Feasibility Analysis of 1 MW Grid Connected Solar Rooftop Plant

Charanjiv Gupta, and Sanjeev Singh

Abstract**—** With the depletion of conventional energy sources, the use of renewable energy sources has become quite popular these days. Solar energy has the most potential of any renewable technology and has turned into a fast growing industry with improvement in its cost effectiveness. In India, where there are approximately 300 sunny days per year, the daily average solar power generation capacity is 0.25 kWh/m^2 of used land area.

The objective of this work is to check the feasibility of setting up a 1MW grid connected roof top solar photovoltaic plant in SLIET, Longowal, Punjab. The feasibility study will include both technical and economic feasibility with an emphasis on the technical standards and regulations set by the PSPCL.

Keywords**—** Fossil fuels, solar energy, solar PV system, feasibility analysis, solar radiation, solar modules, solar inverters.

I. Introduction

CONVENTIONAL sources of energy such as petroleum, coal, natural gas etc. have been in use for a long time. They are all exhaustible and their reserves are getting depleted day by day. They are very expensive to be maintained, stored and transmitted. The use of fossil fuels causes global warming as, on burning, they emit carbon dioxide which is the principal greenhouse gas. Global warming in turn has many effects such as increase in earth temperature, rise in sea-levels, melting of glaciers. Also, they cause pollution when in use as they emit smoke and ash. On the other hand, non-conventional resources such as solar, wind, tidal, biogas, biomass etc. are inexhaustible and are pollution free. They are less expensive due to local use and easy maintenance. Solar power is the conversion of the energy from the sun to usable electricity. Sunlight is converted directly into electricity by using the photovoltaic cells that are made up of semiconducting materials that exhibit photovoltaic effect. Solar energy is a sustainable, renewable and predictable form of energy. Solar energy is environment friendly and no pollution is created in the process of generating electricity. Also, the solar panels do not require a lot of maintenance as they do not have wearable parts and thus can last very long. Solar rooftop plants are very reliable as they can generate electricity using a little space and are free from such mechanical parts that are vulnerable or can fail easily. India's theoretically calculated solar energy incidence is about 5,000 trillion kilowatt-hours (kWh) per year on its land area alone [1].

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As of 31 March 2016, the total installed grid connected solar power capacity is 6762.85 MW. Under the Jawaharlal Nehru National Solar Mission (JNNSM), installation of an additional 10 GW is expected by 2017 which is to be raised to a total of 100 GW by the year 2022 [1].

As there is a scarcity of land in India especially agricultural areas such as Punjab, rooftop solar power generation systems are most suitable for the purpose. The PV system can be of two types: Stand-alone systems which are isolated systems that work alone and Grid Connected systems that are connected to the utility grid. In this paper, feasibility analysis of setting a grid connected 1 MW PV system on the roof top of SLIET Longowal, Punjab is provided.

II. Site Details

The institute, SLIET, is located in Longowal region of Sangrur, Punjab. The PV plant is to be installed on rooftops of various buildings of the institute. Various academic blocks constitute an area of about 35,000 square meters and the administrative block has an available area of 2500 sq. meters. Thus the total available area which can be used for rooftop PV installation is about 37,000 square meters. So, there is plenty of rooftop area for installation of 1 MW PV plant.

A. Load Details

The different types of loads utilized in various academic buildings and hostels are lighting loads, fans, ac, computer systems and some auxiliary loads. There are three transformers that are used to cater the requirement of these loads. There are two 500 kVA transformers located at Electrical Sub-Stations, ESS- I and -II respectively and one 250 kVA transformer located in the Electronics and Communication Engineering block.

An additional load of approximately 400kW is going to be added in the current year due to establishment of new academic buildings. For compensation of this additional load, a new transformer of capacity 500 kVA will be installed in the Electrical Sub-Station, ESS-II.

For various transformers the peak load is given in Table 1.

TABLE I
PEAK LOAD OF TRANSFORMERS

Sr. No.	KVA Rating	Location	Maximum Load
1	500 KVA	ESS-I	225kW/ 250 KVA
2	500 KVA	ESS-II	371 kW/ 412 KVA
3	250 KVA	ECE Block	219 kW/ 243 KVA

III. Solar Radiation Data

The solar radiation incident on Sangrur varies from 3.26 kWh/m^2/day in December to 7.23 kWh/m^2/day in May [2].

The solar radiation variation in Sangrur on a monthly basis is as given in table 2.

