Economic Analysis of Distributed Generation for Hybrid Renewable Energy System

Fahid Javed Sattar Randhawa[1], Muhammad Bilal Sarwar[2], Muhammad Haseeb Shams[3], Abdul Rehman Saeed[4]
[1,2]The University of Faisalabad, [3, 4] Riphah International University Faisalabad

Abstract—Because of the fossil fuel dominant energy mix operating cost of most of the power plants is high while the renewables have almost negligible Operating cost and emissions. Seasonal pattern of Pakistan is pro to renewable energy resources. Solar insolation and wind speed in Pakistan are enough to harness energy. It is preferable to use a standby diesel generator with Hybrid Renewable Energy System (HRES). Many distribution generators like natural resources several types of renewable energy sources can be integrated to entertain off grid and grid connected loads. Components of HRES are technically modeled and then HOMER Pro has been used on a specified given off grid location.

Economic assessment of HRES is performed by HOMER Pro that uses hourly time series data (solar radiations, wind speed and load data) to perform energy balance on each component. This could save cost incurred on the extension of the national grid to remote areas. This paper would be helpful for the foreign as well as indigenous investors in the field of energy. The feasibility study of implementing a Hybrid Renewable Energy System for Riphah international University Faisalabad extension is assessed.

After considering the technical requirements of implementing a Hybrid Renewable Energy System and simulating the economic performance of such a system, it was determined that implementing a Hybrid Renewable Energy System could benefit Riphah International University Faisalabad and that it could be considered feasible to do so. The result are approximately accurate according to the needs of this research.

Index Terms—Micro grid, Distributed generation, Hybrid Renewable Energy System (HRES).

1. Introduction

A critical increases in reliance upon petroleum based power generation cannot be finished in long-term. Therefore there must be a separate micro-grid should be implemented based on maximum use of renewable energy resources. In this thesis I focused on designing a low cost and efficient micro-grid application for Riphah International Univeristy Faisalabad Campus.
As the electricity outage is increasing day by day and meanwhile expansion of university if also taking place so in absence of Electricity supplied by FESCO use of petroleum to operate the generator for continuous energy supply also increased and the maintenance cost of GenSet is also expanding.

The Future goal for this project is to create an extendable setup that can be applied to all types of institutions. The project is designed so that is should be sufficient for stationary device but portable devices for run time operations will also considered. Renewable energy sources (RESs) have been used in an inefficient and non-technical way since the Stone Age. With the advancement of renewable technologies these RESs can be integrated in an effective manner to produce electrical power [1],[2],[3],[4].These RESs include solar Photo Voltaic, solar thermal, wind, biomass, geothermal, micro hydro and tidal energy.
Riphah International University Faisalabad located at the coordinates of 32∘46.6′ N, 72∘ 42.1′ E has been selected as a case study having an annual average solar radiation 6 kWh /m2 /day and wind speed 5.4 m /s. A solar/wind hybrid system along with a standby diesel generator and storage batteries is proposed at the site to entertain a load of 30 kWh /d. During off peak hours load is entertained by photovoltaics and wind generators while the excess energy is stored in batteries which is used in peak hours. If the batteries are unable to share the load then a stand by diesel generator takes part to meet the load demanded as shown in figure 5.

- *Fahid Javed Sattar Randhawa is currently pursuing masters degree program in electric power engineering in The University of Faisalabad, Pakistan ,E-mail: Randhawa461@gmail.com*
- *Muhammad Bilal Sarwar is currently serving as lecturer in electric power engineering in The University of Faisalabad, Pakistan, E-mail: Bilal.Sarwar@tuf.edu.pk.*

2. System Components Modeling

System components are modeled so as to optimize the power flow from the point of production to the point of consumption. The energy balance of the HRES is as follow

$$E(t) = E_{PV} + E_{WG} + E_{DG} \qquad (1)$$

Each term of the equation (1) is explained in corresponding component's detailed model as follow.

2.1 Solar photovoltaics:

Figure 1 shows average solar insolation in Pakistan

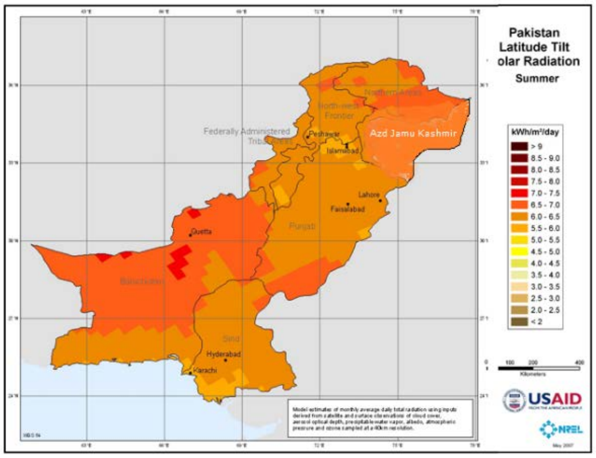
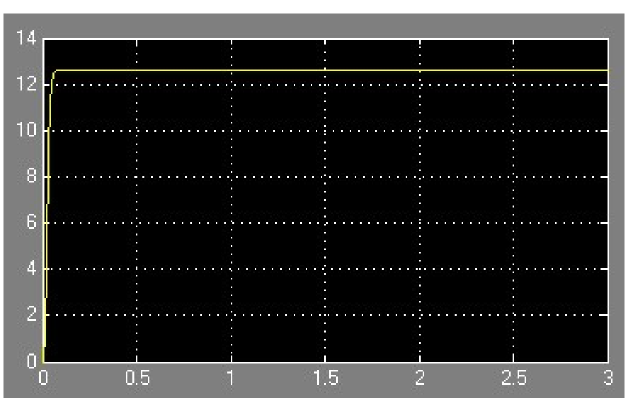


