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Design and Optimization of Hybrid Renewable Energy Source for Economic Analysis

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Abstract—*Due to tremendous growth in population, technological developments and increasing domestic consumption, demand for electricity has increased in last few decades. Fossil fuels are also exhausting rapidly and their harmful effects are also inevitable. Therefore Hybrid Renewable Energy System (HRES) can provide Smart solution for these increasing demands without harming environmental conditions. India is emerging as leader in renewable energy harvester which is significant in national energy security and economic stability. Government of India is also supporting renewable energy sectors, by providing financial aids and education. But the problem in using HRES is to design economic system and optimize the system for its cost of generation and reliability. The objective of this paper is to design a grid connected HRES for an academic building and to evaluate the Net Present Cost and Cost Of Energy of the system with the help of HOMER Pro software. The results provide simulated combination and sizing of components with minimum cost for the system as- Solar photovoltaic 50 KW, Bio-diesel generator 10 KW, converter 9 KW and 198 KWh Battery, with gird connection for backup. The Cost Of Energy for the overall system is Rs. 5.48 per KWh which approximately same as grid energy cost and surplus energy is supplied back to the grid.*

Keywords: *Hybrid Renewable Energy System (HRES), Solar photovoltaic, Biomass and HOMER Pro Software.*

1. INTRODUCTION

India is the second largest populated country in the world and third biggest consumer of electricity in the world. Energy consumption has increased in all areas including industries, agriculture, commercial and residential and further expected to grow. [1] Energy sector, especially electricity production plays important role in meeting imperishable development and environmental issues. World is endangered to climatic changes like global warming, sea-level rise, beach erosion and increasing temperature due to utilization of fossil fuels in energy generation. India's electricity generation system is mainly based on coal and it has been reported that coal and oil, it has been reported that world's coal and oil manufacturing will reach near its exhaust in 2020. Next to coal, nuclear energy is source of electricity production and uranium is expected to gain its peak in 2035 which means it will also eventually run out. Nuclear fuel again has its own effects on environment. Recycling of nuclear fuel is possible but it is very risky. [2] Therefore scientists around the world are looking for some alternative sources of energy which are renewable and everlasting. Such sources are less or non hazardous to environment. India is also a big harvester of renewable energy and according to draft on optimal generation capacity mix of India published in 2016, India will increase its share of renewable in unrivalled manner and installed capacity will be raised to 175 GW by the year 2021-22. [3] Because of India's renewable energy policy, emission of CO_2 has not grown corresponding to high rate of energy consumption and generation. Being geographically diverse, India has very large potential of solar and wind energy and there is further scope of exploring renewable energy sources to meet demand and environmental targets. [4, 5]

A. Hybrid Renewable Energy Sources

When two or more renewable energy sources are used together for energy generation or storage, to overcome intermittent nature of renewable sources, such a system is called Hybrid Renewable Energy system (HRES). It is mostly used as stand-alone system for remote and islanded areas as it utilizes local available resources for electricity generation which is used by local load or nearby places only. Hence transmission and distribution losses and cost also reduces. Therefore HRES has social, economic and environmental benefits. [6]

In India, grid supply cannot fulfill energy demand of all consumers, because there is large number of population and there is subsequent growth of demand in industrial, agricultural and commercial areas. Electrical supply by conventional power generation has major problem of long distance transmission losses, high cost of grid installation and Green House Gases (GHG) emission. Remote areas and villages need local power generation which can fulfill energy requirement and can be adjusted as per end-user requirement. Distributed generation system using HRES can ensure 100%availability of electricity. Such type of generation depends on availability of resources like solar radiation, wind speed or biomass availability which changes with weather and seasonal changes. Therefore it is less reliable and unpredictable in nature. To ensure reliable system and to utilize available resources, On-grid or Off-grid HRES is used. [1, 7-8]

For better utilization of available HRES in terms of efficiency and economics, it requires proper planning for optimal sizing. [9-11] Literature survey shows that various methods have been used for optimal sizing, such as Genetic algorithm (GA), [9] Particle Swarm Optimization [12,13] Simulated Annealing (SA) and Tabu Search (TS). [14] Many software has been studied for different optimization problems of HRES, viz. MATLAB, Simulink, HOMER, iHOGA, and RETscreen [15, 16]

