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THE FEASIBILITY REPORT ABOUT GREENHOUSE GAS EMISSIONS REDUCTION BY UTILIZATION OF SOLAR ENERGY TO PRODUCE ELECTRICITY

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This paper describes a case study about supplying the electricity demand of a plant by two different energy sources to compare the greenhouse gas emissions ratio difference and cost-benefit ratio. Energy demand of the plant was first determined by monitoring the system with data logger for one month. Then simulations were performed for two conditions: powered by conventional power generation unit (PGU) and by hybrid power system (photovoltaics and grid). The results of the two simulations were compared considering the greenhouse gas emissions. Additionally, a cost analysis was performed considering lifetime, operational and maintenance expenses of the solar system.

Keywords: greenhouse gas emissions, utility interactive photovoltaic.

1. Introduction

Since both the world population and the industrialization grow up significantly, the world energy demand increases accordingly. To supply this demand, fossil fuels are still mostly used as primary energy source. However, it is a known fact that these sources are going to be exhausted in the near future and the energy coming from these type of sources pollute the environment dramatically. Due to this fact, the human kind is seriously concerned about that problem and looks for alternative solutions. The obvious and definite solution is generating energy from renewable sources such as solar, wind, wave, etc, which are assumed to be continuous and pollution free.

The aim of the study is to estimate the annual greenhouse gas emissions of a plant which has 60 kVA ($\cos\varphi = 0.7$, $P = 42$ kW) installed apparent power for the process and to find the cost of the implementation of solar energy sources instead of fossil fuels to produce this energy. Unlike traditional fossil fuel sources,

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greenhouse gas emissions from renewable sources are mainly associated with the construction of a power plant. However, in this report the emissions which are produced during construction of the photovoltaics were ignored.

2. Load Characteristic

In this study, the plant's energy consumption was monitored with data logger for one month. And the daily energy consumption of the plant was found to be 200 kWh/day. Moreover, the plant's monthly electricity bills were checked to determine the deviation of this data due to summer or winter time period. The recorded data showed that the plant starts operation between 7 - 8 a.m., and is open for two shifts occasionally, which extends the operation till 10 p.m. Furthermore, sometimes workers perform overtime work at weekends, and this starts at 9 a.m. and ends at 6 p.m. During the nights and weekends, only emergency and stand-by systems are ordinarily operational and the average load is 5 kW at these hours.

In summer time period, power consumption may decrease due to yearly holidays; however, it reaches peak values at certain hours of the day. Daily load values have a tendency to change for about 15%, while hourly load may also vary about 20%.

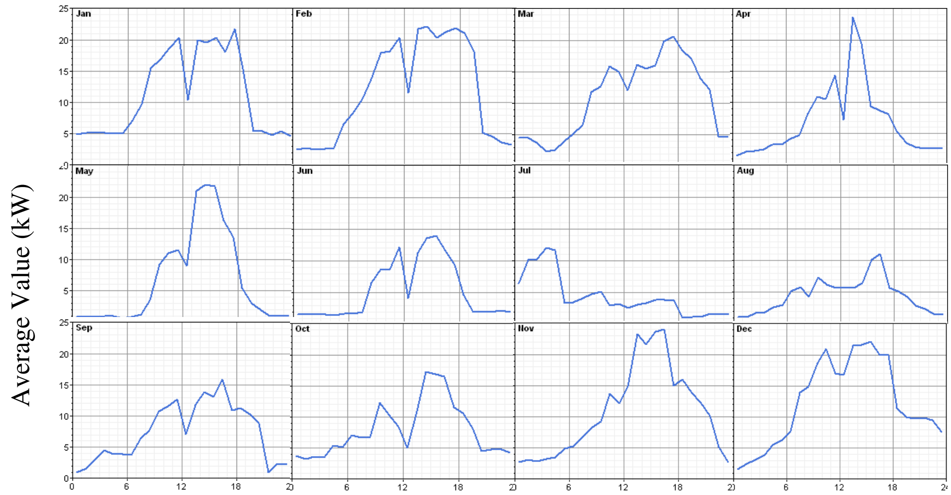

Fig. 1. Monthly averaged hourly load profile

For example, during first five days of January, daily load is about 200 kWh, however, this increases to 230 kWh at sixth day, and decreases to 170 kWh at seventh day. It has also been observed that, the measured power consumption have a value of 10 kW between 9 – 10 a.m. on these days, but it increases to 12 kW or decreases to 8 kW on some other days. Evaluating all the data, the load distribution is discussed in the curves as given in the Fig. 1 and distribution of load monthly averages is shown in Fig. 2 [1].