Fig.1. Solar resource map of Pakistan (kWh/kW-yr)

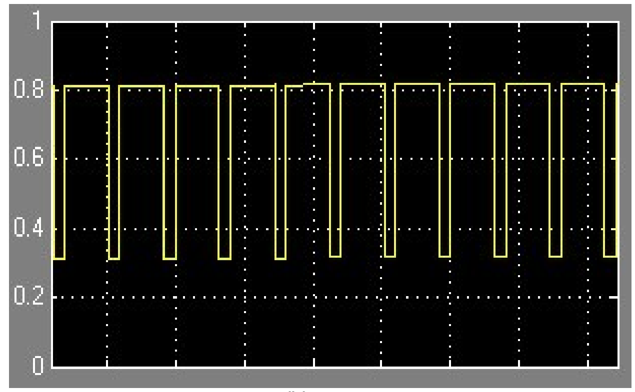
The output power of PV is used to serve the load (L) and battery storage (BS) as shown in energy flow equation (2).

$$E_{pv} = E_{pv\rightarrow L} + E_{pv\rightarrow BS} \quad (2)$$

The output power of the PV cell is vulnerable to the PV cell temperature and solar insolation. With the variation in solar insolation maximum power point (MPP) continuously varies on power curve of the PV. To gain maximum output from photovoltaic(PV),maximum power point tracker (MPPT) is proposed using Incremental Conductance (InC) algorithm that controls the duty cycle D of the converter switch by comparing InC ($^{\Delta I}/_{\Delta V}$) to instantaneous conductance ($^{I}/_{V}$) and tracks the maximum power point on the power curve [7]. Solar PV system along with MPPT is modeled in MATLAB SIMULINK. Output power of solar PV and duty cycle fed to the converter are shown in figure 2. Duty cycle D is the output of the MPPT.



(a)



(b)

Fig.2. (a) Solar PV output after converter. (b) Duty Cycle

Solar daily radiation and clearness index data for the proposed site is shown in figure 3.

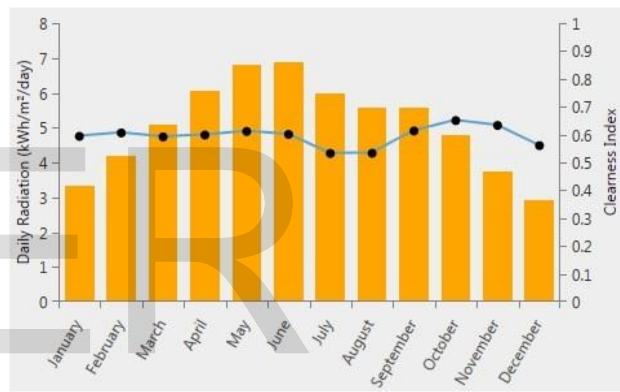


Fig.3. Solar Daily Radiation Data

2.2 Wind Turbine Generator:

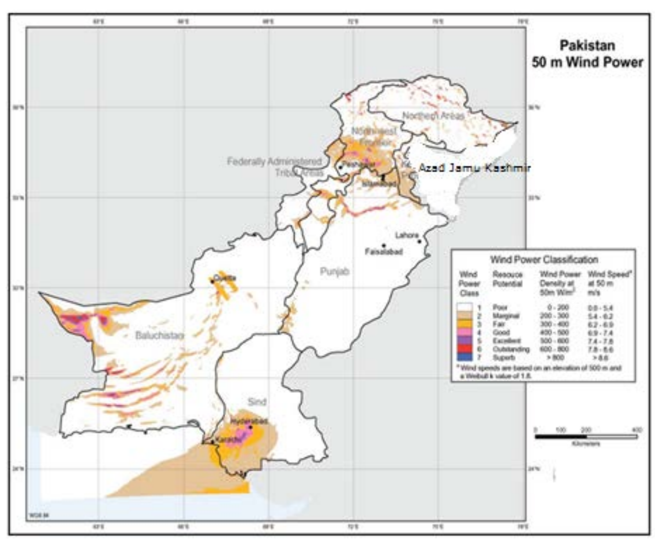


Fig. 4. Wind resource map of Pakistan

The wind turbine generator is used to serve the load and charge the battery storage (BS) shown in equation

$$E_{WG} = E_{WG\rightarrow L} + E_{WG\rightarrow BS} \quad (3)$$

HOMER Prouses both power law profile and logarithmic profile to model the wind shear [3]. Wind shear is the change in wind speed with respect to height. In our study height of the anemometer is 10m while the hub height is 50 m. Following power is used for that purpose.

$$U_{hub.} = U_{anem.} \left(\frac{z_{hub.}}{z_{anem.}}\right)^{\alpha} \quad (4)$$

$U_{hub.}$ and $U_{anem.}$ are the wind speeds at hub height of WT and anemometer height respectively. Z_{hub} and Z_{anem} are the hub height of WT and anemometer height respectively.$\alpha$is the power law exponent.