B. *Introduction of HOMER Software*

The National Renewable Energy Laboratory (United States) developed free software Hybrid Optimization of Multiple Energy Resources (HOMER) in 1993 for internal use of Department Of Energy (DOE) to evaluate technical and financial options for hybrid system design. Later NREL made a publically available free version to develop interest of researchers in the field of HRES design. It is a very robust tool for modeling conventional and renewable energy sources. It can be used for off-grid or on-grid power system, stand alone or distributed system. [17]

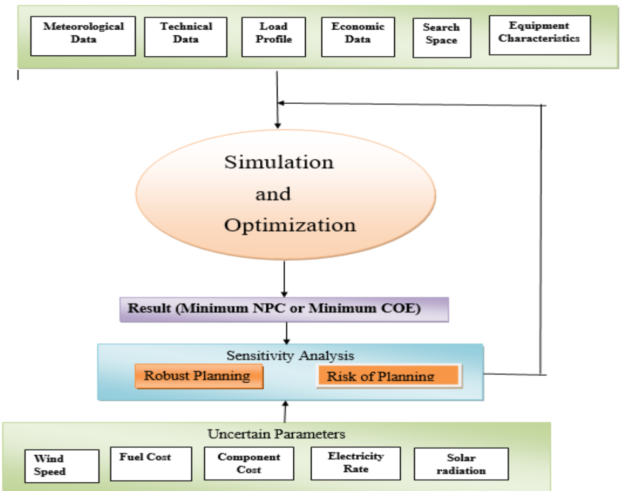

Figure 1: Procedure of Homer software

Procedure of simulation and optimization with input data and uncertain parameters is shown in Fig.1. Steps followed in this procedure is explained below-

Simulation- HOMER carries out energy balance calculation on different configuration of HRES which has various components in different sizes; therefore it tries to simulate a viable system for all possible combinations of equipment considered in model. HOMER simulates hundreds or even thousands of system to find most practical solution. Efficiency of simulation procedure depends on input parameters fed such as installation cost, operation & maintenance cost, fuel cost, interest, replacement cost etc. while simulating model, it decides either of the dispatch strategy to operate battery and generator. Load following and cycle charging are two dispatch strategies. [18]

Optimization-. HOMER automatically finds the optimal size of different components during optimization process with the constraints imposed by the designer. Optimization process begins after simulation and in this process mixed components are optimized with the sizes specified in search space to find lowest NPC and output provide each combination of system that can fulfill load demand. Decision variable are controlled by the designer as per requirement, such as size of component, dispatch strategy etc. [18]

Sensitivity Analysis- HOMER can perform sensitivity analysis with the multiple values of a particular input given by the designer. It repeats the optimization process for each value of the variable and result shows the effect of sensitivity parameter which is either displayed in tabular or graphical form. Designer can give several sensitivity parameter as per problem, it can be climatic or cost, for example, wind speed, solar radiation, fuel cost, interest rate, operating reserve etc. From the results obtained, designer can choose optimal configuration with lowest NPC.

2. SYSTEM DESCRIPTION

Although urban areas are grid connected and fulfill demand of big consumers but if space available big consumers can generate their own electricity for self consumption and sometimes serve surplus power to grid which improves grid efficacy. In this paper, an academic building with an average consumption of 180 KWh per day is assumed in the city of lakes, Udaipur, a district in state Rajasthan India. All metrological data are chosen at 24°35.1’ N, 73°42.7’ E from National Aeronautics and Space Administration (NASA) and National Renewable Energy Lab (NREL). To evaluate and optimize a grid connected HRES, HOMER pro software is used which can simulate different system configurations. HOMER simulates the proposed model by calculating energy balance equations for a year and 8760 hours.

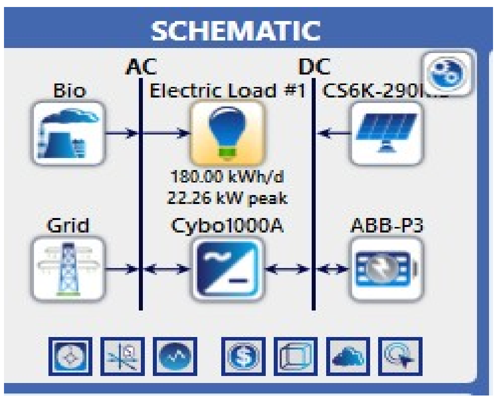

Figure 2 Schematic Diagram of proposed Model

HOMER requires several input data such as meteorological data, load profile, component description, economic and technical data and search space for simulation and optimization. Accuracy of output depends upon the accuracy of these inputs given for the system.

