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Design of Hybrid Electrical Power System for an Industrial Unit in Pakistan

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***Abstract*—This paper is about the design of a solar power system for an industrial unit in Lahore Punjab, Pakistan. A hybrid power system is designed in HOMER after collecting the site data and load profile The land requisition analysis has been done using the PVWatt software. The average load of consume is found to be 2485.6 kW and the peak load is 3257.7 kW. After the simulation, the system architecture is such that 8382 kW, ENN Solar Energy 480EST solar module-based array is required in a grid tied operation. For converting the DC to AC, 3119 kW Eaton Power Xpert inverter is needed. Overall, the initial cost of designed system is found to be $ 3080100.00. The proposed system reduces the cost of energy to $ 0.1020 per kWh, which provides good savings along with a renewable energy system. Design details and system simulation results are included in the paper.**

Keywords*—Hybrid Power System, Solar Energy, Renewable Energy, HOMER Pro, PVWatt

I. INTRODUCTION

Electricity is the basic requirement of every human. It is generated using various resources like gas, coal, hydro furnace oil, etc. Recently, most of the production is done using conventional resources which cause global warming [1]. Countries like Pakistan are going through development and Industrialization phase; if they depend on conventional resources, it will ruin the nature. Mostly, the electricity generation is done with coal, gas, or furnace oil, as Pakistan imports all these non-renewable energy sources from different countries, which eventually puts a burden on the economy and end-user in additional cost[2]. Therefore, a hybrid power system is mandatory for meeting the electrical load demand of consumers with cheap fuel. Fig. 2 illustrates Pakistan's solar insolation distribution, which clearly shows that Pakistan has substantial solar resources that could be used. These facts inspired the use of photovoltaic power to produce electricity and integrate solar energy at commercial and industrial levels[3].

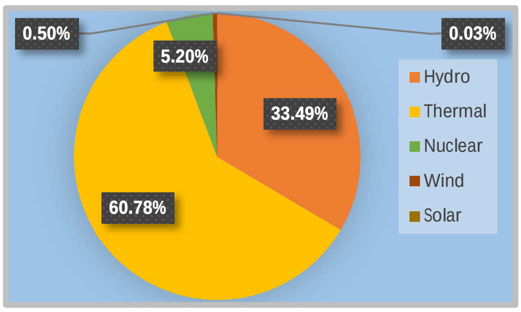


Fig. 1. Electricity Generation Mix of Pakistan [2]

In this paper, the selected site is the premises of Shafi Texcel Limited, Lahore, Pakistan for which feasibility and cost analysis has been done using HOMER Software. The site specifications and load calculation will be discussed in the second part of this paper. In the third part, the optimization of the solar system and the cost analysis has been elaborated using the HOMER software. Finally, at the end, final results, conclusion, and future work is discussed.

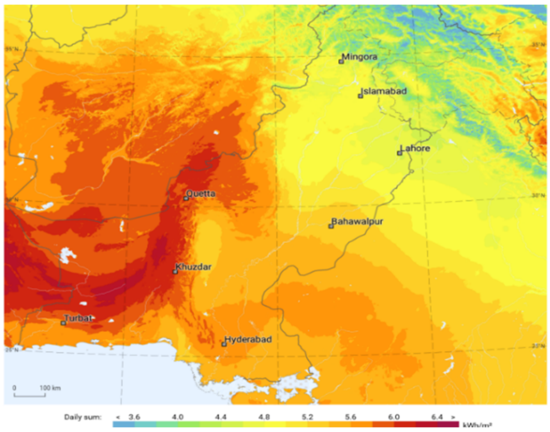


Fig. 2. Solar Insolation levels in Pakistan [3]

II. SITE DETAILS AND LOAD CALCULATION

A. Selected Site

First, the selected site is Shafi Texcel Limited, situated on 4.5km Raiwind Manga Road, Lahore, Punjab 55150 Pakistan (31.2616, 74.1674). Fig. 3 indicates the longitude and latitude of the site on google maps.

It has more than 12 acres of land located at the back end of factory area premises that could be used for solar installation. Fig. 4 shows a view of selected site. Roof areas cannot be used because it has many ventilation fans, ducts, cooling towers, steam pipelines and other equipment.

