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FEASIBILITY STUDY OF A GRID CONNECTED SOLAR PV SYSTEM FOR A RESIDENTIAL LOAD IN JABALPUR

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ABSTRACT

This paper focuses on the optimal designing of grid connected solar photovoltaic power system for a residential building of Jabalpur city, Madhya Pradesh, India (latitude and longitude of 23 10'N and 79 54'E respectively). Madhya Pradesh state is very rich potential of renewable energy sources, especially in solar energy (about 300 solar days), for installation of grid connected photovoltaic system. The research paper uses the software Hybrid Optimization Model for Electric Renewable (HOMER) to design and analyze a domestic power system which includes a grid connected solar photovoltaic (PV) based power system with battery storage to supply a residential load. For optimal system design the analyses have been carried out in two modes – grid connected as well as stand-alone. The simulation results of these two modes have been studied on the basis of cost of energy, payback period, environmental emissions etc. And compared with the grid-only (base) mode. Performance of each component (i.e. Battery, inverter, rectifier etc.) of the model is evaluated and finally sensitivity analysis is performed to optimize the system out of different conditions.

KEYWORDS: Renewable energy, PV-solar, HOMER, Grid connected system, Optimization

INTRODUCTION

Energy has become an crucial and one of the basic framework for economic development of a country. Excessive use of conventional resources like coal, petroleum have lead to noticeable global efforts in exploit the alternative energy resources. The non-conventional energy resources such as the solar, wind, biomass and geothermal heat are environmental friendly and persistent in nature. The large scale use of renewable energy resources are not common. Utilization of energy through these resources using adequate technologies is expected to play an important role in serving as clean and green energy sources to humanity. Most governments have substantial plans directed towards encouraging these technologies in order to develop then commercially. They have yet to achieve the cost-benefit ratio possible with conventional fuels and are not likely to replace fissile fuel in near future. Research work in the field of renewable energy will minimize its cost as well as increases the efficacy of the equipment (like solar Photovoltaic for solar resources) for tapping these resources. And social awareness will increase the market demand of these technologies. Thus the equipment will be sold out at the economy of scale. [1]-[2]

Solar photovoltaic is third most important non-conventional energy source in terms of worldwide installed capacity, after wind energy and Hydro electric power. More than 100 nations use solar photovoltaic. As the advancement in technology takes place and increases in production scale goes with sophistication, the prizes of solar panels has decreased. Net metering and economic incentives, such as preferential feed-in tariffs for solar-generated electricity, have supported solar PV installations in many countries. Solar PV systems convert solar energy into electricity which can then be used by a household. If a household needs more electricity than the solar PV system can provide, this additional electricity can be drawn from the electricity grid. If the solar PV system is producing more electricity than the household needs, the excess electricity can be sold back to the grid. PV system should supply the electric power to the interrupted customers considering the discharge rate of batteries. Without storage, solar PV, typically, contributes less than 40% of its rating towards distribution capacity. [3] - [7].

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A research paper was published in the field of grid interactive PV power system. S.P.Gon Chaudhuri and Indradip Mitra [8] have design a brief idea for a Remote Village Electrification through Non-conventional Energy in the Islands of Sundarbans, West Bengal, India. Extensive research was made by P. Lilienthal and T. Givler with the help of HOMER Software, NREL's Micropower Optimization Model, to Define the Role of Gen-sets in Small Solar Power Systems in Sri Lanka [9]. Anagreh et al [10], prepared technical report on the potential of solar energy of seven sites in Jordan. Yousif El-Tous [11] done a research on the topic of incentive tariff on the economic per-feasibility of a grid-interactive Photovoltaic domestic System in Amman.

The purpose of this paper is an analysis of a grid-interactive PV system for a residential load in Jabalpur (Madhya Pradesh). Optimization of a complete system is analyzed both at grid-connected and stand-alone cases. Comparison are done on the basis of pay-back period, environmental emission, cost of energy. Sensitivity study give the best optimal result out of different options. The system is optimized and simulated with the help of HOMER optimization software.

SYSTEM MODEL

Research Method

Expected model have a solar photovoltaic panels of 2 kW power, a converter of 2 kW capacity (grid-connected type) with a Surrette 4KS25P battery storage. Following power system is designed to have a life of 25 years so the Photovoltaic modules will not needed to be replaced. The proposed system is shown in Fig-1.