The performance of wind turbine is specified under standard Temperature & Pressure (STP). HOMER Procalculates actual WT output power by applying a density correction by using equation (5).

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right).P_{WTG,STP} \quad (5)$$

Where ρ and ρ_0 are the actual air density and air density at STP respectively,$P_{WTG,STP}$ is the output power at STP, P_{WTG} is the actual output power of WT.

Wind speed data for the proposed location is shown in figure 5.

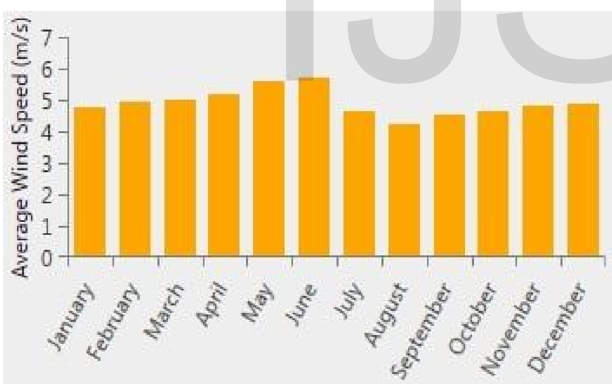


Fig. 5. Wind Speed Data

2.3 Diesel Generator:

The dispatch strategy that is used in the simulation model is the load following strategy where the generator operates to serve only primary load whereas the low priority loads such as battery storage and deferrable loads are served by the renewables only. HOMER Proprovides both load following strategy and cycle charging strategy. Both strategies has been studied in detail in [8]. Energy flow strategy is shown in figure 6.

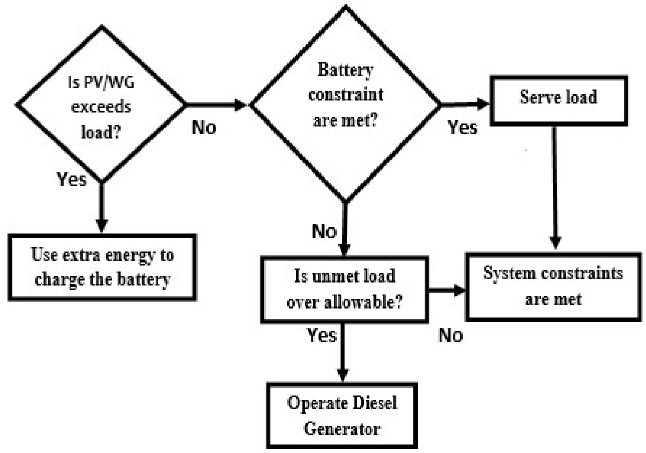


Fig. 6. Energy Flow Strategy

2.4 Battery Storage:

The excess amount of energy of the renewables is used to charge the battery bank so that it could be used in peak hours.Charge controllers are used to avoid the overcharging and deep discharging of the battery banks to save them against the irreparable damages. The following constraints are set for the battery bank.

$$SOC_{max.} \geq SOC(t) \geq SOC_{min.} \quad (6)$$

$SOC_{min.}$ is set at 30% of the capacity of the batter bank and $SOC_{max.}$ is at 100%.

2.5 Converter:

A bidirectional buck-boost converter is proposed in this Hybrid Renewable Energy System application. Converter operates in buck mode to charge the battery, when renewables exceed the load demand, and in boost mode for discharging the battery storage to the Hybrid Renewable Energy System when load exceeds the renewable energy generation. DC-DC buck-boost converter is shown in figure 7. Pulse generator is MPPT in actual model.

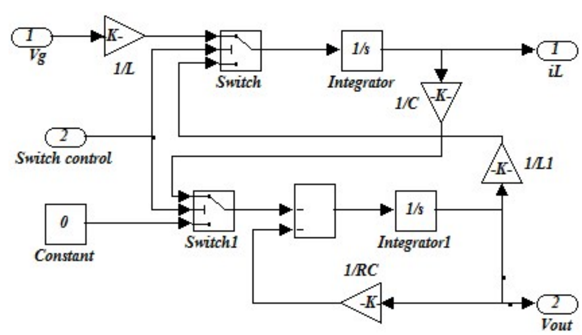


Fig. 7. Buck-Boost Converter

Diode, SCR, GTO, MOSFET and IGBT can be used as semiconducting switch to control the operation of the DCDC converter [4].
By applying KVL and KCL, state space equations 7) and (8) are obtained for both ON and OFF states of the switch S.

$$\begin{cases} i_L = \int \left(\frac{V_g}{L}\right) dt \\ V_{out} = -\int \left(\frac{V_{out}}{RC}\right) dt \end{cases} \quad 0 < t < DT_s \qquad (7)$$

$$\begin{cases} i_L = \int \left(\frac{V_{out}}{L}\right) dt \\ V_{out} = \int \left(-\frac{i_L}{C} - \frac{V_{out}}{RC}\right) dt \end{cases} \quad DT_s < t < T_s \qquad (8)$$

Using these state space equations DC-DC buck-boost converter is modeled in MATLAB/SIMULINK.

