off grid solution for the remote area electrification of the Pakistan as a long-term eradication of energy crises from the country. Off-grid configuration is chosen in order to lessen the burden on the current transmission network of the country and to provide an uninterrupted supply to the load. The paper will include a detail frame work for the construction of a hybrid system at proposed sites. Two different sites are selected for this purpose and different models are made at those sites using different renewable and traditional resources. A techno-economic analysis is then done using Homer Pro software in order to extract a most feasible and economical solution with least amount of environmental hazard. Following are few of the main objectives of this research in order to design an inexpensive hybrid system of Sustained Resources for two different locations of Khyber Pakhtunkhwa, Pakistan: (1) To study different renewable resources and different generation components used to harvest the renewable resources in Paksitan. (2) To Study the Homer Pro software in detail and check the feasibility and performance of different system at selected sites using the software. (3) To address different constraints issues for practical implementations in order to make system more accurate and precise and to do cost and sensitivity analysis for different hybrid systems at the proposed site. (4) To determine annual energy production, consumption, renewable fraction and annual emissions of different systems at the proposed sites. (5) To check the commercial efficacy of the system by comparing the cost of electricity of the system with the government tariff.

II. LITERATURE REVIEW

The researchers have been using several different software's and procedures to make a self-sustained hybrid system for electrifying of an area by integrating different renewable and non-renewable resources. Homer pro is one such tool recently used by a lot of researcher for optimization and cost analysis. The software has been developed by the National Renewable Energy Laboratory USA (NREL). This software is capable of handling new renewable technologies of solar, wind, biogas, fuel cells etc. and also non-renewable resources like diesel generator, hydro power plants. Renewable systems are considered to be best solution for remote area electrification but high initial capital cost due to expensive instruments poses difficulty in slow growth of these renewable systems according to Ibtiouen et. al [7]. Renewable resources are the best mean to provide electricity to different communities and agricultural farms in order to make these independent from the central grid station and provide low cost uninterrupted electricity according to Rohit and Subhes [8]. Previously a lot of different hybrid renewable systems were designed at different locations where the objective was to reduce the cost of operations. Ajitha k. et al. [9] performed a cost comparison analysis of two different system where one was grid based another was fuel cell bases on a hospital located in rural area of India using Homer pro software. Another hybrid system comparison was made by Ankit Bhat et al. [10] who performed a feasibility analysis for a remote rural community in India and consider three different renewable resources.

The resources considered were photovoltaic, biomass and hydro with a backup of conventional resources of diesel engine to generate electricity using Homer Pro. One another study by Kamilu et al. [11] concludes the result for Nigeria where he carried out a feasibility study of different composite renewable systems. Different resources like solar and wind were used for such purpose. These resources were used to supply to a transceiver that was mobile-based. For this purpose, a PV array of 10 Kilowatts was used. The diesel generator used for this purpose was of 5.5 kilowatts. Trojan L16P, 64 unit's battery system was used for backup purpose. Using economic study, it was found out that the capital cost of the project was $69,811 and that of the single unit of electricity will cost up to $0.409. According to the Ohunakin et al. [12] when the inspection of different arrangements of different hybrid system of photovoltaic/Diesel Engine/Battery is done to obtain a superlative result it was found out that the best solution was obtained for the sensitivity case of $1.3/liter and $1.1/liter of diesel.

Hosseinalizadeh et al. [13] performed optimization simulation in Iran for different renewable resources like solar, wind and fuel cells. It concluded with the results that wind and solar system with batteries as a backup was a most feasible solution for the area. Fuel cell was not a feasible solution for the area. Al-falahi et al [14] conducted a detail comprehensive economic optimization analysis for different renewable resources like Solar, wind, batteries, hydro power, diesel generator and fuel cell. Moreover according to one another study conducted in 2019 by Assaf and Shabani [15], a continuous heat and power supply to a remote area load with the help of solar and fuel cell with high reliability can be obtained using Homer Pro. Shahzad et al. [16] conducted a techno-economic feasibility analysis of a hybrid system of solar and biogas for an agricultural farm and a small residential community is a remote district of Pakistan. The cost of energy and capital cost was obtained as a result which was quite feasible considering local market prices. According to Gautum [17] a load of 480.58 kwh/day can be satisfied using a hybrid system of solar and biomass. The result obtain as a result of this study were most feasible one. According to one another study by Ekren et al. [18] a hybrid system was made of Solar and wind for the electrification of electric vehicle charging station. The sizing of the components was done using homer pro.

Another study was performed by Islam et al. [19] in 2021 to investigate a PV/Wind/micro-hyrdo for the electrification of the coastal community. The system made was an off-grid one. The most optimized solution cost of electricity was \$0.136/kwh as compared to the grid connected one that cost \$0.12/Kwh. The system required batteries also. Another study performed in 2020 was by Elkadeem et al. in which an optimized solution with minimal environmental hazard was proposed for a newly constructed airport in new capital of Egypt. The system made was providing the airport with daily electricity and water requirement. The cost of electricity to be calculated was around \$0.08/Kwh. The proposed hybrid system produced 58.5% less carbon dioxide then a conventional resource. The payback time for the proposed system was 1.2 years. Ramesh et al. [20] performed another feasibility analysis for remote areas of India. The system was able to load shift based on Demand side management. Lithium-Ion battery were used with different renewable and non-renewable resources alongside load management. The capital cost of the system and cost of electricity was \$467,644 and 0.106 \$/kWh respectively without demand side management and \$153,080 and 0.034 \$/kW respectively with demand side management.