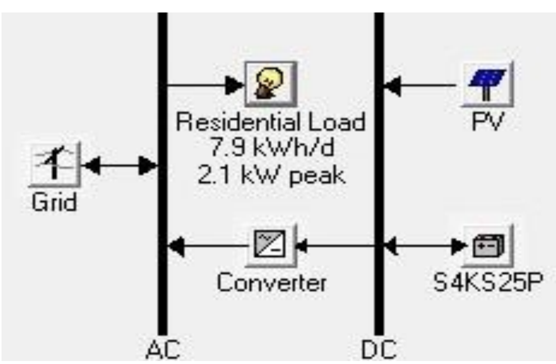

Fig-1:Proposed System Configuration with HOMER

Solar Photovoltaic Modules

The sun radiates energy uniformly in all directions in the form of electromagnetic waves. Solar radiation data for the research work was adapted from the NASA Surface Meteorology and Solar Energy website [12], [13], [14]. Clearness index of 0.577 and average solar radiation of 5.218 kWh/m2/day is obtained for the particular research area (Table-2). The clearness index is nothing but a measure of the clearness of the atmosphere, and is expressed by the fraction of the solar radiation which is transmitted through the atmosphere to strike the surface of the Earth. The Global horizontal radiations and Solar irradiation at Jabalpur are shown in Table-1 & Fig-2.

The Photovoltaic panels gives DC output voltage which is direct proportion to incident solar radiation. The capital cost of Photovoltaic panels is assume \$2000/kW [15] and reinvestment cost is taken as \$1800/kW. Due to the life time of 25 years is taken, the Operation and maintenance (O&M) expenditure is approximately zero. A derating factor of 80% is enforced to every single panel because the degrading factors induced by wiring losses, shading, snow cover, aging temperature, soiling, tilt, etc is considered.

Table-1: Solar Radiation and Clearness Index Data for Jabalpur

Month	**Clearness Index**	**Daily Radiation (kWh/m2/d)**
January	0.640	4.481
February	0.650	5.253
March	0.629	5.911
April	0.652	6.822
May	0.620	6.822
June	0.510	5.682
July	0.370	4.083
August	0.366	3.883
September	0.509	4.950
October	0.658	5.553
November	0.665	4.807
December	0.657	4.372
Average	**0.577**	**5.218**

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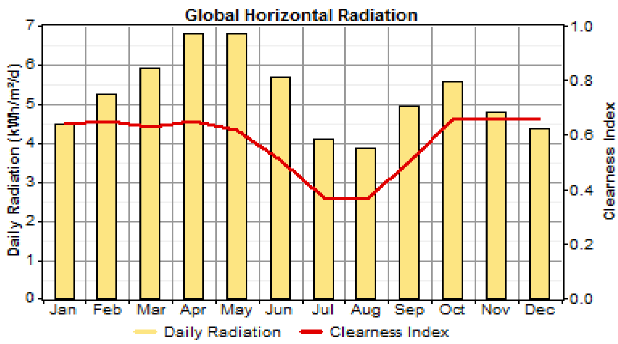

Fig-2: Solar radiation and clearness index for Jabalpur

Daily Load Profile

An ideal house in Jabalpur is selected for the study. The everyday electrical load profile of the selected area is based on typical demands of uses such as room lighting, home PC, fan, refrigerator, CFL's, television and other ordinary appliances. (Table I). The average daily electricity consumption data is shown in Fig.3. As well as the seasonal figures for the load is accustomed in Fig.4. Both these profiles are adapted with the help of HOMER software.

Table-1: Total average energy consumption

Appliances	Units	Power (Watt)	Average Hours Used per day (h/day)	Energy (Wh/day)
Florescent Lamp	4	80	5	1600
Ceiling Fan	4	120	10	2400
Television	1	151	4	604
Refrigerator	1	80	16	1280
CFL	4	15	8	480
Washing Machine	1	385	0.75	288
Desktop PC	1	250	3	750
Electric Iron	1	100	0.25	250
Night Lamp	2	5	9	90
Water Pump	1	380	0.40	152
Total Energy Consumed per day = 7894				

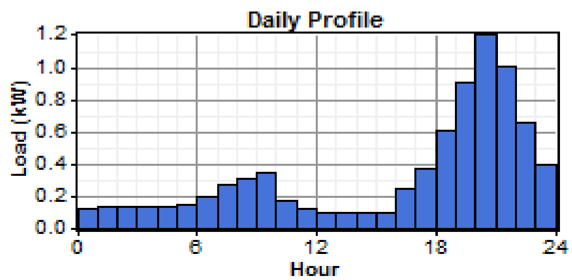

Fig-3: Average load profile.