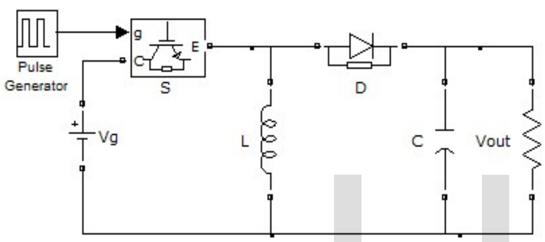


Fig. 8 Model of Buck-Boost Converter

3. Economic Analysis:

The final stage of this research paper involved performing economic analysis operations using HOMER Pro, an application developed by the NREL. Other software packages were considered before HOMER was finally selected; various authors have identified and compared the available software while others designed their own modeling software using MATLAB or proprietary architectures. HOMER was selected for this research largely because it is the most-used software for Hybrid Renewable Energy System economic feasibility simulation. Figure 9 displays the relationship between the technical and economic sides of the problem.

This economic analysis was designed according to the technical framework described above. Many of the required inputs were satisfied using data obtained while the actual equipment considered for use was determined in system modeling.

3.1 Home Pro Simulation Results:

HOMER PR vitality demonstrating programming is the most well-known apparatus used to plan and dissect crossover control frameworks, for example, micro grids. It is utilized to decide the monetary practicality of different framework setups and enhance their last outline.

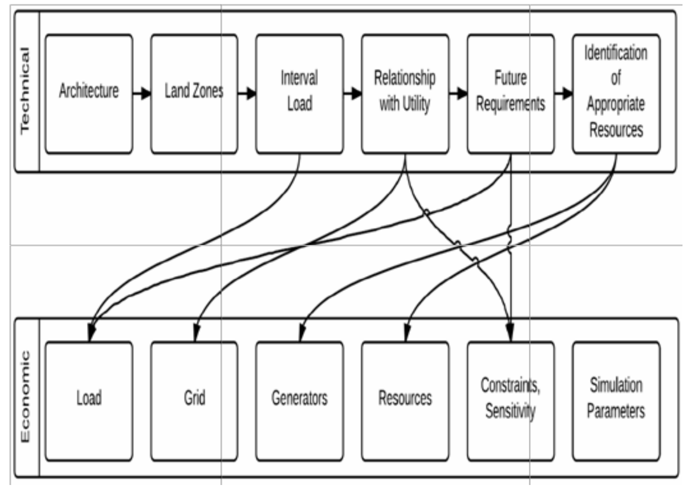


Fig. 9. Relationship of Technical and Economic Feasibility Considerations.

HOMER PRO's usefulness can be gathered into three standard undertakings: reproduction, enhancement, and affectability investigation in the reenactment procedure, HOMER PRO models the execution of a given setup in indicated time increases. In the streamlining procedure, numerous designs are reenacted and arranged by how well they fulfill given restrictions. In the affectability examination, HOMER PRO plays out numerous advancements with various information esteem. Along these lines it tends to be utilized to recreate various Hybrid Renewable Energy System designs on the double, utilizing improvement and affectability investigation to choose the "best fit" in light of the client's limitations, enabling the client to look at a wide range of situations and objectives. This practical relationship is appeared in Figure 10.

By using wind speed, solar irradiance, load profile and details of the components, HOMER uses hourly time series data, simulates a hybrid energy system and generates a list of optimization cases. Simulation was done with and*Figure.*

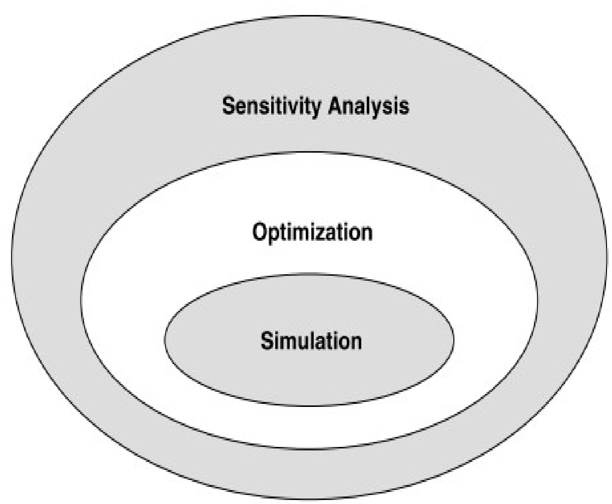


Fig. 10. HOMER PRO Operations

without the consideration of sensitivity variables like load profile and diesel price.

The simulation Results are shown in table III. The most optimum case carries a COE 0.375($/kWh) with a NPC of $53,070. In this hybrid energy system renewable is the dominant source of energy with 53% of its share. Cost summery of the optimum case reveals that a major portion of the cost is incurred on the diesel generator. Homer Pro Interface is shown in figure 11.