TABLE II
INCIDENT SOLAR RADIATION ON SANGRUR ON MONTHLY BASIS

Jan	Feb	March	April	May	June
3.39	4.30	5.65	6.62	7.23	6.78
July	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
6.31	6.09	5.57	5.21	4.13	3.26

(Unit: kWh/m^2/day)

The variation in solar radiation taking monthly average is shown in Fig. 1.

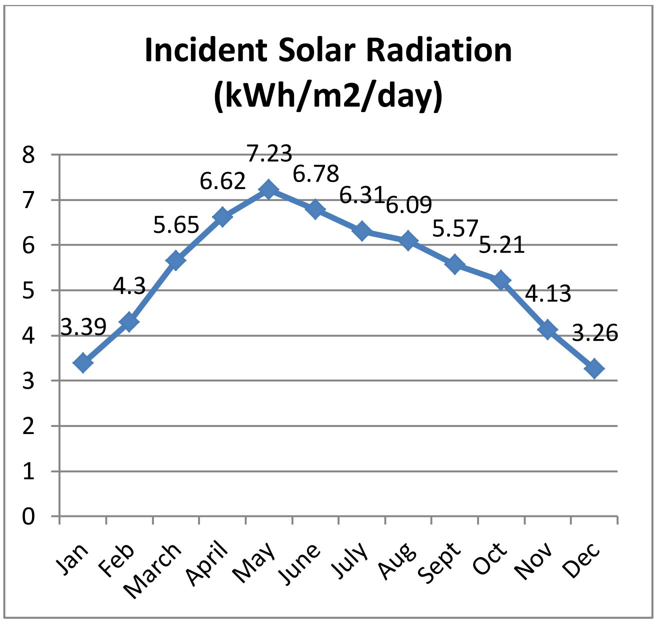

Fig. 1 Monthly average solar irradiation in Sangrur, Punjab

The annual average solar radiation is 5.38 kWh/m^2/day. There are around 300 sunny days in most parts of India including Punjab.

IV. Requirements

For setting a solar rooftop plant, various equipments such as solar panels, inverters, cables, junction boxes etc are required.

A. Solar Modules

Solar module is the heart of a photovoltaic system. Many solar cells are wired together to form a solar module. They are composed of silicon having different structures based on which the solar modules can be of three types, namely mono-crystalline, poly crystalline and thin film [3]. Mono-crystalline solar cells are made of silicon ingots which are cylindrical in shape. They have highest efficiency but are the most expensive of all. Poly-crystalline cells are made of square shaped ingots and consist of small crystals. They are less expensive with a bit lower efficiency than the mono-crystalline cells. Thin film cells are constructed by wedging several layers of photovoltaic material of minimum thickness onto a substrate such as glass or metal. They are least expensive but have lowest efficiency as compared to others. Poly-crystalline silicon solar modules will be used here owing to their lesser cost and good efficiency. The efficiency of the solar module will be approximately 16%.

1) Number of Panels Required: For a 1 MW plant, the total number of solar panels required can be calculated as shown in Table 3.

TABLE III
CALCULATION OF NUMBER OF PANELS

Average sun hours	5
Total Power per day	5 MW
Total Watt-hour per day	5x1000x1000 W-h/day
Maximum solar insolation in Sangrur	7.2 kWh/m^2/day
Watt-hour/day divided by max solar insolation	6,94,444.44
Multiplying by 1.2 (to cover inefficiency of solar panels)	8,33,333.33
No. of solar panel of 300 W each	2777.78

The total number of solar panels required will be 2778. For greater efficiency, we can use 2780 solar panels of 300 W each

2) Cost of Solar Modules: For polycrystalline solar panels, the cost per watt is about Rs 42. Thus for one solar panel of 300W, the cost will be Rs. 12,600. The total cost of solar panels for 1 MW capacity will be about Rs. 3,50,28,000.

B. Solar Inverters

Inverters are used to convert dc power generated by solar panels into required ac power.

1*) Cost of Inverters*

The inverter converts the DC input from Solar Modules into usable AC output. Multiple MPPT inverters are used to get maximum power output from the inverters. The cost of inverters is about Rs 16 per watt. Thus for 1 MW plant, the total cost for inverters will be Rs. 1.6 crores.

C. Cost of System

The total cost of the system is calculated as given in Table 4.