Fig. 3. Location of the Site on Google Map

Fig. 4. Front View of the Site

B. *Selected site solar insolation details*

Solar irradiance is a crucial parameter for site feasibility. It is the light energy of sun measured at a specific site. From Fig. 5, it can be notice that solar radiation is available throughout the year, and its values alter between 3.05 to 6.90 kWh/m^2/day. The clearance index is the parameter to measure the clarity of atmosphere. Fig. 5 also shows that for selected site.

$$\text{Clearance Index} = \frac{\text{Surface radiation}}{\text{Extraterrestrial radiation}} \quad (1)$$

Its value is always less than one and varies between 0.556 to 0.633 throughout the year.

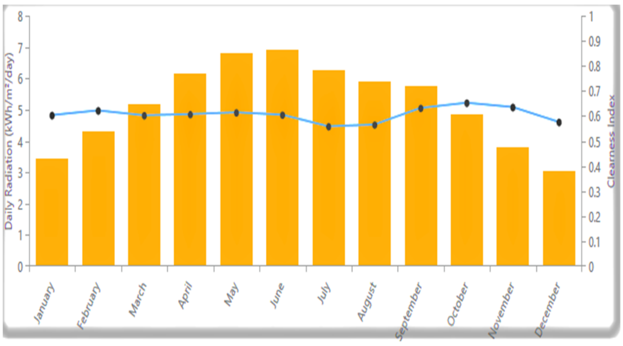


Fig. 5. Irradiance and Clearance Index of the Site

C. *Electrical Load*

The site Electrical Load is monitored and was obtained from the site. Mainly, the load in the industry is inductive due to the use of motors for various compressors, fans, water turbines, pumps etc. The hourly data of load has been collected for the year 2020, and the corresponding monthly load profile is described below in Fig. 6.

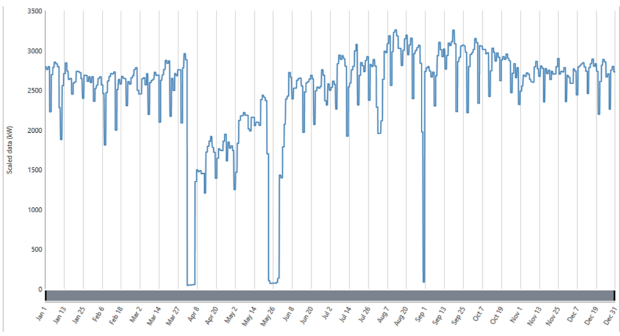


Fig. 6. The Site Electrical Demand

The load profile in Fig. 7 shows that the average consumed units per day are 59655, and average & peak load over the year is 2485.6 kW & 3257.7 kW. In Fig. 6, load dips in April, June and September are due to the Covid-19 lock down imposed by the provincial government.

Load factor is the efficient utilization of electrical power network, and it can be derived from the above-given load data.

$$\text{Load Factor (LF)} = \frac{\text{Average Load}}{\text{Peak Load in given period}} \quad (2)$$

$$LF = \frac{2485.6}{3257.7}$$

$$LF = 0.76$$

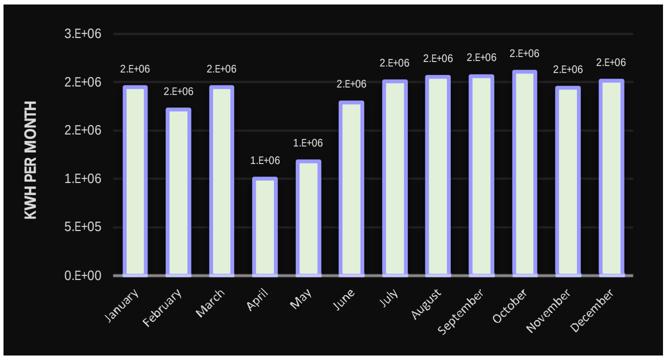


Fig. 7. Monthly Electrical Consumption

III. Plant Electrical Layout

Plants bus configurations are designed for flexibility in operation and maintenance without affecting the consumers. Because an uninterrupted supply is indispensable for the reliable operation and customer satisfaction. Therefore, the captive power plants are designed efficiently with standby resources to supply 24/7 without any interruption. The Single Line Diagram of power flow of site is given in Fig. 8.