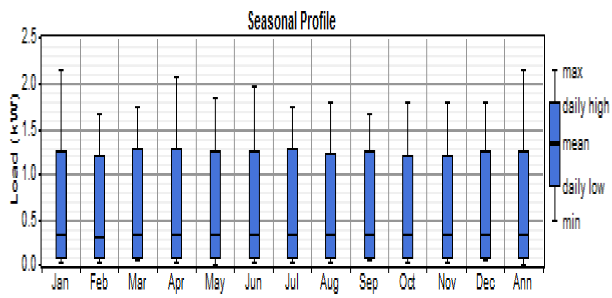

Fig-4: Seasonal load profile.

DC to AC Convertor

The converter is used in an inverter mode for this particular study. Capital costs of unidirectional converter and replacement cost are pretended to be \$850/kW and \$25 subsequently for a period of 30 years. The operating and maintenance cost assumed is nil [11]. The efficiency of inverter is taken to be 90%.

Electricity Grid

The tariff of electrical power is taken as \$ 0.08/kWh for purchase and \$ 0.21 /kWh for selling back to the connected grid [16]. (Sale back tariff not yet declared by the MP Electricity Board, tariff from the West Bengal electricity board are considered for the study.)

Solar Battery

The solar PV power system is considered for working 24 hours, so that the battery is also taken as an essential element of the system. Here Surrette 4KS25P is taken because it is accomplished of giving appropriate back up at the time of load-shedding. The prize of battery and it's replacement cost are both taken as \$439 [17].

EXPERIMENT AND RESULT

Optimized Result from the system which is designed with the help of HOMER consist of, 2 kW Photovoltaic Array, 2 kW converter and one solar inverter battery (12 volt). The research study also acknowledge that in case of load shedding or even grid breakdown the preferred no of battery bank able to give the fundamental back up for 5 hours to run one ceiling fan and three CFL's under 15 watt.

Simulation Result
Simulation is achieved with described data using HOMER software to get the best possible result for the system of Fig-2. The comprehensive simulation results for different cases are as given below.

Case I: Grid alone System (Base Case)
Annual Electricity Generation & Consumption statics are shown in Table III. In this particular study, the overall net present cost (NPC) is achieved as $2882 and levelized cost of energy (COE) is achieved as $0.080/kWh. Annual emissions of Base case are given in Table-4.

Table-3 Annual Electricity Generation & Consumption in Grid alone System

Production	kWh/yr	%	Consumption	kWh/yr	%
Grid purchases	2,818	100	AC primary load	2,818	100
Total	2,818	100	Total	2,818	100

Table-4: Yearly Emissions of Grid alone System (Base Case)

Pollutant	Emissions (kg/yr)
Carbon dioxide	1,781
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	7.72
Nitrogen oxides	3.78

Case II: Grid-interactive Photovoltaic System
Converters are worked as an inverter mode when the power system is connected to the grid. The solar battery is charged by only with the Photovoltaic array. From Table-5 we can understand that the Annual Electricity Generation & Consumption are 5569 kWh and 5191 kWh respectively. And the cost of annual converter deficiency (i.e. 307 kWh) is given in Table-6. From the simulation result we can further notice that 70kWh/year and 1kWh/year power are vanished because of battery loss and battery storage reduction respectively. So measure of annual electricity generation, consumption and overall losses (i.e. 6.78% of full electricity generation and 13.4% of total electricity utilization by fundamental load) show that the power system is extremely efficient. Also from Table-6 it admit that the volume of excess electrical power is 0.267 kWh /annum. It has been confirm that total electrical power generation and consumption along with all losses are stabilize properly.

Table-5: Annual Electricity Generation & Consumption

Production	kWh/yr	%	Consumption	kWh/yr	%
PV array	3,138	56	AC primary load	2,818	54
Grid purchases	2,431	44	Grid sales	2,373	46
Total	5,569	100	Total	5,191	100

Table-6: Yearly Electrical Power Losses in Converter

Quantity	Inverter	Rectifier	Units
Hours of operation	4,421	0	hrs/yr
Energy in	3,067	0	kWh/yr
Energy out	2,760	0	kWh/yr
Losses	307	0	kWh/yr

After getting the optimum result we can say that the cost of energy is less as related to the grid only system. So the proposed power system is attainable from economic point of view. Also payback duration for proposed power system is achieved as 12.4 years (Table-8) which provide almost 13 long years of exclusive income for a period of 25 years.