3. METEOROLOGICAL DATA-

Meteorological data consists of physical parameters that are measured directly by instrumentation and include temperature, wind speed, wind direction, solar radiation and current weather. These measured values are fed into HOMER software in the form of monthly average values or time series data. Different metrological data for the proposed model is shown in table 1. [19]

- *Solar Radiation-*

At the upper reaches of atmosphere, solar radiation is approximately 1368 W/m^2. At the Earth's surface the energy density is reduced to 1000 W/m^{2,} which can be utilized to harness electricity form solar energy. [20] According to measured data and NASA resource data, the maximum and the minimum solar radiation for Udaipur

Biomass input means average availability of biomass in tonnes/day. These data are fed either manually or taken from daily record of collection.

Table 1: Input data: Solar radiation, Temperature and Biomass availability

S.No.	Month	Clearness index	Daily Radiation (Kwh/m^2/day)	Daily Temperature (°C)	Available Biomass (Tonnes/day)
1	January	0.656	4.450	18.400	10.00
2	February	0.643	5.090	20.870	12.00
	March	0.633	5.900	26.400	13.00
	pril	0.620	6.480	30.160	14.00
5	ay	0.597	6.590	31.310	15.00
	June	0.531	5.950	29.560	16.00
7	July	0.408	4.520	27.270	14.00
8	August	0.396	4.190	26.590	12.50
9	September	0.535	5.130	27.180	13.00
10	October	0.615	5.060	26.790	14.00
11	November	0.647	4.520	23.410	17.00
12	December	0.628	4.030	19.720	15.00

4. LOAD PROFILE

As already discussed, the efficiency of simulation and location are 6.59 kWh/m2/d in May and 4.03 kWh/m2/d in December.

- *Temperature-*

Temperature has significant effect on energy conversion from solar energy to electric energy as solar panels are temperature sensitive. Therefore temperature of selected location are measured everyday of the year and fed as average daily temperature.

- *Biomass-*

Biomass energy is conversion of organic waste of plant and animals into electrical energy. It can be derived from waste of crops, animal waste, sewage, municipal waste etc. Therefore it is best utilization of waste by products.

Optimization depends on input data, therefore proper estimation of load profile is most important factor in this process. Load profile is a graph of the variation of electrical load versus time. For some sites real load consumption can be found easily from its meter reading or calculated from by counting all connected loads but for some regions like remote areas or large scattered load, real load are not available. For such problem load profile is approximated and forecasted according to that area specification. [20]

In HOMER real time load is fed as time series data. Daily load profile and seasonal load profile is shown in Fig.3 and Fig.4 respectively. Homer uses this data for simulation as power balance constraint. For proposed model, load consumption of academic building is estimated from past record data and approximated about 180 KWh per day and 22.26 KW peak demand.

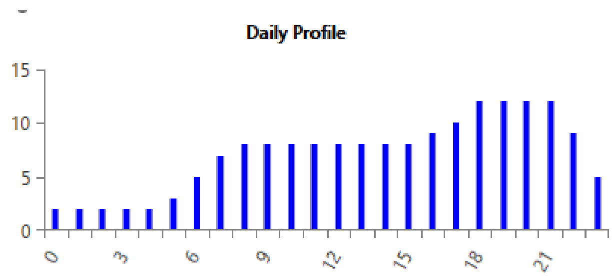

Figure 3 Daily Load Profile

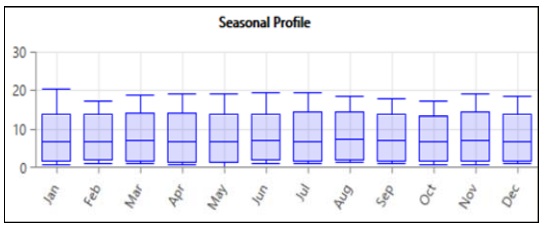

Figure 4 Seasonal Load Profile

5. COMPONENT DESCRIPTION

Solar Photovoltaic – Solar PV systems use cells to convert sunlight into electricity. Number of PV cells are added together to produce module and modules are combined together to form an array. [21]

The suggested PV module in proposed system uses mono-crystalline PERC cells with a dark colored back- sheet and black frame to enhance asthetic appearance. The nominal max power of this array is 290 W. Temperature coefficient is -0.390, operating temperature is 45.00° C and efficiency is 17.72%. Different sizes of PV panels considered in search space of the proposed model are (0.29,0.5,0.75,1,2,5,10,20,30,40,50 KW).