In the below Fig. 8, different sources are used for the supply of power to the load. Overall, Solar & Grid will be utilized maximum, and Gas & Diesel generators will act as backup sources. The detailed structure, constraints, efficiency of each source is discussed below.

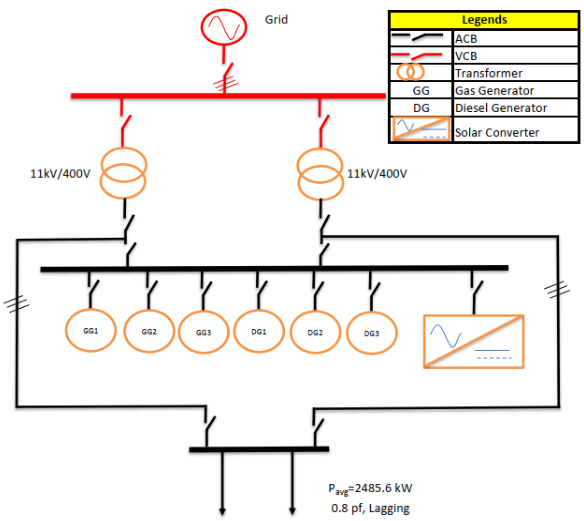


Fig. 8. Single Line Electrical Diagram of the Site

A. Grid

Grid is an infinite bus source of power and can tackle high load variations as well. Lahore Electric Supply Company (LESCO) is a power distribution company on our selected site. It offers different tariffs as per load requirement and time of use. The contracted load as per load demand is 3500 kW, for which tariff B3 (14)T is applicable in which 20.39 PKR/kWh is charged for peak load, and 12.61 PKR/kWh charges for off Peak [4].

Maximum demand indication (MDI) is also applied per month based on the meter reading. Peak demand is considered to be maximum if it is available for more than 15 minutes. It is charged 380 PKR/kW/M[5].

B. Gas Generator

A gas generator uses natural gas to produce electricity with the help of a 04 Stoke gas engine. Sui Northern Gas Pipelines Limited (SNGPL) is the distributor of gas. Caterpillar GENSET 3516B has been selected for generation. It is 1030 ekW rating with a fuel consumption of 9776 Btu/kWh at 100 % load[6-7]. With the help of following equation, we can find the fuel consumption in m^3

$$\text{mmBTU} = \frac{HM^3 \text{ x } GCV}{281.7385} \quad (3)$$

$$9776 \text{ x } 10^{-6} = \frac{M^3}{100} \text{x} \frac{1000}{281.7385}$$

$$M^3 = 0.2754 \text{ m}^3/\text{kWh}$$

The efficiency of engine varies with load. The efficiency-load curve is given in below figure 9.

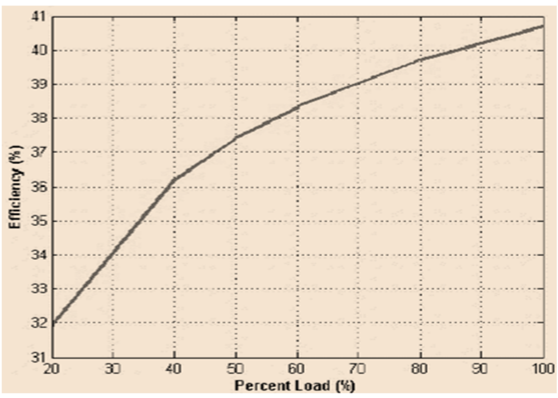


Fig. 9. Engine Efficiency w.r.t Load for Gas Generator

Other than the operations mentioned above, some preventive maintenance schedules must follow for the reliable and secure operation of the plant. Engine Oil and Filter should be changed entirely after 2000 hours of service.

C. Diesel Engine

Diesel Engines also act as a backup source of power and use in a standby position. CAT 3512[8] model are used at the selected site, which has a power rating of 1056 ekW. The main difference between gas and diesel engine is the spark plug. Diesel Engines don't have spark plugs and ignition is caused by the rise in temperature due to compression [9]. The visualization of Diesel Engine working is given Fig. 10.