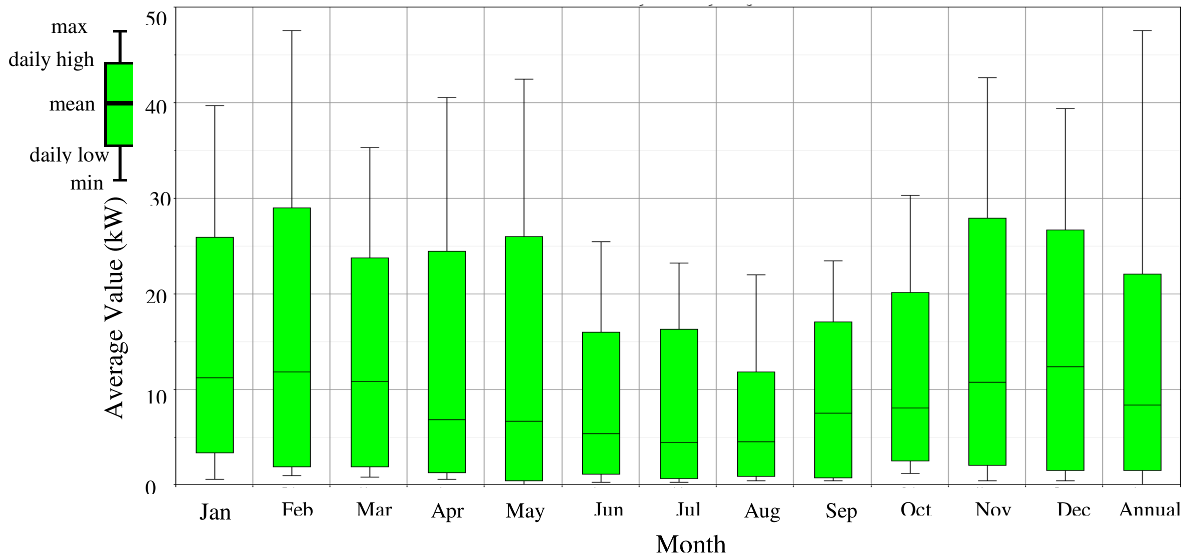

Fig. 2. Load monthly averages

3. Conventional PGU

a. Cost Analysis

To determine the energy costs of the plant some assumptions were made as given in Table 1. As the average life of the PV system is about 25 years, the life time of the grid was assumed to be 25 years to compare the results for same time period.

Table 1

Features of the grid

The installation costs	$25,000
Annual maintenance and operation costs	$1,000
Lifetime of system	25 years
Electricity cost	$0.2/kWh

- One day electricity cost:
  $$\$0.2\text{x}200\,\text{kWh} = \$40/\text{day}\,, \tag{1}$$
- One year electricity cost:
  $$\$40\text{x}365\,\text{day} = \$14{,}600/\text{year}\,, \tag{2}$$
- One year electricity cost including annual maintenance and operation costs:
  $$\$14{,}600/\text{year} + \$1{,}000 = \$15{,}600/\text{year}\,, \tag{3}$$

- Lifetime (25 years) electricity cost including installation, maintenance, and operation costs :

$$\$15{,}600 \text{x } 25 \text{ years} + \$25{,}000 = \$415{,}000, \qquad (4)$$

Table 2

Total grid costs

Initial Capital ($)	Annual Operation & Maintenance Costs ($/yr)	Total ($/25yr)
25,000	15,600	415,000

b. Carbon Emission Definitions

In this study, it was assumed that the turbine which generates energy for our process uses Siberia lignite coal as fuel. Lower thermal value, ash and sulphur ratios of Siberian lignite coal are given as below.

Table 3

Siberian lignite coal's values

Ash Ratio %	13.23
Lower Thermal Value (MJ/kg)	30.83
Total Sulphur Ratio %	0.35

According to the fuel chemical characteristics and efficiency (30%) of the PGU, the total amount of the required fuel per one day consumption can be determined as following.