Grid- Indian government introduced roof top solar schemes to encourage solar PV generation under new and renewable policy. Under this policy, solar PV panels can be installed in consumer premises i.e., roof top or other open place with minimum 1 KW and maximum 1MW rating. [22]

In proposed model grid connected HRES is used for an academic building so that grid can provide power at the time of unexpected peaks and serves as secure back up to the system. Also surplus power left after self consumption can be fed back to grid. For this purpose, system uses Net metering. It is a smart meter with bidirectional register to record import and export of electricity and the final bill is the difference of energy purchased and sold. In this proposed model, the grid power price of Rs.10 per KWh (including fixed cost and cost of energy) and grid sellback price of Rs. 8 per KWh. **Battery and Converter**-

Batteries are the collection of cells whose chemical reaction creates a flow of current in the circuit. Several batteries connected in series-parallel to form a battery bank. Choice of battery is very important in HRES as it provides storage of energy and its cost affects overall system cost. The battery used in proposed model is ABB- BatP3 model with the rating of 3.7 V, 78 Ah, and 0.289 KWh. Then different sizes are also specified in search space so that optimizer can select appropriate option out of it.

Converter plays important role in interfacing between energy generation and consumption points, as load and grid are connected to AC bus-bar and solar PV and batteries are connected to DC bus-bar. Converter may operate as inverter or rectifier as per requirement. The converter used in the proposed model is manufactured by Cybo Energy. It is Grid-Interactive model with the capacity of 1150W, 240V, 50Hz AC power. Different sizes of are specified in search space.

6. ECONOMIC DATA

Economic data is the cost data of each component such as capital cost, replacement cost, operation & maintenance cost. Fuel cost, price of electricity transaction with grid, rate of interest, project lifetime, and emission penalty are HOMER economic data. These costs are important in simulation and optimization as Net Present Cost (NPC) and Cost Of Energy (COE) depends on it.

Table 2 Cost Data of each Component

Components	Capital cost (₹/KW)	Replacement cost (₹/KW)	O &M cost (₹/Hour)	Lifetime (Years)
PV Array	30000	28000	5.00	25
Bio-diesel Generator	30000	30000	10.00	20
Converter	20000	18000	5.00	10
Battery	10000	9000	2.50	20

7. COST OPTIMIZATION

Optimization is the process of finding best solution from all possible solution with a set of constraints or prioritized value. HOMER simulates all different combination of component sizes given in the search space and considers sensitive variables to obtain best configuration. Thus HOMER optimization problem is to find best feasible configuration and components which have lowest NPC with all physical and operational constraints like economics, reliability and weather condition.

Net Present Cost and Cost Of Energy is calculated in HOMER as follows: [4, 23, 24]

Net present cost (NPC): NPC is the cost of installation and operational cost of the system during its lifetime and it is calculated by-

$$NPC = \frac{Total\ annual\ cost}{Capital\ recovery\ factor} \quad - (1)$$

1. Total annualized cost: Total annualized cost is the sum of the cost of each equipment in the HRES including capital cost, replacement cost, fuel cost and cost of operation & maintenance.
2. Cost of energy (COE): COE is the same as the unit energy generation cost of the system. It is the average cost per KWh of electricity produced by the system and it is calculated as-

$$COE = \frac{Total\ Annual\ Cost}{\text{Total load(AC+DC)}} \quad - (2)$$

3. Levelized Cost of Energy: LCOE is the marginal cost of energy and termed in currency units per KWh. The main components of LCOE are fuel cost and capital cost and capital cost can be recovered by selling electric units. In the beginning, capital cost is major part of LCOE for 4-5 years and later when capital cost is recovered after 4-5 years, fuel cost become major part of LCOE.[23]

8. RESULT

In the proposed model, a HRES is modeled in HOMER pro software and simulated for a grid connected solar PV system and a bio-diesel generator, battery banks and converter are also incorporated for storage and AC-DC conversion. This system is simulated for 14080 solutions out of which feasible solutions are shown in Fig.7. After simulation HOMER optimizer optimizes the system to find best configuration of components which is reliable and have minimum NPC. Further, the optimal combination with grid and all sensitivity parameters of other components is PV array - 50 KW, bio-diesel Generator -10KW, and 9 KW converter with COE of Rs 5.48. The Net present cost of system is Rs. 719000 with a renewable fraction of 98.5% and there is zero unmet loads and zero capacity shortage. Fig. 8 shows monthly average electricity generated by system. Table 3 and 4 shows production by different components and total consumption by different loads respectively. This data is used by net meter to generate the utility bill for academic building. It is obvious that after installation of this HRES at this academic building, utility bill has been reduced to great extent.