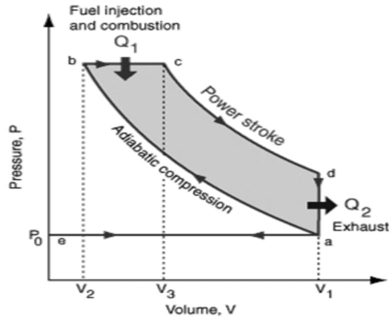


Fig. 10. Four Stokes of Engine

The CAT 3512 Engine has a fuel consumption of 0.28 L/kWh [10]. Like the gas engine, its lube oil and filter also need to be changed every 2000 hours. Due to the high price of High-Speed Diesel (HSD) per unit marginal cost of a diesel engine is high from all other resources. Therefore, the use of diesel is the last option in the standby power.

D. HOMER Cost Analysis Techniques

HOMER uses the following techniques for calculating the different costs of system.

Net present cost (NPC) represents the total operations and installation cost of the system over its entire life, which can be calculated as follow

$$NPC = \frac{TAC}{CRF}(i, Rpr_j)$$

Where TAC is total annualized cost ($), CRF is capital recovery factor, i is the interest rate and Rpr_j is project lifetime in years.

Total annualized cost is the total accumulative sum of cost of each component of power system, including the capital, operation & maintenance fuel, and replacement cost.

Capital recovery factor is a ratio that is used to determine the present value of a series of equal yearly cash flows

$$CRF = \frac{i \ x \ (1+i)^n}{(1+i)^{n-1}}$$

Where n is the number of years and i is annual real interest rate

Cost of energy (COE) is the average price of per kWh of electric energy. It can be calculated as follow.

$$COE = \frac{TAC}{L_{prim,AC} + L_{prim,DC}}$$

Where, $L_{prim,AC}$ is the AC primary load and $L_{prim,DC}$ is primary DC load.

IV. Optimization of PV Based Captive Power Plant

For optimization of power plant, a computer tool named as HOMER (Hybrid Optimization Model for Electric Renewables) is used which was originally developed at National Renewable Energy Laboratory (NREL) [11]. In the software, the load data of one year is entered in the CSV file, on this, HOMER has done the PV module, Solar Converter, and Storage sizing. At the end, HOMER rate the selected configuration based on Net Present Cost (NPC) and levelized cost analysis.

A. System Configuration in HOMER

The configuration of the system designed in HOMER is shown in the Fig. 11. It has two buses: Alternating Current

(AC) & Direct Current (DC). DC bus voltage is 806 V_{dc} and AC bus voltage is $400V_{ac.}$ DC bus is connected with 480 W flat plate solar module of ENN Solar Energy480EST-480 [12] with a derating factor of 85 % due to dust and high temperature.

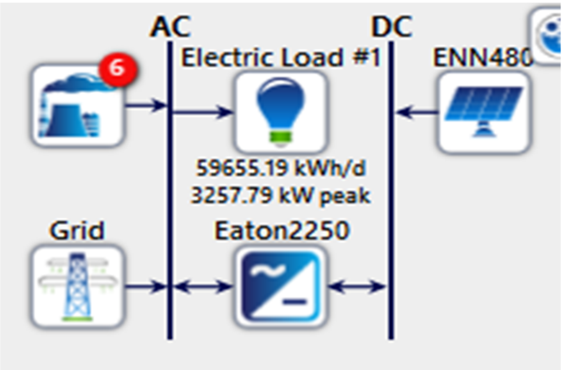
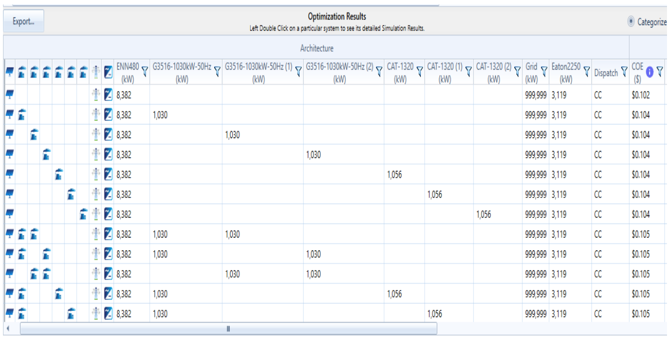