In another study performed by Ahmed et al [21], a hybrid system was made up of solar, wind, battery and converter for the remote area electrification of Balochistan. The most feasible system capital cost was calculated as \$127,345. The cost of energy is calculated as \$0.137. One study was performed for different sites in Australia by the Barun [22]. Different hybrid systems were made for different sites. PV/Wind/MGT/Li-ion-based hybrid system was considered to be most economical and feasible for the proposed site. For remote site in India, Rajasthan a study was performed by Nijhawan [23], the study concluded that MHD, solar, wind and fuel cell combine to give an optimized solution.

III. METHADOLOGY

For energy simulation different software's like Transient System Simulation Tool (TRNSYS), HYBRID 2, Matrix laboratory (MATLAB) are used alongside different algorithms in order to perform feasibility analysis and techno-economic analysis. Different techniques were used previously where the objective function was cost optimization and increasing the efficiency of the Hybrid Renewable system like Particle Swarm Optimization (PSO), Meta Particle Swarm Optimization (Meta-PSO), Probabilistic approach, mixed-integer Quadratic programming technique, graphical construction technique and genetic algorithm. Homer Pro software can perform both simulation and optimization. So, A standalone system will be made in Homer Pro and then its optimization will be done in order to get most feasible results.

A. Homer Pro Development

National Renewable Energy development with their aim to harness maximum renewable energy and stop depletion of conventional resources, in 1990, made a software named Homer Pro for developing countries so that they can easily deploy different hybrid renewable systems for remote area electrification. After making the software, it was improved with different features and then dispensed by Homer energy.

B. Working

The software can execute different viability and feasibility study of different hybrid models. The software actually merge the Engineering with the economics.It can run multiple different combination of components in a single run. There are three different core categories that is very essential to understand for the user to make system efficiently in the software.

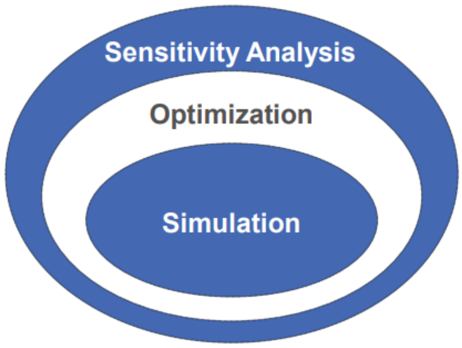

Figure 1. Homer Pro Working Categories

C. Simulation

There are very few software's that perform optimization and simulation both at the same time and Homer Pro is one of them. The optimization is done within the constraints defined to the software by the user. The optimization algorithm used by the Homer Pro is "derivative free". It was designed so in order to simplify the optimization process so that a feasible solution can be obtained on the basis of net present cost and cost of electricity in a short time [24]. Homer pro provide different sizing of components which can be selected on the basis of different circumstances.

Sensitivity Analysis

Sensitivity analysis of any case study is the examination of how the out coming variables vary in accordance with the input variables. Homer Pro provide sensitivity analysis for different models designed. It enable user to compare different results when the input parameters like solar irradiance, wind speed, cost of fuel is changed and how they effects optimal performance of the model [25].

D. Parameters for Optimization

The parameters on the basis of which Homer Pro do optimization are Net Present Cost (NPC), Cost of Energy (COE) and Operating Cost (OC).

1) Net Present Cost (NPC)

NPC is calculated by negating the current value of wholesome revenues, that it acquire over the lifetime of project, from the present cost of installation of all the components, the cost of operation of all the components for the life time [25].

The net present cost can be calculated by the following [25]:

$$NPC = \sum_{N=1}^{N=t} f\ d,n\ (C_{cap} + C_{rep} + C_{main} - C_s) \quad (1)$$

Where $C_{cap}, C_{rep}, C_{main}$ and C_s represent capital cost, replacement cost, operation and maintenance cost and salvage cost respectively. Whereas f d,n in above equation is given by:

$$f\ d,n = \frac{1}{(1+i)N} \quad (2)$$

Whereas *i* and *N* are annual interest rate and the year of calculation respectively [25].

2) Cost of Energy (COE)

The average price of energy that is produced for per kWh of electricity by the designed model is called COE. The cost of energy can be given by:

$$COE = \frac{AC_T}{E_{served}} \quad (3)$$

Where E_{served} is the primary load served while AC_T is the total cost of the component “a” at each year of project total life time [25]. AC_T Can be given by the below equation.

$$AC_T = \sum C_{cap} + C_{rep} + C_{main} - C_s \quad (4)$$

Where
C_{cap} = Capital Cost.
C_{rep} = Replacement Cost.
C_{main} = Operation and Maintenance Cost.
C_s = Salvage Cost [25]

3) Operating Cost (OC)

Operating cost is all the ongoing expenses or annualized value of sum of costs minus the initial expense of the project [25]. Operating cost can be calculated with the help of the following equations.