Figure 8 Monthly average electricity generated by the system

Table 3 Production by different components

Production (Component)	KWh/Yr	Production %
PV module	84051	59.7
Bio-Diesel Generator	54700	38.8
Grid Purchases	2108	1.50
Total	140859	100

Table 4 Consumption by different loads

Production (Component)	KWh/Yr	Production %
PV module	84051	59.7
Bio-Diesel Generator	54700	38.8
Grid Purchases	2108	1.50
Total	140859	100

9. CONCLUSION

Energy consumption in India is constantly rising due population growth and increasing industrialization. Traditional energy generation system cannot meet these requirements with notice to challenges like green house emission and other environmental issues. Although government of India is trying best to provide 24×7 electricity to all under its Power to All scheme. But still there are many rural areas which are not connected to grid. Also there are some sub-urban areas which got its electricity connection but faces problem of considerable power cuts of 6-8 hours a day. Renewable energy sources are appropriate alternative for solving these problems. Again intermittent nature of renewable sources cannot provide reliable power supply, now Hybrid Renewable Energy Systems (HRES) having integration of fossil fuels with renewable sources is best solution. But HRES have large number of design options which should be wisely chosen and uncertainty in its input parameters making system unpredictable. So the overall objective is to design a HRES which is cost economic and reliable throughout the year. Here a grid connected system is used but now a day stand-alone is also gaining interest of researchers all over the world. However there is a limit of electricity generated which is the storage capacity of the battery. Even if renewable energy can generate more electricity, there will be no storage capacity once battery is fully charged. Also increasing the size of battery makes system expensive.

Due to above discussed problems, grid connected HRES is found to be more beneficial and reliable as it can supply excess of electricity generated by HRES back to the grid and when there is less power produced by the system, it can draw energy from the utility grid. This is all possible with the help of smart net meter.

REFERENCES

[1] N. M. Swarnkar and L. Gidwani, “Analysis of hybrid energy system for supply residential electrical load by HOMER and RETScreen: A case in Rajasthan, India,” 2016 Int. Conf. Recent Adv. Innov. Eng. ICRAIE 2016, pp. 1–6, 2017, doi: 10.1109/ICRAIE.2016.7939487.

[2] V. B. Mary, I. W. Christopher, and G. Themozhi, “RHES-Economic Analysis and Power Management for a Technical Institution Using Homer,” 5th Int. Conf. Electr. Energy Syst. ICEES 2019, pp. 1–6, 2019, doi: 10.1109/ICEES.2019.8719307.

[3] CEA et al., “Draft Report on Optimal Generation Capacity Mix for 2029-2030,” Int. J. Electron. Electr.Eng., vol. 7, no. 5, pp. 1–5, 2016, doi: 10.1109/PESMG.2013.6672434.

[4] N. Saiprasad, A. Kalam, and A. Zayegh, “Zero-emission renewable energy system model for a community in India,” Asia-Pacific Power Energy Eng. Conf. APPEEC, vol. 2017-Novem, pp. 1–6, 2018, doi: 10.1109/APPEEC.2017.8308942.

[5] B. Shyam, P. Kanakasabapathy, B. I. Renewable, E. Development, and A. Ireda, “Renewable Energy Utilization in India – Policies , opportunities and challenges,” 2017 Int. Conf. Technol. Adv. Power Energy (TAP Energy), pp. 1–6, 2017. 11

[6] R. R. Bhoyar and S. S. Bharatkar, “Renewable energy integration in to microgrid: Powering rural Maharashtra State of India,” 2013 Annu. IEEE India Conf. INDICON 2013, 2013, doi: 10.1109/INDCON.2013.6725877.

[7] A. Kaddour, S. M. El Amine Bekkouche, S. Bezari, and B. Benyoucef, “Optimization and evaluation of the photovoltaic system in a farm studio located in Ghardaia,” Proc. 2018 6th Int. Renew. Sustain. Energy Conf. IRSEC 2018, pp. 5–8, 2019, doi: 10.1109/IRSEC.2018.8702279.

[8] B. Zohuri and B. Zohuri, Hybrid Renewable Energy Systems. 2018. Springer International Publishing AG 2018, https://doi.org/10.1007/978-3-319-70721-1_1

[9] K. Anoune et al., “Designing of a photovoltaic system for self-consumption at the faculty of technical sciences of Settat,”

Renew. Sustain. Energy Rev., vol. 3, no. 1, pp. 1–6, 2017, doi: 10.1109/IRSEC.2016.7984025.