Fig. 11. Schematic of System without Storage

AC bus voltage is 400 V_{rms}. Gas Genset 3516B, Diesel Generator 3512, Grid and load is connected with AC bus. Two buses are connected with the help of a solar converter. Eaton Power Xpert 2250kW is used to convert the DC voltage into the AC voltage. There are no constraints on the production of renewable energy from solar. In below Fig. 12 the sizing results are shown. Fig. 13 depicts that system takes 50.9 % of electricity from solar energy. Solar Modules having total capacity of 8382 kW along with 3119 kW Eaton inverter are required.



Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

ENN480 (kW)	G3516-1030kW-50Hz (kW)	G3516-1030kW-50Hz (1) (kW)	G3516-1030kW-50Hz (2) (kW)	CAT-1320 (kW)	CAT-1320 (1) (kW)	CAT-1320 (2) (kW)	Grid (kW)	Eaton2250 (kW)	Dispatch	COE ($)
8,382							999,999	3,119	CC	$0.102
8,382	1,030						999,999	3,119	CC	$0.104
8,382		1,030					999,999	3,119	CC	$0.104
8,382			1,030				999,999	3,119	CC	$0.104
8,382				1,056			999,999	3,119	CC	$0.104
8,382					1,056		999,999	3,119	CC	$0.104
8,382						1,056	999,999	3,119	CC	$0.104
8,382	1,030	1,030					999,999	3,119	CC	$0.105
8,382	1,030		1,030				999,999	3,119	CC	$0.105
8,382		1,030	1,030				999,999	3,119	CC	$0.105
8,382	1,030			1,056			999,999	3,119	CC	$0.105
8,382	1,030				1,056		999,999	3,119	CC	$0.105

Fig. 12. Optimization Results without Storage

The analysis of land requirement has also been done in PVWatts because the availability of land is a key factor in solar installation. The landmarking and PV system capacity results are shown in the Fig. 14.

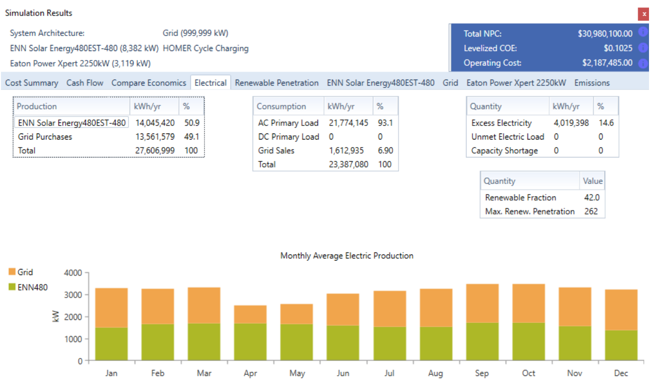


Fig. 13. Simulation Results in HOMER (0% Constraint)

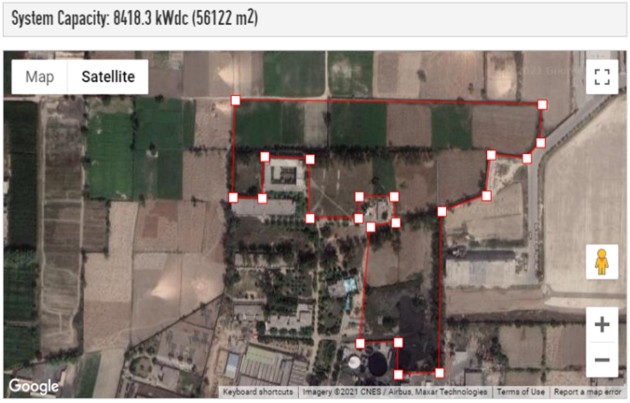
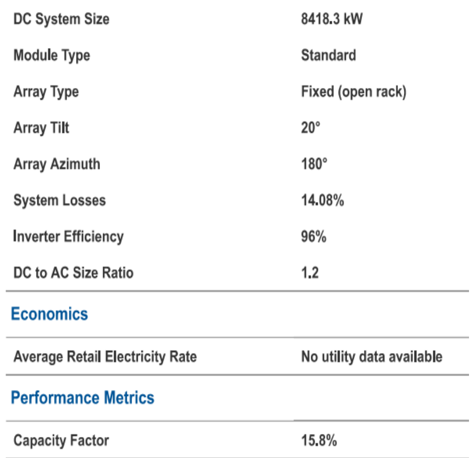