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \quad (5)$$

Where
$C_{operating}$ = Operating Cost.
$C_{ann,tot}$ = Total Annualized Cost.
$C_{ann,tot}$ = Total Annualized Capital Cost.

E. Model Flow Chart

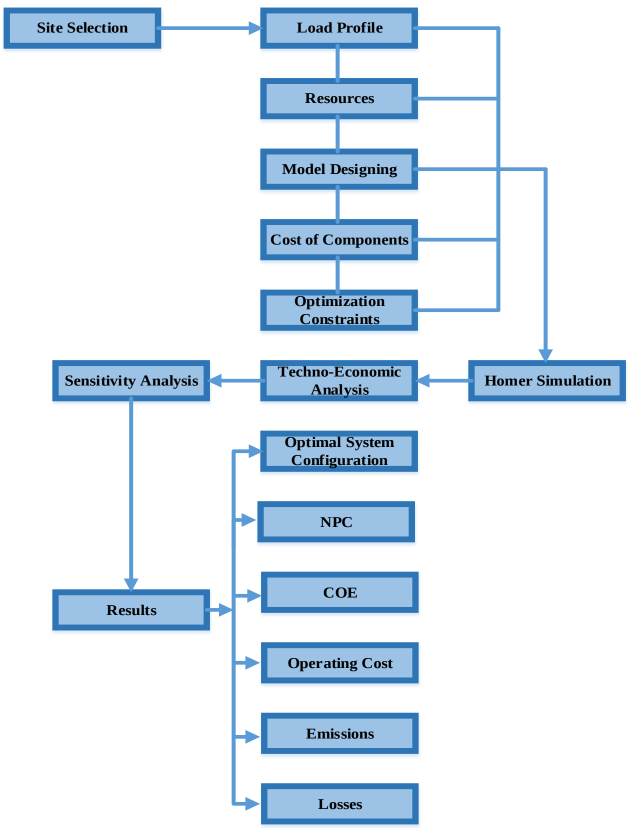

Figure 2. Model Flow Chart

IV. Site Information

Two sites are selected in Khyber Pakhtunkhwa province of Pakistan for techno-economic feasibility analysis. The first site exact location is “Khyber Agency Road, federally administrative Tribal Area”, with Global positioning system (GPS) coordinates of 34° 7.8′ N , 71°16.5′ E . Whereas the exact location of second proposed site is “N-95, Bahrain, District Swat Khyber Pakhtunkhwa, Pakistan” with coordinates of 35°11.9′N, 72°32.6′E.

A. *Renewable Potential at Site-1*

The solar irradiance and the clearness index at the first site is represented graphically in the Homer Pro, shown in the Figure 3.

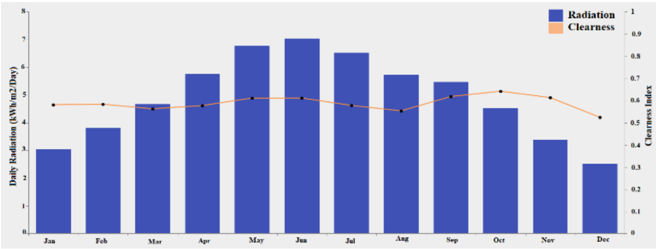

Figure 3. Monthly Solar Radiation and Clearness (Site-1)

The daily radiation is measured in Kwh/m^2/day. As it can be seen that the maximum radiation falls in the month of June. i.e. 5.762 Kwh/m^2/day whereas the minimum in the month of December. i.e. 0.523 Kwh/m^2/day. Similarly, the clearness index is maximum in the month of October i.e. 0.616 and minimum in the month of August i.e. 0.552. The scaled annual average of clearness index is 0.587 whereas the average daily radiation is 4.93 Kwh/m^2/day.

The proposed site has wind speed of 2.86 m/s. The maximum gale pace at the proposed ground is 3.420 m/s. The minimum gale pace at the site is 2.550 m/s. The wind data is collected 50m above from the surface of the earth for past thirty years time span. The site has one hour autocorrelation factor of 0.86. The diurnal pattern strength at the site is 0.25 whereas the Weibull K factor is of 2 at the proposed site. Monthly average speed at the proposed site is shown in the Figure 4.

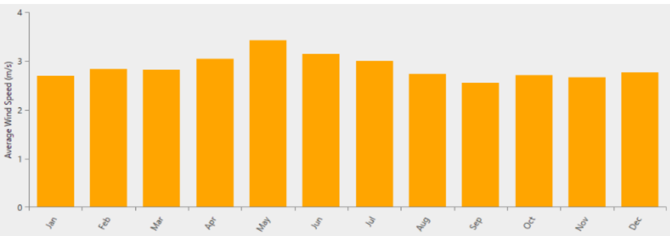

Figure 4. Average Monthly Wind Speed (Site-1)

The wind speed is maximum in summer whereas it is nearly constant in winters. As it can be seen from the figure 4 that maximum wind speed is in the month of May i.e 3.420 m/s. Whereas the minimum wind speed is in the month of September i.e. 2.550 m/s. As we know that the wind speed changes with change in height. So Figure 5 shows the variation of wind speed with change in height.