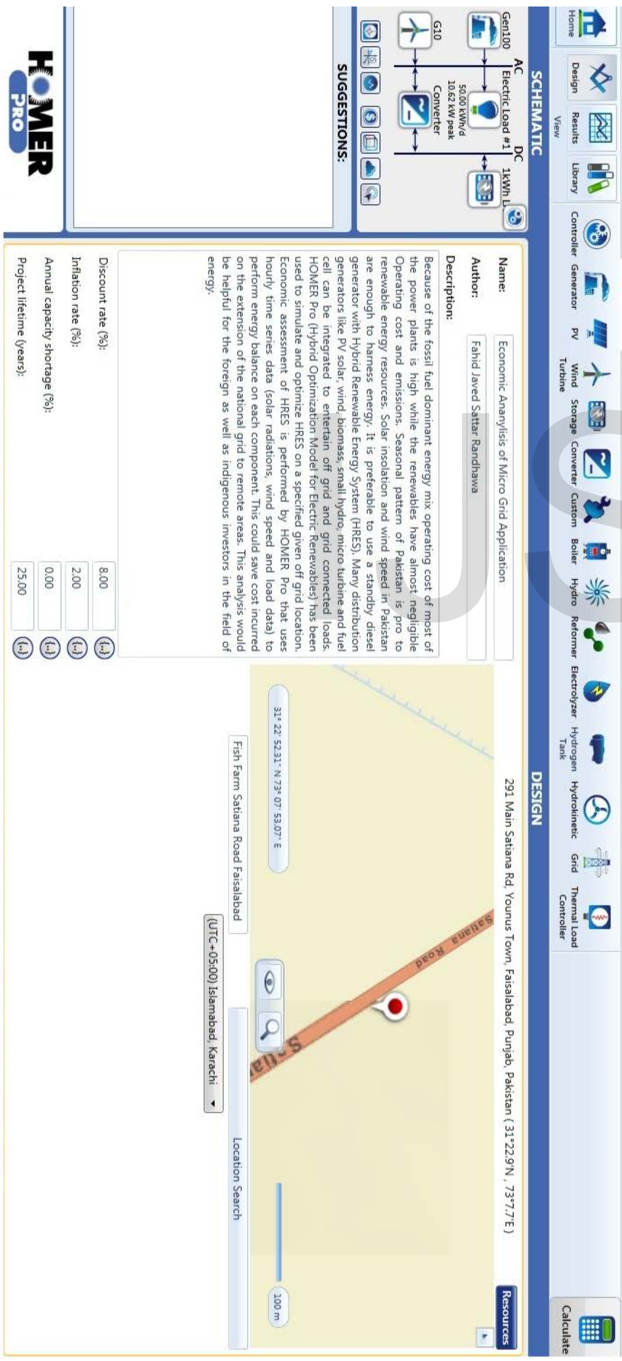


Fig. 11. HOMER PRO Interface

Its interface is relatively simple, yet grows in complexity as more data is entered.

Figure 11 shows the interface when a new project is created. The leftmost column includes Equipment and Resource data, while the large rightmost column contains the simulation results. All fields are empty at this point.

The step wise process is explained below.

3.1.1 Defining location for analysis.

First of all with the help of global resources attached with HOMER Pro the location is selected i.e. in this research Riphah International University Faisalabad has been selected as it is an emerging and developing institution.

3.1.2 Adding Equipment:

Based on the findings of the Identification of Appropriate Distributed Resources section, the components considered for simulation

- Diesel Generator.
- Natural gas Generator
- Biogas-fueled generator.
- Photovoltaic generation.
- Fuel cell.
- DC converter.
- AC converter.

In this research paper PV, Wind, Diesel Generator are used as they the major renewable resources available in high potential in this area.

3.1.3 Economics:

The Economics inputs are used for each system HOMER PR simulates, and is primarily used to calculate the system's economic growth.

TABLE. 1.

System Structure for Optimum Cases

.

I. Photovoltaic		
Quantity	**Value**	**Unit**
Rated Capacity	4	kW
Total Production	6761	kWh /yr
PV Penetration	61.75	%
Operating Hours	4385	hrs/yr
Capacity Factor	19.29	%
COE	0.137	$ /kWh
II. Wind Turbine Generator		
Rated Capacity	3	kW
Total Production	1772	kWh /yr
Wind penetration	16.8	%
Operating Hours	5717	hrs/yr
Capacity Factor	6.742	%
COE	0.217	$ /kWh
III. Diesel Generator		
Rated Capacity	4	kW
Total Production	5146	kWh /yr
Operating Hours	3287	hrs /yr
Capacity Factor	14.69	%
Fuel Consumption	2102	L/yr
Marginal COE	0.23	$ /kWh
V. Converter		
Capacity	3	kW
Capacity Factor	17.9	%
Operating Hours	6046	hrs /yr
Losses	522	kWh /yr

TABLE. 2.
Sensitivity Cases (Electric Load and Diesel Price)