[10] A. González, J. R. Riba, and A. Rius, "Optimal sizing of a hybrid grid-connected photovoltaicwind-biomass power system," Sustain., vol. 7, no. 9, pp. 12787–12806, 2015, doi: 10.3390/su70912787.

[11] Y. Sawle, S. C. Gupta, and A. K. Bohre, "PV-wind hybrid system: A review with case study," Cogent Engineering, vol. 3, no. 1. 2016, doi: 10.1080/23311916.2016.1189305.

[12] H. R. Baghaee, M. Mirsalim, G. B. Gharehpetian, and H.

[13] A. Talebi, "Reliability/cost-based multi-objective Pareto optimal design of stand-alone wind/PV/FC generation microgrid system," Energy, vol. 115, pp. 1022–1041, 2016, doi: 10.1016/j.energy.2016.09.007.

[14] M. Amer, A. Namaane, and N. K. M'Sirdi, "Optimization of hybrid renewable energy systems (HRES) using PSO for cost reduction," Energy Procedia, vol. 42, pp. 318–327, 2013, doi: 10.1016/j.egypro.2013.11.032.

[15] F. Z. Kadda, S. Zouggar, and M. L. Elhafyani, "Optimal sizing of an autonomous hybrid system," Proc. 2013 Int. Renew. Sustain. Energy Conf. IRSEC 2013, pp. 269–274, 2013, doi: 10.1109/IRSEC.2013.6529672.

[16] R. Singh, R. C. Bansal, A. R. Singh, and R. Naidoo, "Multi-Objective Optimization of Hybrid Renewable Energy System Using Reformed Electric System Cascade Analysis for Islanding and Grid Connected Modes of Operation," IEEE Access, vol. 6, no. August, pp. 47332–47354, 2018, doi: 10.1109/ACCESS.2018.2867276.

[17] F. Alkarrami, T. Iqbal, and K. Pope, "Optimal sizing of a stand-alone hybrid energy system for water pumping in Sirte, Libya," 2016 IEEE Electr. Power Energy Conf. EPEC 2016, pp. 1–5, 2016, doi: 10.1109/EPEC.2016.7771679.

[18] A. Kassam, "HOMER Software: Training Guide for Renewable Energy Base Station Design | Mobile for Development," Homer Man., p. 21, 2010.

[19] Y. Sawle and S. C. Gupta, "Optimal sizing of photo voltaic/wind hybrid energy system for rural electrification," Proc. 6th IEEE Power India Int. Conf. PIICON 2014, pp. 1–4, 2014, doi: 10.1109/34084POWERI.2014.7117758.

[20] D. K. Yadav, S. P. Girimaji, and T. S. Bhatti, "Optimal hybrid power system design using HOMER," India Int. Conf. Power Electron. IICPE, no. 1, pp. 1–6, 2012, doi: 10.1109/IICPE.2012.6450416.

[21] A. A. Hafez, Y. F. Nassar, M. I. Hammdan, and S. Y. Alsadi, "Technical and Economic Feasibility of Utility-Scale Solar Energy Conversion Systems in Saudi Arabia," Iran. J. Sci. Technol. - Trans. Electr. Eng., vol. 3, 2019, doi: 10.1007/s40998-019-00233-3.12

[22] M. A. Salam, A. Aziz, A. H. A. Alwaeli, and H. A. Kazem, "Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman," Int. J. Renew. Energy Res., vol. 3, no. 3, pp. 470–475, 2013, doi: 10.20508/ijrer.57520.

[23] G Sandeep et al., "Optimal Combination and Sizing of a Standalone Hybrid Power System Using HOMER," in International *Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) - 2016*, 2016.

[24] M. Nurunnabi and N. K. Roy, "Grid connected hybrid power system design using HOMER," Proc. 2015 3rd Int. Conf. Adv. Electr. Eng. ICAEE 2015, pp. 18–21, 2016, doi: 10.1109/ICAEE.2015.7506786.

[25] A. Iqbal, I. F. Muhammad, M. Faraz, M. S. Tariq, and H.

[26] U. Banna, "Economic analysis of a small hybrid power system," 2015 Power Gener. Syst. Renew. Energy Technol. PGSRET 2015, pp. 1–5, 2015, doi: 10.1109/PGSRET.2015.7312182.