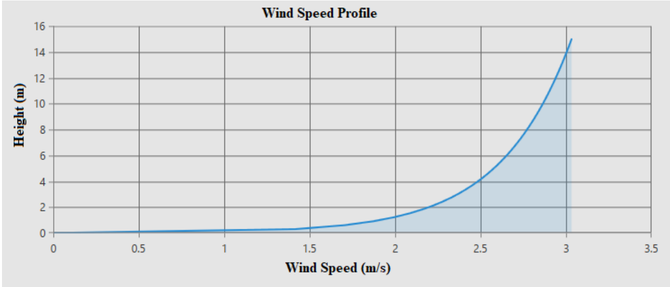

Figure 5. Variation of Wind Speed with Height (Site-1)

B. *Renewable Potential at Site-2*

This valley is rich of solar, wind and hydal resources. Many mini-hyrdo projects are already made by the Government of Khyber Pakhtunkhwa at the site. The site is based on the swat river that starts from the swat. The main source of water are melting glaciers and rain water. The Monthly Solar radiation and clearness index at the site is shown in the figure 6 from Homer Pro.

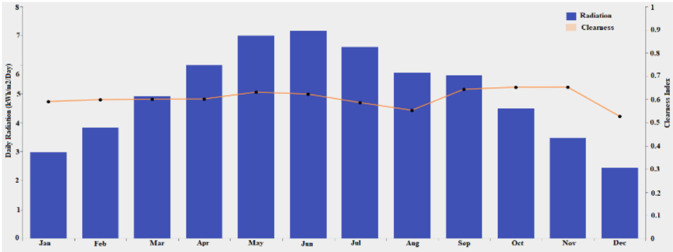

Figure 6. Monthly Solar Radiation and Clearness Index (Site 2)

Maximum radiation falls in June i.e. 7.028 Kwh/m^2/day whereas the minimum in the month of December i.e. 0.526 Kwh/m^2/day. Similarly, the clearness index is maximum in the month of October and November i.e. 0.652 and minimum in the month of August i.e. 0.552. The average irradiance at the proposed site is 5.02 Kwh/m^2/day. While the average clearness index is 0.604.

The tolerable wind speed at proposed ground is 2.86 m/s. The maximum gale pace at the proposed ground is 3.420 m/s. The minimum gale pace at the site is 2.550 m/s. The Average wind speed at proposed site is 1.90 m/s. The average of monthly wind speed at the site is shown in the Figure 7. The maximum wind speed at the proposed site is in the month of June (2.190 m/s) whereas minimum wind speed is in the month of November (1.630 m/s).

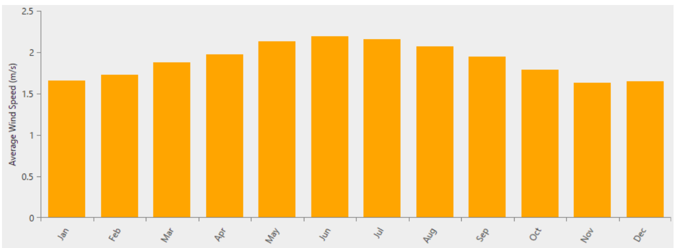

Figure 7. Average Monthly Wind Speed (Site 2)

The micro-hydel plant will be made on Swat River. The main source of water in Swat River is melting glaciers and somewhat monsoon rain water. The mean monthly water flowing through the swat river at the site is taken from Pakhtunkhwa Energy Development Organization (PEDO) and The World Bank assessment report. The maximum stream flow in Swat River is in the month of July (251440 L/s) and minimum in the month of February (13696 L/s) . The above data is fed into the Homer pro and is shown in figure 8.

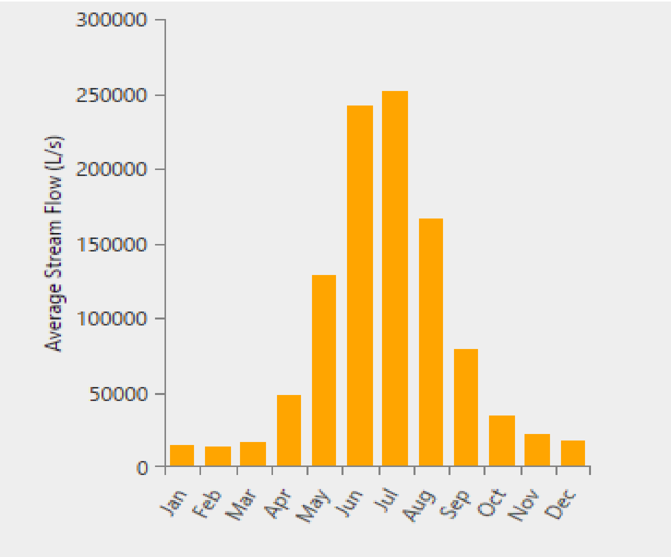

Figure 8. Monthly Average Stream Flow Data

The Swat River starts at the Kalam that is its upper reaches and at lower end near Chakdara it is used for irrigation purpose using different canals. The Swat River also have rain water whereas the average precipitation of entire basin is between 375mm to 1250mm. The canals from Swat River can also be used as potential Micro-Hydro sites [26].