System Type	PV (kW)	WG	DG (kW)	1 KWh LA	Converter (kW)	COE ($/kWh)	NPC ($)	Operating Cost ($/yr)	Initial Capital $	Renewable Fraction %
	4	3	4	8	3	0.375	53,070	2651	18800	53
	4	3	4	8	3	0.385	54,429	2756	18800	53
	3	2	4	4	3	0.390	46,022	2508	13600	45
	4	3	4	8	3	0.394	55,788	2861	18800	53

TABLE. 3.
Optimization Cases

System Type	PV (kW)	WG	DG (kW)	1 KWh LA	Converter (kW)	COE ($/kWh)	NPC ($)	Operating Cost ($/yr)	Initial Capital $	Renewable Fraction %
	4	3	4	8	3	0.375	53,070	2651	18,800	53
	4	3	4	8	4	0.376	53253	2650	19000	53
	4	3	4	8	5	0.378	53466	2651	19200	53
	4	4	4	8	3	0.378	53522	2609	19,800	55

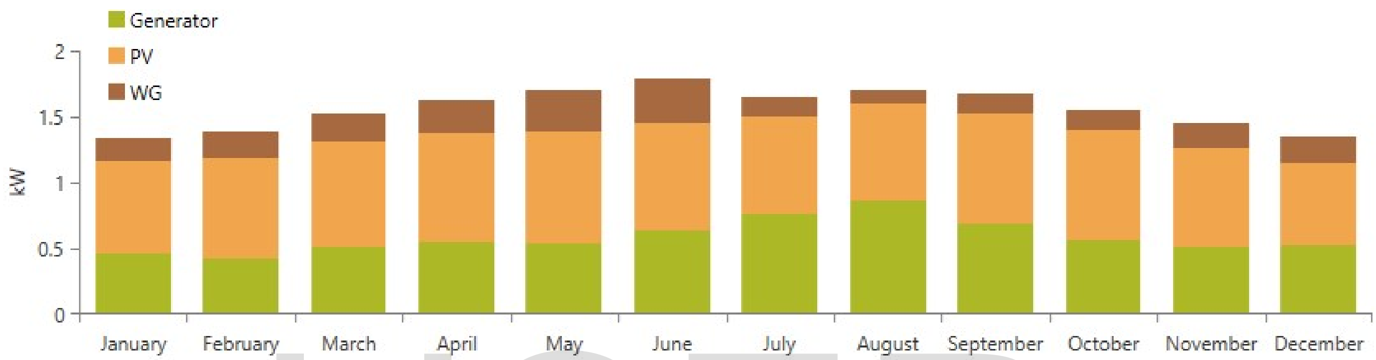


Fig.12. Electrical Energy Production

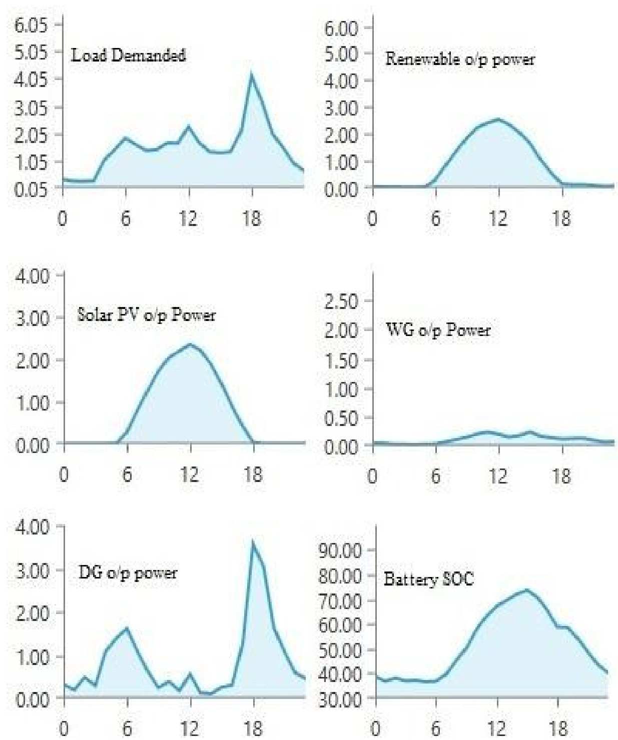
3.2 Daily Profile Analysis:

Daily profile of the renewable power output indicates an increase from 6AM to 6PM and during this time state of charge (SOC) of the battery is also increasing which follows the pattern of solar PV power output which forms a bell shape graph while the power output of wind generator is almost constant throughout 24 hours a day. Diesel generator operates at its rated capacity around 6PM because renewable output power is minimum during this time and load demand is at its peak. Remaining hours of the day it operates according to the load demanded and SOC of the battery as shown in figure 9.

3.3 Cost Summery

Cost summery of the optimum system in table IV depicts that the fuel and O&M cost of the DG increase the cost of the system exponentially. On the other hand cost of the system is directly. The increase in RF of the system increases the initial capital cost and decreases the OC, O&M and NP cost as shown in table II and IV. Simulation results provide an optimum hybrid system (renewable and fossil fuel based) and also indicates a decrease in NPC and COE if only Hybrid Renewable Energy System is adopted because of the high fuel cost as shown in table II and IV. COE by solar PV and WG is 0.13 ($/kWh) and 0.21($/kWh) respectively shown in table I. If a standalone solar PV system is optimized it would include cost of batteries and converter also.