TABLE IV
FINAL COST OF THE SOLAR PV SYSTEM

Total Cost of Solar PV panels after subsidy (15 %)	2,97,73,800
Total cost of 3 phase Inverters	1,60,00,000
Net cost of whole set-up	4,57,73,800
Auxilliary and misc. cost (20%)	91,54,760
Total System cost	5,49,28,560

D. Total Area Required

A single module with an output capacity of 300 W consists of about 72 solar cells of 156 mm x 156 mm each. The size of each 300 W panel including frame in meters is approximately 1.984 x 1 x .04. So for 2780 panels, total area required will be about 6000 square meters.

V. PSPCL REQUIREMENTS

For setting a rooftop plant, certain eligibility criteria are there. The consumer should obey all the rules and codes as specified by PSPCL/DISCOM/CEA [7]. For installing a solar plant, the process is as given below:

- The consumer has to pay a processing fee of Rs 50/kVA subject to a maximum of Rs 10,000 along with the solar net-metering rooftop Application form for getting permission to set up the rooftop plant on a first-cum-first serve basis.
- The feasibility of plant will be checked by Sr. XEN/Addl. SE and an approval letter will be issued within 30 days after the application form is received.
- The consumer has to set up the approved plant and a work completion report has to be submitted along with a Single Line Diagram of the synchronising and protection arrangement within 180 days.
- The consumer shall be given a maximum extension of 2 months, failing which the granted approval shall elapse.
- After the SLD is approved and site is verified, the Bi-directional and unidirectional meters will be installed and sealed by PSPCL within 10 days after work completion report is submitted.

All the equipments such as PV panels, inverters, synchronizers, cables, transformers, junction boxes, MPPT etc should be as per latest standards as specified by IEC. Bidirectional energy meter, having recording facility for both import and export of energy, should be as per State Grid Code /CEA metering regulations and approved by PSPCL.

A. Installation Capacity

The maximum capacity of the Roof Top Solar PV system, as mentioned on AC side at the output of inverter based on rated inverter capacity, should not be more than 80% of the Sanctioned Connected Load. The power factor is taken as 0.9.

The excess power generated by solar PV plant will be injected into the Grid using the same service line that the consumer uses for extracting power from the utility network and should maintain synchronism with the PSPCL system.

In a settlement period, the injected power should be less than 90% of the total power consumed by the consumer from the licensee's supply.

B. Banking and Billing

PSPCL will take bi-directional meter reading for the amount of power imported and exported by the consumer at the end of each settlement period/billing cycle.

- If the final flow is towards PSPCL i.e. surplus energy is exported by the consumer into the PSPCL system, this amount of energy will be processed as energy gained by the consumer in the present billing cycle and will be accounted for in the following billing cycle. This amount of energy will be deducted from the energy used in the next cycle before billing.
- If the final flow is from PSPCL, then the consumer has to pay for the net power drawn. An Energy Account Statement is issued to consumer by PSPCL which contains the account of energy imported/exported from PSPCL and Solar PV system, energy deposit of former cycle and net energy billed or net energy deposited that will be taken forth to following billing cycle.

The settlement of net energy is done after a settlement period is over and takes into account the total consumption. If the injected power is more than 90%, the extra amount is set to nil. The total carried over energy, at the beginning of each settlement period, is readjusted to zero.

VI. ECONOMIC VIABILITY

With an average of 5 sunny hours in a day and about 300 clear sunny days, the total energy generated per year by the photovoltaic plant will be 1500 kWh/m^2 per kW. So, for 1 MW, the total generated electricity will be 1500000 kWh.

In 25 years, 37500000 kWh of energy will be generated.

A. Carbon dioxide Mitigation

The total carbon dioxide emission reduced by the use of 1 MW rooftop solar plant is about 34,419.5 tonnes[9]. One ton of carbon dioxide is equivalent to 1 carbon credit. The cost of one carbon credit is approximately Rs.110. In an year, the total carbon credits saved are 1376.78 which will amount to Rs. 1,51,445.8 per year. Over a lifetime of 25 years, the total carbon credits saved are 34419.5 and thus the total amount will be Rs. 37,86,145.

B. Total Savings

Total cost of setting up the plant including solar panels, inverters, mounting structures, cables, fuses, meters etc. is approximately 5.5-6 crores.

At a tariff of Rs 6.18/kWh, the monthly savings will be Rs. 7,72,500 and annual savings will be Rs. 92,70,000. For a working period of 25 years, the total savings will be Rs. 23,17,50,000.