C. Load Profile at Site-1

After the selection of site, the second most important step is selection of load. Load is assumed on the basis of the current trend in Pakistan. The load at Site-1 consist of agricultural and residential load. The load curve at site-1 is shown in the figure 9 below.

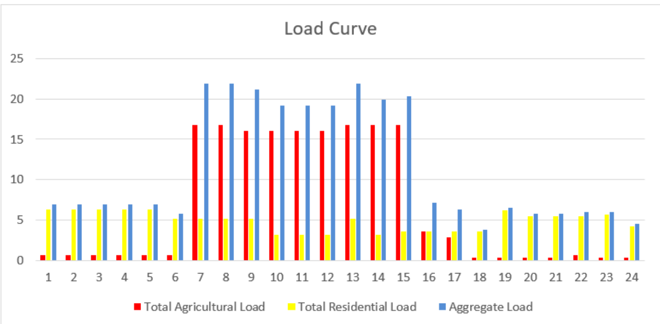

Figure 9. Load Profile at Site-1

Heat map of the load is extracted from the Homer Pro software. The red area in the heat map shows the time frame where maximum load is connected whereas green spots shows mediocre load and blue spot shows when the least load is connected. Figure 10 shows the heat map of the load at site-1.

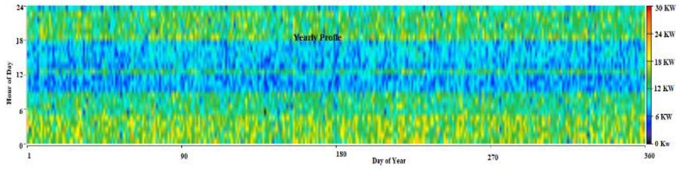

Figure 10. Yearly Heat Map of Load at site-1

D. Load Profile at Site-2

At the second site, only residential load is selected. The load curve and heat map of the residenial load is shown in the figure 11.

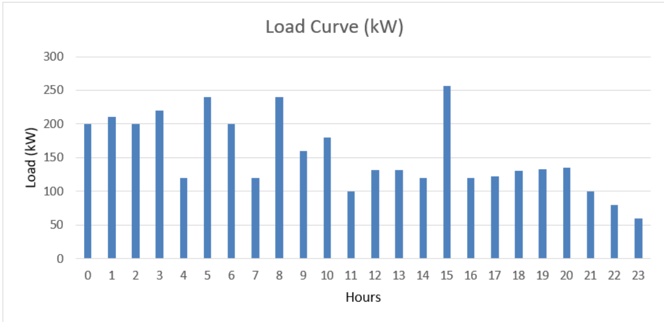

Figure 11. Load Profile at Site-2

Heat maps helps the design engineer to understand better the pattern of the load being followed for a course of time. The yearly heat map profile of the load is shown in the figure 12.

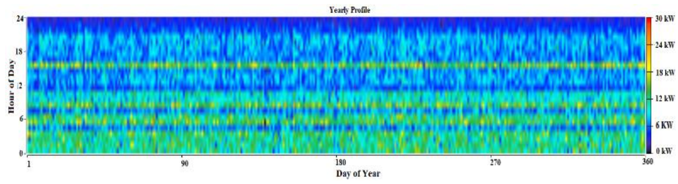

Figure 12. Yearly Heat Map of Load at Site-2

V. SOFTWARE MODELLING

Two different models are made at each site. At the site-1 two different models, named as model-1 and model-2 will be designed whereas at the site-2, model-3 and model-4 will be designed.

A. Model-1

At the first site, the first hybrid off-grid model will be made of Solar PV modules, Wind turbine and Batteries. The converter will be acclimated to alter the DC output that the PV is producing into AC that will be used for load. The solar PV and energy pods are linked with the DC bus whereas the wind turbine is linked to the AC bus. This model will provide to the agricultural and domestic load at the first site. The model-1 is shown in the figure 13.

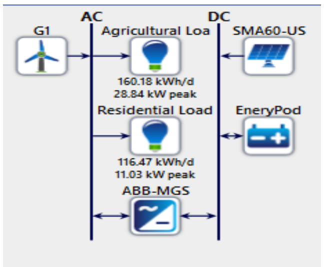

Figure 13. Model-1 Schematic Diagram

The PV array used is SMA sunny tripower 60-US. SMA sunny tripower 60-US are available in the market with different sizes that vary from 1kW to 120 kW. Any can be used for the simulation purpose. The efficiency of the PV array is 17.30 %[27]. The capital Cost of the PV array is 1200$ per kW while replacement cost is considered as 1200$/kW with operation and maintenance cost of 34/year [27]. The life time of the PV array is about 25 years and has a rerating factor of 96% [27]. The wind turbine used in this model is Generic 1 kW" wind turbine manufactured by "Generic". The wind turbine is available in different tower heights 16m, 23m, 30m, and 36m. The hub height is 17m. The wind turbine capital cost $7000/kw while the replacement cost is 7000/kW. The operation and maintenance cost of wind turbine is 70/kW with 20 years of lifetime. "ABB MGS-100" converter is used in this model. The rated capacity of the converter is 20kW, 40 kW, 60kW. The life time of the converter is about 15 years. It has an efficiency of about 95%.