Fig.9. Daily Profile Analysis



ISSN 2229-5518

3.4 Cash Flow:

From the commencement of the project till the end of the project a high fuel cost and an almost constant operating cost occur for each year as shown in figure 10. Replacement cost of the batteries occur repeatedly 7 times throughout the project. All these cost discussed above are cash outflows while at the end of the project there is a salvage value of the project that is called cash inflow. The cash flow summary for 25 years of the project is shown in figure 10.

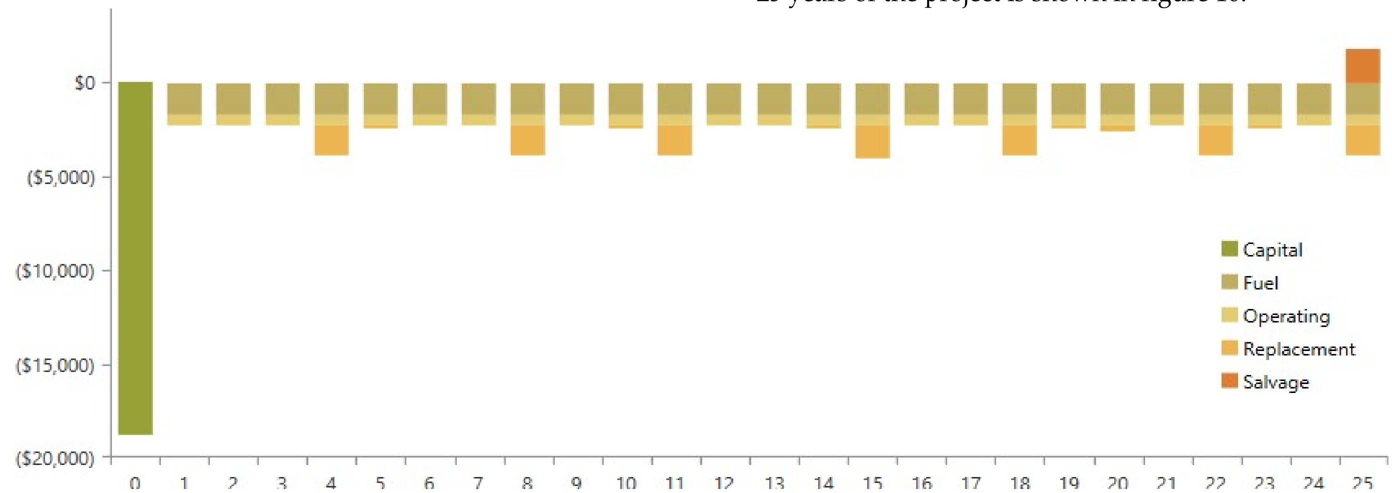


Fig.10 Cash Flow

TABLE. 4.

Cost Summary

Components	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	12,000	0.00	0.00	0.00	0.00	12,000.00
WTG	3,000	95.64	1939.00	0.00	53.90	4,980.90
DG	800	391.18	5099.10	21,748.00	20.00	28,018.00
1kWh LA	2,400	5,395.10	0.00	0.00	366.07	7,429.00
Converter	600	50.91	0.00	0.00	9.58	641.33
System	18,800	5,932.80	2178.00	21.748.00	449.55	53,070.00

4. CONCLUSION

In this research work a solution to the lack of electricity and energy conversion technologies is proposed. Distributed sources of energy (solar wind and Diesel generator) are integrated forming a micro grid. Components of a hybrid energy system are modeled and using HOMER Proan optimum system is configured. Cost of energy was found to be 0.34 $/kWh. However, it is found that diesel generator is a cost effective source of energy in terms of fuel cost that is much high in a country that depends upon imported oil. In future study many distributed sources like micro turbine, steam turbine, fuel cell, micro hydro and bio gas generators can be integrated to the system that put a positive economic impact to the whole system and can be have indigenously.

The results of the HOMER simulation are highly dependent upon the accuracy of the assumptions made; in this case, all assumptions were "best-case" scenarios, and therefore the results obtained should be considered to be an upper limit. Furthermore, many of the inputs were modeled as static values, not fluctuating throughout the simulation period as they would in reality.

This is especially significant for the grid electricity rate and fuel cost. This simulation calculated that the gas generators provided more efficient performance as compared to other power generation devices. this could easily change with changing fuel prices or availability. Likewise, any change to the costs to install and operate other generation types would likely change the results. Because of the many assumptions made, the information presented in the HOMER model should not be taken to be representative of the true

ISSN 2229-5518

performance of a Hybrid Renewable Energy System at Faisalabad.

Additionally, while the costs of interconnection were included in the capital costs for each generation source, they did not include the indirect costs of adding or replacing certain electrical components that must be matched to the capacity of the system. Moreover, the costs of additional communication and control systems were not considered. These costs would have to be considered if a Hybrid Renewable Energy System were to be considered beyond the feasibility stage.