- Daily coal energy requirement:

$$\begin{gathered} 200 \text{ kWh} / 30\% = 667 \text{ kWh} \\ 667 \text{ kWh x } 3{,}600 \text{ kJ} / \text{kWh} = 2{,}401{,}200 \text{ kJ} \end{gathered}, \qquad (5)$$

- The amount of coal needed to generate 200 kWh of energy per day:

$$2{,}401{,}200 \text{ kJ} / 30{,}830 \text{ kJ/kg} = 77.9 \text{ kg}, \qquad (6)$$

- The amount of the ash and sulphur:

$$\begin{gathered} 77.9 \text{ x } 13.23/100 = 10.306 \text{ kg of ash} \\ 77.9 \text{ x } 0.35/100 = 0.272 \text{ kg of sulphur} \end{gathered}, \qquad (7)$$

- Carbon and hydrogen in lignite (C/H ratio is assumed to be 1):

$$\begin{gathered} 77.9 - (10.306 + 0.272) = 67.32 \text{ kg } (C + H); \\ 67.32 \text{ kg equals } 62.14 \text{ kg of C } (5{,}178 \text{ mol}); \\ \text{and } 5.178 \text{ kg of H } (5{,}178 \text{ mol}). \end{gathered} \qquad (8)$$

This means 5,178 mol CO_2 or 228 kg of CO_2 is released in 200 kWh of energy production. 0.272 kg of sulphur yields 8.5 mol of S for the same process. If complete combustion was observed, the emission outputs would be CO_2, SO_2, N_2, H_2O, O_2. However, the chimney also releases CO, NO, NO_2 gases and some particular substances. To find out these values the amount of air needed must be found first [2, 3].

With 5,178 mol CO_2, 2,589 mol H_2O, and 8.5 mol SO_2, the process needs 6,481 mol O_2. With a 25% of excess air it becomes 8,101 mol O_2. Thus, the amount of air (with a oxygen ratio of 21%) needed is 38,577 mol.

- Released N_2 amount:

$$\frac{8{,}101}{21} \cdot 79 = 30{,}476 \text{ mol}, \quad (9)$$

- Released O_2 amount:

$$\frac{6{,}481}{100} \cdot 25 = 1{,}620 \text{ mol}, \quad (10)$$

- So the total moles of gases released from the chimney can be calculated as:

$$5{,}178\,CO_2 + 2{,}589\,H_2O + 8.5\,SO_2 + 30{,}476\,N_2 + 1{,}620\,O_2 = 39{,}871.5 \text{ mol}, \quad (11)$$

For a coal power plant, the temperature of the gases released from the chimney is considered to be 600°C.

- Daily volume of gases released (P = 1 atm, R = 0.082 lt.atm/mol.K):

$$V = \frac{m.R.T}{P} = \frac{39{,}871.5 \times 0.082 \times 873}{1} = 2{,}854{,}241.2 \text{ lt}, \quad (12)$$

According to the conditions stated in environmental regulations, the amount of NO - NO_2, and CO should not exceed 800 mg (2.28 kg), and 200 mg (0.57 kg), respectively. If some of total carbon (62.14 kg) is used for 0.57 kg of CO (20 mol), the remaining amount of carbon (61.896 kg) is used for CO_2 (5,158 mol). Similarly, the NO, NO_2 gases values are found as 76 mol and 50 mol respectively. In this case the new amount of oxygen becomes to 6471 mol O_2 with 1,617.75 mol excess value. So, the new value of nitrogen would be 30,429 mol and 38 mol and 25 mol of it is used for NO and NO_2. The total gas emission values are found as below:

Table 4

Total emission values of the plant

Pollutant	Emissions		Annual Emissions	Total Emissions
	(mol)	(g/kWh)	(kg/yr)	(tons)
CO_2	5,158	1,134.76	82,837.48	2,071
CO	20	2.8	204.4	5.11
NO	76	11.4	832.2	20.805
NO_2	50	11.5	839.5	21
N_2	30,366	4,251.24	310,340	7,758.5
SO_2	8.5	2.72	198.56	4.964
O_2	1,530	244.8	17,870.4	446.76
H_2O	2,589	426	31,098	777.45

4. Hybrid PGU

The electric power generation system, which consists of renewable energy and fossil fuel generators together with an energy storage system and power conditioning system, is known as a hybrid power system. This hybrid power system has an ability to provide 24 hour grid quality electricity to the load. The system components which offer a better efficiency, flexibility of planning and environmental benefits compared to the traditional system are compared here.

a. Cost Analysis

Bidirectional Converter:

Since the output voltage of PV array is DC, it shall be inverted to AC voltage as the system supplies the AC load only. The converter should be bidirectional in order to be able to charge the battery from grid in case of insufficient PV output. Here the efficiency of the converter is selected as 90% and consequently the input power of it is 52.2 kW (η = 0.9, maximum load range = 112%, output power = 42 kW). Including installation, the cost of converter was considered as $12,000.