B. Model-2

The second model comprises of Solar PV, Wind Turbine, generator and Batteries. The only additional component in this model from the previous model is a diesel generator. The diesel generator used in this model is "Generac 100kW SD100". It has a minimum load ratio of 25% and life time of 15000 hours. The fuel price for the diesel generator is taken as $0.75/Liter. The The schematic diagram of the model-2 is shown in the Figure 14.

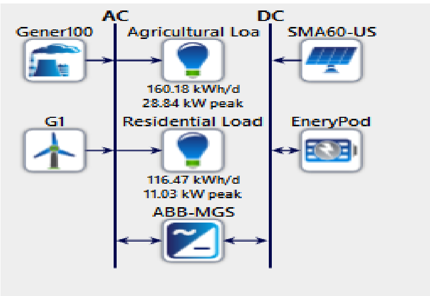

Figure 14. Model-2 Schematic Diagram

C. Model-3

The first model designed at site-2 consists of Solar PV, Batteries, Micro-hydel turbine and converter. The solar PV and energy pod are connected to the DC bus whereas the Hydro-electric generator is connected to the AC bus. The load is also connected to the AC bus. A converter is connected to both the buses and is used to convert DC into AC. It can also work as a rectifier. It can convert AC back into DC. Because sometimes the batteries are also charged with the Hydro-electric generator. The schematic diagram of the model-3 is shown in the Figure 15.

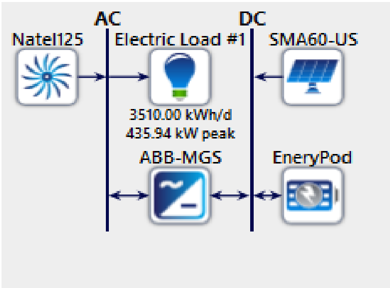

Figure 15. Model-3 Schematic Diagram

The hydro turbine used in this model is "Natel FullyFlooded Hydroengine 125kW" manufactured by "Natel". Its nominal capacity is 125.128kW. The capital cost of the Hydroengine is $45000 while the replacement cost is $22000 and the operation and maintenance cost is $1200/year. The life time of the Hydroengine is 30 years. The available head for the turbine is 2.0m whereas the design flow rate is 8010 liters per second. The efficiency of the Hydroengine is 79.62%. The pipe head loss in 15%.

D. Model-4

The second model designed consists of same components are the previous one, except for that it has a wind turbine in addition to the previous components. The wind turbine used in this model is "Eocycle EO25 class IIA" manufactured by "Eocycle". It has a rated capacity of 25kW. Its rotor diameter is of 12.6m whereas its cut-in speed is about 3.5 m/s and cut-out speed of it is 25 m/s. The schematic diagram of model-4 is showin in the figure 16.

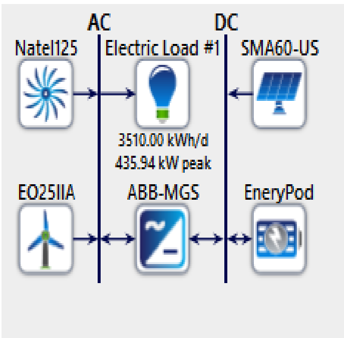

Figure 16. Model-4 Schematic Digram

VI. SIMULATION AND OPTIMIZATION RESULTS

Techno-economic feasibility analysis is performed by Homer Pro and results are established for each site. The results of different simulations are as following:

A. Model-1 Simulation Results

The first model of the first site is simulated and optimized with the help of Homer Pro. 678 different solutions were simulated out of which 264 were feasible solutions. The feasible solutions are shown below in the Figure 17.