ACKNOWLEDGMENT

I wish to thank Sir Bilal Sarwar, Sir Furqan Asghar for all support in making this research work possible and Abdul Rehman Saeed for assisting me in successful publication of this paper in IJSER

REFERENCES

[1]. Ali L, Shahnia F, (2017) Determination of an economically-suitable and sustainable standalone power system for an off-grid town in Western Australia, Renew. Energy, 106, 243–254.

[2]. Bhatt A, Sharma M, Saini R, (2016) Feasibility and sensitivity analysis of an off-grid micro hydroephotovoltaicebiomass and biogasedieselebattery hybrid energy system for a remote area in Uttarakhand state, India, Renew. Sustain. Energy Rev. 61, 53-69

[3]. Barr, Dave, Chrissy Carr, and Eric Putnam. 2013. "Hybrid Renewable Energy System Effects and Opportunities for

[4]. Utilities Hybrid Renewable Energy System Effects and Opportunities for Utilities."

[5]. Basso, Thomas, and R DeBlasio. 2012. "IEEE Smart Grid Series of Standards IEEE 2030

[6]. (Interoperability) and IEEE 1547 (Interconnection) Status." In Grid-Interop 2011. Vol. 2030.

[7]. http://www.nrel.gov/docs/fy12osti/53028.pdf.

[8]. Hoque MM, Bhuiyan IKA, Ahmed R, Farooque AA, Aditya SK, (2012) Design, Analysis and Performance Study of a Hybrid PVDiesel Wind System for a Village Gopal Nagar in Comilla, Renew. Sustain. Energy Rev., 12 (5), 1–5.

[9]. Latif A, Ramzan N, (2014) A review of renewable energy resources in Pakistan, J. Glob. Innov. Agric. Soc. Sci. 2(3), 127–132.

[10]. J. Int. Environmental Application & Science, Vol. 12(4): 270-276 (2017) 276

[11]. Li C, Ge X, Zheng Y, Xu C, Ren Y, Song C, (2013) Techno-economic feasibility study of autonomous hybrid wind / PV / battery power system for a household in Urumqi , China," Energy, 55, 263-272.

[12]. Maatallah T, Ghodhbane N, Ben Nasrallah S, (2016) Assessment viability for hybrid energy system (PV / wind / diesel) with storage in the northernmost city in Africa, Bizerte, Tunisia, Renew. Sustain. Energy Rev., 59, 1639-1652.

[13]. Munuswamy, K. Nakamura, A. Katta, (2011) Comparing the cost of electricity sourced from a fuel cell-based renewable energy system and the national grid to electrify a rural health centrein India: a case study, Renew. Energy, 36 (11), 2978-2983.

[14]. Papaioannou DI, Papadimitriou CN, Dimeas AL, Zountouridou EI, Kiokes GC. "Optimization & Sensitivity Analysis of Microgrids using HOMER software- A Case Study." Renew. Sustain. Energy Rev, 16 (8), 6183–6190.

[15]. Phrakonkham S, Chenadec JLe, Diallo D, Ieee SM, (2013) Optimization software tool review and the need of alternative means for handling the problems of excess energy and mini-grid configuration: A case study from Laos. Renew. Sustain. Energy Rev, 107, 24–30

[16]. Sinha S, Chandel SS,(2014) "Review of software tools for Hybrid Renewable Energy System s, Renew. Sustain. Energy Rev., 32, 192–205.

[17]. Türkay BE, Telli AY, (2011) Economic analysis of standalone and grid connected hybrid energy systems, Renew. Energy, 36 (7), 1931–1943.

[18]. M. Gujar, A. Datta and P. Mohanty, ―Smart Mini Grid: An

[19]. Innovative Distributed Generation based Energy System,‖ Proc. of IEEE Innovative Grid Technologies – Asia (ISGT Asia), Bangalore, 2013.

[20]. Dehghani-Arani, A.; Maddahi, R., "Introduction a multi-objective function in unbalanced and unsymmetrical distribution networks for optimal placement and sizing of distributed generation units using NSGA-II," Electrical Power Distribution Networks (EPDC), 2013

[21]. 18th Conference on , vol., no., pp.1,9, April 30 2013-May 1 2013

[22]. Türkay, Belgin Emre, and Ali Yasin Telli. "Economic analysis of standalone and grid connected hybrid energy systems." Renewable energy 36.7 (2011): 1931-1943.

[23]. B. Kroposki, C. Pink, R. Deblasio, H. Thomas, and P. K. Sen, ―Benefits of power electronic interfaces for distributed energy systems,‖ in Proc. IEEE Power Eng. Soc. General Meeting, 2006, Jun. 2006.

[24]. Yadav and L. Srivastava, ―Optimal placement of distributed generation: An overview and key issues‖, International Conference on Power Signals Control and Computations (EPSCICON), pp. 1-6, 2014.

[25]. D. T. Rizy and W. T. Jewell et. al, ―Operation and design

[26]. Considerations for electric Distribution Systems with Dispersed Storage and Generation (DGS)‖, IEEE Trans. PAS, PP.2864-2871, 1985.