The simple payback period is about 7 years without subsidy whereas with subsidy it is about 6 years.

TABLE V
TOTAL SAVINGS

Carbon Credits Savings	Yearly Saving	Total Savings	Payback Period
Rs. 1,51,445.8	Rs. 92,70,000	Rs. 23,17,50,000	6 years (with subsidy)

VII. SIMULINK MODEL

Fig. 2 shows the simulink model designed for a 1 MW Grid connected Solar Photovoltaic plant. It consists of an array of 2780 solar photovoltaic panels, each panel having a capacity of 300 W. 139 strings, each having 20 panels in series, are connected in parallel to achieve the required output. The output of this array is connected to an inverter which converts the DC input into an AC output with fixed frequency, 50 Hz here. The inverter is made using 3-level IGBT bridge with PWM control and has inbuilt MPPT system which uses perturb and observe method for extracting maximum output.

The output of the inverter is then fed to a transformer which increases the voltage level to 33 kV so that power can be fed to the utility grid. The grid here includes an equivalent 132 kV transmission system, a 33 kV feeder and grounding transformer. A 3 phase load is connected to the AC side for demonstrating the working of the grid connected system at different solar intensities and loads.

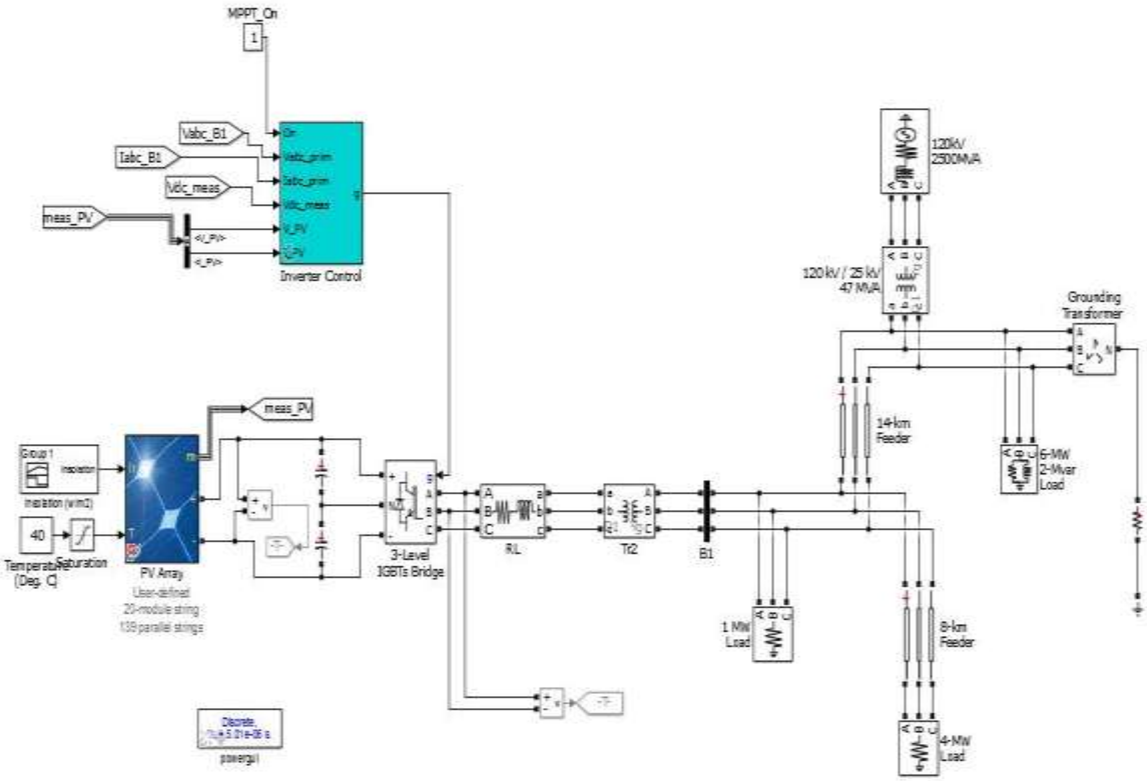

Fig. 2 1 MW Grid connected solar photovoltaic system

VIII. Results and Discussions

As the intensity of solar radiation changes, the output power from the solar photovoltaic array also changes. This is shown in Fig. 3. The mean voltage remains constant whereas the current changes according to the solar intensity. With a decrease in intensity, power decreases and with high intensity, the output power increases.