Architecture						Cost				System	
SMA60-US (kW)	SMA60-US-MPPT (kW)	G1	EneryPod	ABB-MGS (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
91.1	60.0	1	9	40.2	LF	$202,666	$0.155	$3,487	$157,586	100	0
91.1	60.0	1	9	40.2	CC	$202,666	$0.155	$3,487	$157,586	100	0
91.2	60.0	1	9	39.8	LF	$202,703	$0.155	$3,488	$157,613	100	0
91.2	60.0	1	9	39.8	CC	$202,703	$0.155	$3,488	$157,613	100	0
91.2	60.0	1	9	40.4	LF	$202,720	$0.155	$3,488	$157,626	100	0
91.2	60.0	1	9	40.4	CC	$202,720	$0.155	$3,488	$157,626	100	0
91.6	60.0	1	9	40.2	LF	$203,483	$0.156	$3,504	$158,184	100	0
91.6	60.0	1	9	40.2	CC	$203,483	$0.156	$3,504	$158,184	100	0
91.9	60.0	1	9	35.7	LF	$203,724	$0.156	$3,509	$158 358	100	0
91.9	60.0	1	9	35.7	CC	$203,724	$0.156	$3,509	$158 358	100	0
92.0	60.0	1	9	35.6	LF	$203,831	$0.156	$3,511	$158,436	100	0
92.0	60.0	1	9	35.6	CC	$203,831	$0.156	$3,511	$158,436	100	0
92.0	60.0	1	9	35.8	LF	$203,863	$0.156	$3,512	$158,459	100	0
92.0	60.0	1	9	35.8	CC	$203,863	$0.156	$3,512	$158,459	100	0
92.1	60.0	1	9	35.4	LF	$203,929	$0.156	$3,514	$158,508	100	0
92.1	60.0	1	9	35.4	CC	$203,929	$0.156	$3,514	$158,508	100	0

Figure 17. Homer Pro Optimization for Model-1

The most feasible solution of the model is the one that is at the top of the Table. The results are arranged in ascending order on the basis of feasibility. The total net present cost of the most feasible solution is $202,830.10 and the cost of energy of the system is $0.1554. The operating cost of the feasible solution is $3491.

B. Model-2 Simulation Results

This model differ from the previous model with the addition of diesel generator. 1328 different solutions were simulated by the Homer pro shown in the Figure 18. The total net present cost of the most feasible solution is $173,614 and the cost of energy of the system is $0.1330. The operating cost of the feasible solution is $4055.

Architecture							Cost			
SMA60-US (kW)	SMA60-US-MPPT (kW)	G1	Gener100 (kW)	EneryPod	ABB-MGS (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
70.0	60.0	1	100	5	39.5	LF	$173,614	$0.133	$4,055	$121,189
70.0	60.0	1	100	5	39.1	LF	$173,619	$0.133	$4,055	$121,194
72.1	60.0	1	100	5	39.7	LF	$173,658	$0.133	$3,860	$123,758
70.3	60.0	1	100	5	39.9	LF	$173,672	$0.133	$4,032	$121,548
70.2	60.0	1	100	5	39.1	LF	$173,705	$0.133	$4,047	$121,389
72.5	60.0	1	100	5	39.2	LF	$173,714	$0.133	$3,836	$124,123
72.0	60.0	1	100	5	40.4	LF	$173,722	$0.133	$3,871	$123,674
71.6	60.0	1	100	5	39.9	LF	$173,748	$0.133	$3,918	$123,098
71.9	60.0	1	100	5	39.4	LF	$173,756	$0.133	$3,888	$123,491
69.8	60.0	1	100	5	39.7	LF	$173,788	$0.133	$4,090	$120,918

Figure 18. Homer Pro Optimization for Model-1

C. Model-3 Simulation Results

Model-3 is designed for the second site and its comparison is made with model-4. In this model solar PV, and hydro-electric generator is used alongside batteries and a converter. The Hydro-electric generator is connected to the AC bus while the solar PV and batteries is connected to the DC bus. Converter is connected at the middle between the two buses. The load is connected to the AC bus. When the above model is simulated in homer pro for feasibility analysis following results are attained shown in the Figure 19.

Architecture						Cost		
SMA60-US (kW)	SMA60-US-MPPT (kW)	EneryPod	Natel125 (kW)	ABB-MGS (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)
1.40	60.0	10	125	247	LF	$121,530	$0.00734	$1,622
1.40	60.0	10	125	247	CC	$121,530	$0.00734	$1,622
1.75	60.0	10	125	246	LF	$121,927	$0.00737	$1,622
1.75	60.0	10	125	246	CC	$121,927	$0.00737	$1,622
1.66	60.0	10	125	250	LF	$121,981	$0.00737	$1,625
1.66	60.0	10	125	250	CC	$121,981	$0.00737	$1,625
2.07	60.0	10	125	244	LF	$122,177	$0.00738	$1,620
2.07	60.0	10	125	244	CC	$122,177	$0.00738	$1,620
2.39	60.0	10	125	240	LF	$122,388	$0.00739	$1,617
2.39	60.0	10	125	240	CC	$122,388	$0.00739	$1,617
2.56	60.0	10	125	247	LF	$122,959	$0.00743	$1,625
2.56	60.0	10	125	247	CC	$122,959	$0.00743	$1,625
2.40	60.0	10	125	253	LF	$123,074	$0.00743	$1,631
2.40	60.0	10	125	253	CC	$123,074	$0.00743	$1,631

Figure 19. Homer Pro Optimization of Model-3

The total net present cost of the most feasible solution is $121,529.80 and the cost of energy of the system is $0.007341. The operating cost of the feasible solution is $1621.8.