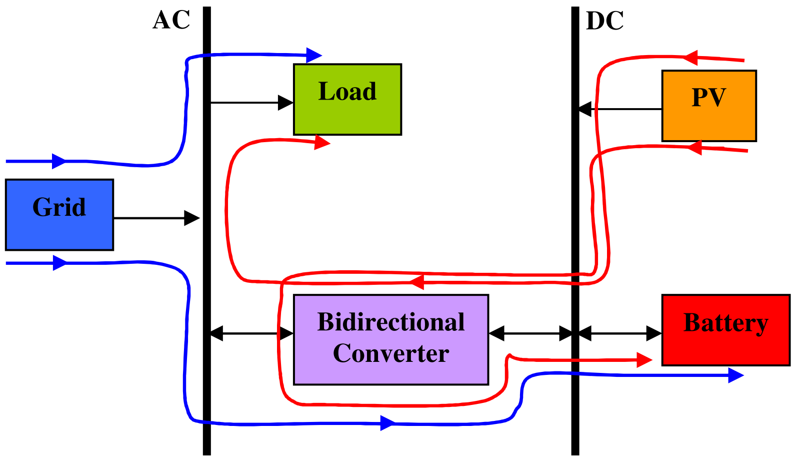

Fig. 3. Single line block diagram of the system

Photovoltaic Module:

The PV's rated power was chosen to be equal to the converters rated power. Therefore, 290 PV modules with a rated power rating of 180W were used in the simulation and the rated power of the modules is equal to 52.2 kW. In the PV array combination 10 PV modules were connected in series, and 29 PV modules were connected in parallel. So, the total PV array's output voltage is 358V (peak voltage), and the output current is 145.58 A (single PV array cost was considered as $900) [4].

Batteries:

With 12 V nominal voltage and 100 Ah nominal capacity 120 pieces of batteries were selected considering operation time and effective cost. To equalize the battery voltage and PV voltage 30 batteries were connected in series with 4 parallel branches. Here, one battery cost was considered as $90. Initial, annual and operation costs are presumptive values [5].

Table 5

Total costs

	Initial Capital ($)	**Annual Operation & Maintenance Costs ($/yr)**	**Total ($/25yr)**
PV	10,000 (installation) 900 x 290 = 261,000	50	272,250
Battery	90 x 120 = 10,800 5 year life time expectancy	50	55,250
Converter	12,000	50	13,250
Grid	-	8,652.8	216,320

The simulation program showed that when PV array, grid and battery group are used together, the daily energy consumption level decreases from 200 kWh to 43,264 kWh per day.

b. Carbon Emission Definitions

To find out the new emission values, the same calculation method was performed that was used in the previous section. Due to the new daily energy consumption value (43,264 kWh/day) the emission values are revised as following.

Table 6

Total emission values of the plant

Pollutant	**Emissions**		**Annual Emissions**	**Total Emissions**
	(mol)	(g/kWh)	(kg/yr)	(tons)
CO_2	1,096	241.1	17,601	440
CO	20	2.8	204.4	5.11
NO	76	11.4	832.2	20.805
NO_2	50	11.5	839.5	21
N_2	7,770	1,087.8	79,409.4	1,985.25
SO_2	1.8	0.57	42.05	1.05
O_2	328	52.48	3,831.04	95.77
H_2O	558	92.07	6,721.11	168.02

5. Conclusions

This paper presents a scenario for supplying electricity demand of a specific plant by using hybrid power system consisting of renewable energy, battery and conventional power generator unit.

First of all, the energy demand of the plant was defined, 200 kWh/day. It was decided to supply load demand from a common power plant using Siberia lignite. According to the fuel chemical characteristics and efficiency of power plant, the total amount of required fuel for a day demand was determined. In addition, in order to specify the total amount of polluting emission gases detailed chemical calculations were performed.

As an alternative solution, approximate simulations of a hybrid plant performance were carried out through the software HOMER. Optimum configuration of appropriate power stations was suggested in the plant depending on energy resources available at specific locations. The results showed that depending on the load sharing, the greenhouse gas emissions and the energy purchased from grid were decreased significantly.

Consequently, this study showed that the fossil fuel burning is obviously and deeply polluting environment. Since the solar power technology is still considerably expensive, the cost analysis resulted in high expenditures. Although the cost is quite high and requires long payback time, it is a fact that PV system releases pollution-free energy. This study was done so as to increase mankind's attention on results of fossil fuel burning and may also light the way for the people who intend to make an investment in solar energy for their plant.

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