Table-7: Various Cost & Renewable Fraction of Present Power System

Total NPC: $ 2,805
Levelized COE: $ 0.078/kWh
Operating Cost: $ -261/yr

Quantity	kWh/yr	%
Excess electricity	0.267	0.00
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.563

Table-8: Economic results

	PV (kW)	H1000	Conv. (kW)	Grid (kW)	Initial Capital	Total NPC
Base case				1,000	$ 0	$ 2,882
Current system	2	1	2	1,000	$ 6,139	$ 2,805

Metric	Value
Present worth	$ 76
Annual worth	$ 6/yr
Return on investment	7.92 %
Internal rate of return	6.13 %
Simple payback	12.4 yrs
Discounted payback	24.6 yrs

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The measure of annual emissions of the current power system is displayed in Table-9. In this case amount of emission of SO2, nitrogen oxides and CO2 decreased to 0.158 kg/year, 0.077 kg/year, 36.3kg/year, respectively. These values are very less as compared to the grid-alone system. Hence this proposed power system is favorable in the context of green and clean environment, too.

Table-9: Annual Emissions of Current System

Pollutant	Emissions (kg/yr)
Carbon dioxide	36.3
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	0.158
Nitrogen oxides	0.077

Case III: Stand alone System

For the study of this case, initially we have assumed the stand alone system with different sequence of loads. Finally we obtained the basic ideal condition in which the power system is capable of giving back up at the time of load shedding or grid breakdown at least for 5 hours with one fan and three CFL's at night. The exact simulation results of this condition about Annual Electrical Power generation & Consumption, measure of annual converter losses and various cost data are displayed in Table-10, Table-11 & Table-12 respectively. And Overall energy loss occurred in battery is 33 kWh/ year. (according to simulation result)

Table-10: Annual Electricity Generation & Consumption in Stand–alone System

Production	kWh/yr	%
PV array	3,138	100
Total	3,138	100

Consumption	kWh/yr	%
AC primary load	562	100
Total	562	100

Table-11: Annual Electrical Power Losses in Converter Stand–alone System

Quantity	Inverter	Rectifier	Units
Hours of operation	5,839	0	hrs/yr
Energy in	624	0	kWh/yr
Energy out	562	0	kWh/yr
Losses	62	0	kWh/yr

Amount of surplus electrical power is obtained 2481 kWh /year in this case (Table-12). There are a few possibility when the grid break down. So, this surplus electrical power will cut down the quota. Table-12 also displayed that the measure of NPC and COE becomes $6279 and $ 0.874 / kWh which are high enough But as we know grid break down or load shedding are not generally happened in good power system. So we can say the power system is feasible during emergency condition. It is also important to note that the annual emission in the time of standalone condition, as shown in Table-13, is nil.

Table-12: Different Cost & Renewable Fraction of Stand – alone System

Total NPC: $ 6,279
Levelized COE: $ 0.874/kWh
Operating Cost: $ 11/yr

Quantity	kWh/yr	%
Excess electricity	2,481	79.1
Unmet electric load	0.334	0.1
Capacity shortage	0.535	0.1

Quantity	Value
Renewable fraction	1.00

Table-13: Annual Emissions of Stand-alone System

Pollutant	Emissions (kg/yr)
Carbon dioxide	0
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	0
Nitrogen oxides	0

CONCLUSION

Amount of annual energy generation, consumption and finally COE have been achieved at various conditions to get the optimum system. The study acknowledge that the COE is $0.078/kwh in case of the grid-interactive power system (Case II) - lower as compared to grid alone system. This is beneficial in context of economy. But when we consider the standalone system, the COE becomes $0.874/kwh (case III). So we can say that the COE is higher in case of grid-interactive system as compared to grid only system. But we will not concern as standalone power system is convenient only in case of emergency condition (during grid break down or load-shedding). Another important advantage of this approach is that in case of load-shedding & grid break down battery can give the needed back up for emergency load. In this case of study only one no of battery is used for back up. Because more batteries will increases the capital cost of the system. All the same the system with one battery is efficient enough of giving back up. It is conspicuous that Sun based power systems are more favorable to the environment as compared to grid only system. Due to adding of

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solar PV to the grid, it decreases the carbon di-oxide and other adverse gases emission in environment.

After the study of simulation result we can find out that the payback period estimated is 12.5 years, this is very much essential for a long run system. Also it has a very low running and maintenance cost. It also facilitate to boost the living standards of remote areas and spur more efficient economic development. On the other hand the capital cost of the power system is quite high because of the prize of solar PV panels, but in future it is going down with advancing in technology.

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