D. Model-4 Simulation Results

Homer Pro simulated 928 different solutions for the model. Out of this, 536 solutions were feasible. 392 solutions were infeasible due to the capacity shortage constraint. The results of the simulation is shown in Figure 20. The total net present cost of the most feasible solution is $263683.30 and the cost of energy of the system is $0.01593. The operating cost of the feasible solution is $2406.62

Architecture							Cost			
SMA60-US (kW)	SMA60-US-MPPT (kW)	EO25IIA	EneryPod	Natel125 (kW)	ABB-MGS (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
60.0	60.0	1	9	125	338	LF	$263,683	$0.0159	$2,407	$232,572
60.0	60.0	1	9	125	338	CC	$263,683	$0.0159	$2,407	$232,572
60.0	60.0	1	9	125	338	LF	$263,745	$0.0159	$2,407	$232,632
60.0	60.0	1	9	125	338	CC	$263,745	$0.0159	$2,407	$232,632
60.0	60.0	1	9	125	341	LF	$263,829	$0.0159	$2,410	$232,680
60.0	60.0	1	9	125	341	CC	$263,829	$0.0159	$2,410	$232,680
60.0	60.0	1	9	125	341	LF	$263,891	$0.0159	$2,410	$232,740
60.0	60.0	1	9	125	341	CC	$263,891	$0.0159	$2,410	$232,740
60.0	60.0	1	9	125	344	LF	$263,988	$0.0159	$2,413	$232,798
60.0	60.0	1	9	125	344	CC	$263,988	$0.0159	$2,413	$232,798
60.0	60.0	1	9	125	344	LF	$264,050	$0.0159	$2,413	$232,858

Figure 20. Homer Pro Optimization for Model-4

CONCLUSION AND DISCUSSION

The comparison between model-1 and model-2 is shown in the table 1.

TABLE I. MODEL-1 AND MODEL-2 COMPARISON

Results	**Model-1**	**Model-2**
Net Present Cost	$202,830.10	$173,614
Capital Cost	$157,706	$121,189
Cost of Energy	$0.1554	$0.1330
Operating Cost	$3,491	$4,055
Annual Electricity Production	151,589 kWh/year	130,650 kWh/year
Annual Electricity Consumption	100,964 kWh/year	100,977 kWh/year
Fuel Consumed	---	1,934 Liters/year
Excess Electricity	40,538 kWh/year (26.7% of total Electricity Produced)	6,868 kWh/year (5.26% of total Electricity Produced)
Emissions (CO_2)	---	4412 kg/year
Wind Contribution	188 40,538 kWh/year	188 kWh/year
PV Contribution	151,401 kWh/year	125,062 kWh/year
Battery Quantity	9	5
Diesel Generation	---	5400 kWh/year
Converter (Inverter-Rectifier)	60kW-36kW	60kW-36kW
Renewable Fraction	100%	94.7%
Losses	40,538 kWh/year (26.7% of Total Electricity Produced)	22,805 kWh/year (5.26% of Total Electricity Produced)

Selecting an appropriate solution for any site is a difficult task as every model has its own pros and cons. The same is the case with these two models. The second model capital cost, net present cost and cost of electricity is less than the first one but the second model produce more emissions than the first one. A compromise should be made between cost and emissions. On the basis of all the results it is proposed that the 2nd model is more techno-economically feasible. The electricity tariff of Pakistan as regularized by the National Electric Power Regulatory Authority is Rupees 22.35/kWh i.e. $0.14. So the electrical tariff of the model-2 is less than the electrical tariff of the NEPRA, Government of Pakistan. Similarly the comparison between model-3 and model-4 is shown in the Table 2.

TABLE I. MODEL-3 AND MODEL-4 COMPARISON

Results	Model-3	Model-4
Net Present Cost	$121,529.80	$262,683.30
Capital Cost	$100,565	$232,572
Cost of Energy	$0.0073	$0.01593
Operating Cost	$1621.76	$2406.62
Annual Electricity Production	1,514,781 kWh/year	1,627,466 kWh/year
Annual Electricity Consumption	1,280,747 kWh/year	1,281,002 kWh/year
Excess Electricity	150,9378 kWh/year (9.96% of total production)	278,163 kWh/year (17.1% of total production)
Emissions (CO_2)	0 kg/year	0 kg/year
Hydro Generator Contribution	1,512,151 kWh/year	1,512151 kWh/year
Wind Contribution	---	2142 kWh/year
PV Contribution	2,630 kWh/year	113,173 kWh/year
Battery Quantity	10	9
Losses	83,096 kWh/year (5.4% of Total Electricity Produced)	68,301 kWh/year (4.19% of Total Electricity Produced)

The Cost of electricity, Initial capital cost and the net present cost of model-3 is less than that of model-4, so the most feasible solution at site-2 is model-3. The electricity tariff of Pakistan as regularized by the National Electric Power Regulatory Authority is Rupees 22.35/kWh i.e. $0.14. So the cost of electricity of model-3 is also less than electrical tariff of the Government of Pakistan. Pakistan is producing most of electricity from the conventional resources that are producing drastic environmental effects. Renewable resources will not only help in filling the energy deficient void but will also help in reducing environmental hazards. Using renewable resources will provide cheap electricity for the remote area electrification of Pakistan and will improve the standard of living of people.

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