Fig. 14. Required Land Marking for 8382 kW_{dc} Solar System



DC System Size	8418.3 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2
Economics	
Average Retail Electricity Rate	No utility data available
Performance Metrics	
Capacity Factor	15.8%

Fig. 15. System Parameters for $8382kW_{dc}$ PV System

The cost analysis has also been done in the HOMER for zero storage system. For this purpose, prices of ENN Solar Energy480EST, Eaton solar inverter and CATERPILLER engines have been used.

Final cost results have been depicted in Fig. 16, and it can be seen that the total cost of equipment installation and operation over its whole life span named net capital cost is $ 30,980,100. Levelized cost is the net present cost of electricity generation over the entire life of plant, it is $ 0.1025 for our selected site. The operating cost is $ 2187485; initial capital cost was found to be $ 2701344.87. The component level Net Present Cost (NPC) over 25 years of life is given below Table I.

TABLE I. NPC OF COMPONENTS IN THE PROPOSED PV SYSTEM (0% CONSTRAINT)

Sr. #	Component	NPC ($)
1	Eaton Power Xpert 2250 kW	242073.53
2	ENN Solar Energy480EST	4440394.08
3	Grid	26297630.35
4	System	30980097.97

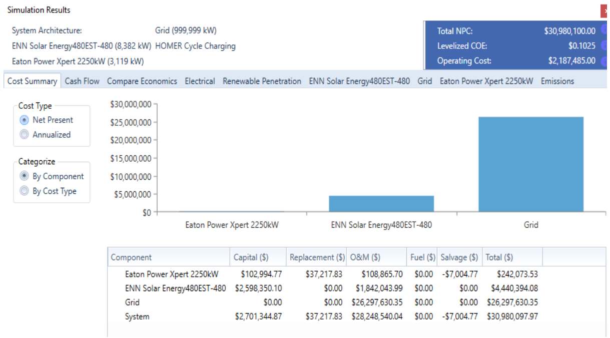


Fig. 16. Cost Summary of 8382kW PV System

The cash flow analysis result is shown in the below Fig. 17. The upfront capital required for the entire system is $ 2701344.87. Every year operating cost of $ 2185148.24 will be consumed, and at 15 years, the replacement of component $ 87721.24 will be invested. At the end of 25 years, $ 29240 salvage value is expected.

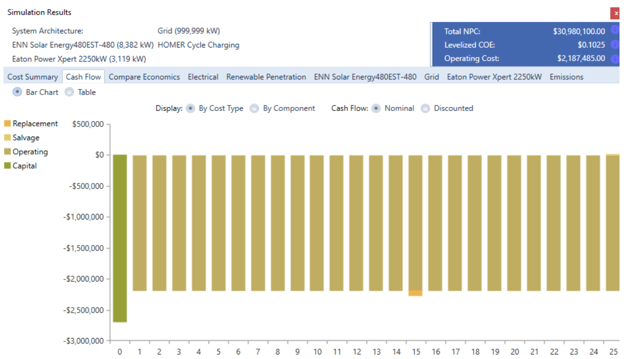


Fig. 17. Cash Flow of 8382 kW PV System

V. Conclusion and Possible Future Work

Design of a solar energy system is presented in this paper. After the detailed analysis and optimization of the system in the HOMER, it is deducted that the operation and maintenance cost is very low. The per-unit cost of electricity with PV is the cheapest because no fuel is required for generation. For 8382 kW system, 17462 ENN-480 solar modules are required. 17 modules are connected in series to generate the desired input voltage for Eaton solar inverter and 1027 such strings are connected in parallel to produce the desired output power. Such as system could be installed on the land owned by the plant.

Finally, there is a substantial reduction in per-unit cost of electricity generation using PV system. The greater the generation from solar, a significant decrease in energy cost occurs.

Acknowledgment

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