On the AC side of the inverter also, the voltage remains same whereas the current changes with the solar intensity. The power output at the ac side is shown in Fig 4. The power is approximately 1000 kW when the intensity of sunlight is 1100 W/m^2. It decreases to around 500 kW when the radiation falls to 600 W/m^2 and then again increases when the light intensity increases. This shows the variation of output with variation of solar intensity which keeps on changing throughout the day.

When a load of 1 MW is fed from the system, only about 80 kW power is imported from the grid when the light intensity is high. As the light intensity decreases, the power from solar PV system decreases and thus more power is imported from the grid. This imported power is shown as negative power in Fig 5.

At lower loads and high solar intensities, the excessive power produced by the solar PV system is supplied to the utility grid. When load is reduced to 500 kW, at high intensity, 450 kW of power is exported to the grid whereas at lower intensities, no power is imported/ exported to the grid. This is shown in Fig. 6. The power exported to the utility grid is shown as positive power in the graph.

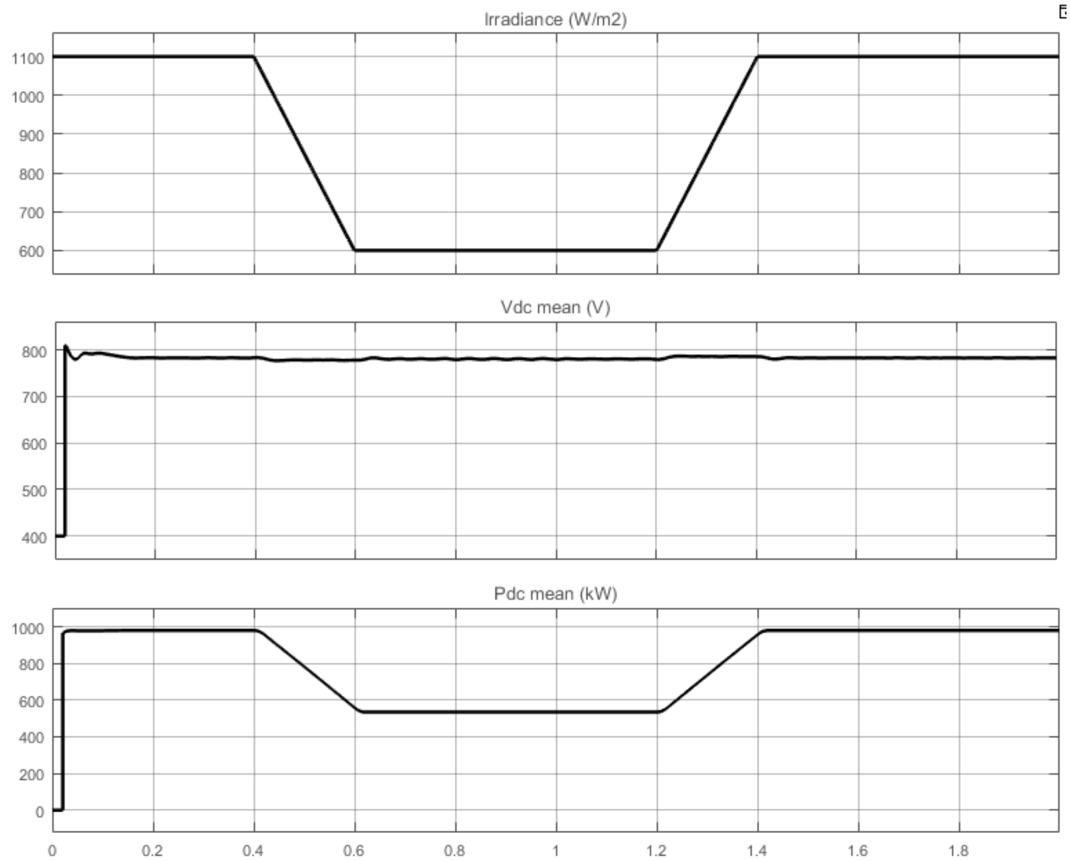

Fig. 3 Solar irradiance, average DC voltage and the average power output

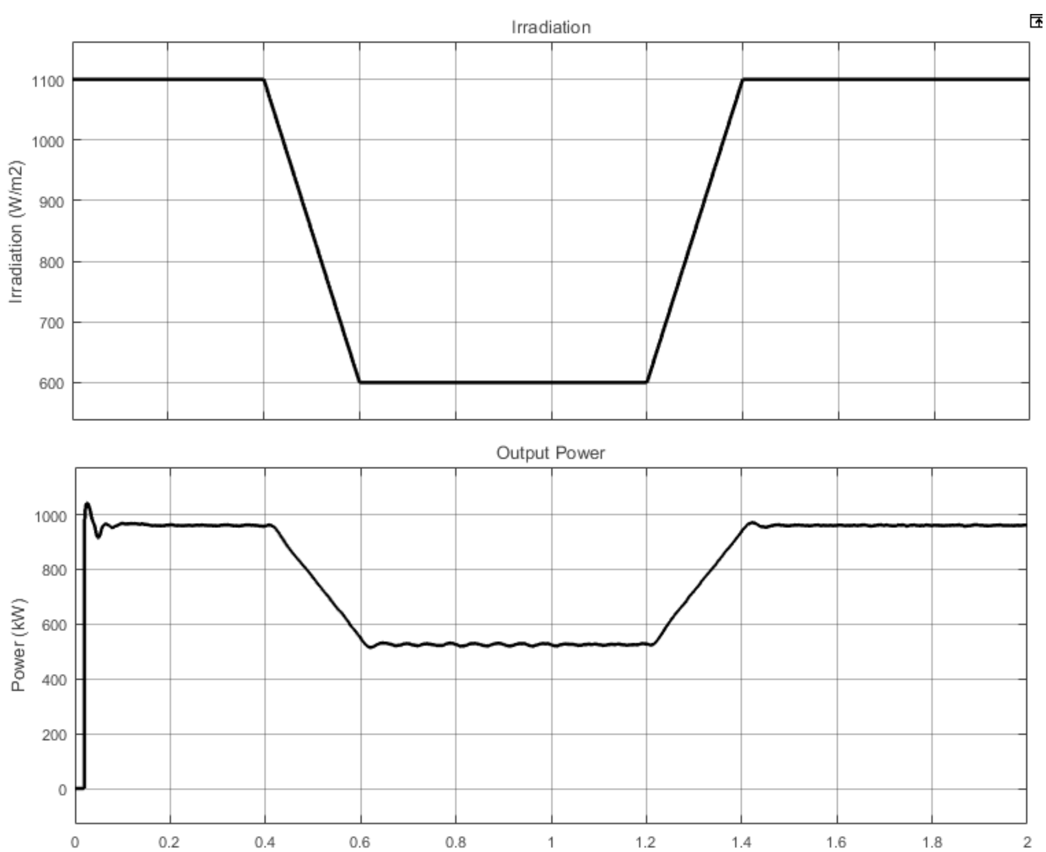

Fig. 4 Variation of output power with change in radiation

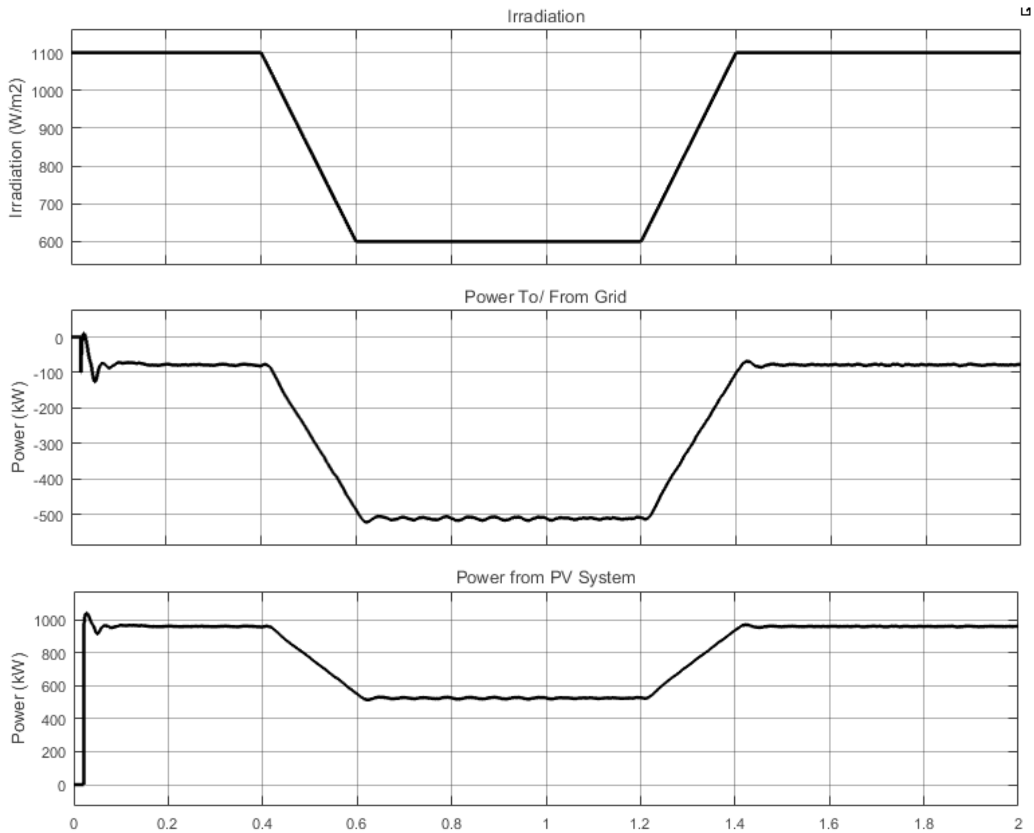

Fig. 5 Import of power from the grid during heavy loads/ low light

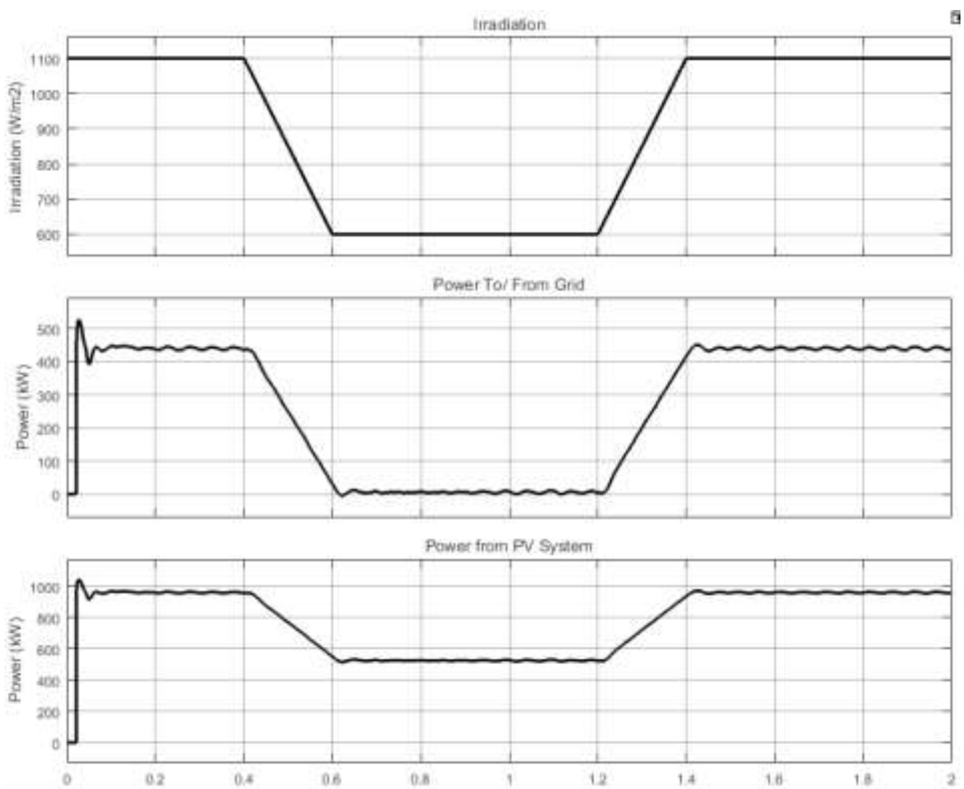

Fig. 6 Export of power to the grid during light loads/ high intensity

IX. CONCLUSION

The grid connected plant can be used for providing power to commercial/industrial users during the day and the excess energy produced can be fed to the grid. This energy is banked with the DISCOM and balances the energy used during the night hours. This leads to overall reduction in power usage from the grid to a great extent.

The 1 MW plant to be installed is found to be feasible both technically and economically with a saving of around Rs. 97,70,000 per year and a reduction of carbon dioxide emission by 1377 tonnes per year. This installation is equivalent to planting around 55,000 trees over the lifetime [11].

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