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Effective low cost Grid-Connected Solar Photovoltaic System to Electrify the Small Scale industry/Commercial Building

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Abstract- With the fast depleting fossil fuel reserves, energy security and environmental concerns there is a huge requirement of alternate sources of energy to fulfil the present energy demand. Out of the various available renewable energy sources, solar energy is a clean, vast and reliable energy source to meet up the present energy scenario in the world, especially in India. Therefore, the solar photovoltaic system (SPV) has gained attention both in grid connected and off-grid modes and such systems are being developed rapidly in the recent years. However, there is a need for a continuous supply of energy to feed the different types of loads, but SPV systems cannot provide continuous power because solar irradiance varies throughout the day, therefore storage system is necessary with the solar photovoltaic systems, this would further increase the overall cost of such system. Alternatively, if the solar photovoltaic system is connected to the grid then there is no need of storage devices because in this case grid would act as a battery of infinite capacity. If generated power from the SPV system is more than the demand then surplus power will be sold out to the grid otherwise load will be supplied by the utility.. Therefore an idea of renewable energy generation and control of grid automation system is proposed in this paper. This paper proposed the effective low cost 10 KW grid-connected solar photovoltaic system to meet up the present load demand. This work introduces the optimal scheduling of Grid-Connected Solar PV system for economical and efficient operation of the system. Between the Grid-connected solar photovoltaic system and off-grid solar photovoltaic system that has been considered for solar power generation, the proposed grid-connected solar photovoltaic system is best suited for small scale industry/ commercial buildings having the lowest cost of energy as INR 2.12/kWh.

Keywords Solar energy, MPPT, inverter, AC grid, PVsyst.

1. Introduction

With fast depleting fossil fuels, environmental concerns and energy security there is an urgent need to look for alternate sources of energy, therefore, renewable energy sources have gained marvellous attention and developed rapidly in recent years. Out of various factors causing hindrance to the large-scale use of renewable energy sources, the cost is the important concern of any renewable energy source. Various schemes for integration of solar system and wind system have been developed which are based on various methodologies. The cost effective solution is to integrate to the grid different renewable energy sources like solar and wind because of their complementary nature but in this case, the stability of the system is affected as presented in the literature. The various ratings of the inverter are chosen according to power feed to the grid if grid power is less for high rating inverters consequently the cost would be increased. If the system avoids the flow of circulating current during solar irradiance then the overall efficiency would be increased. Various control algorithms are developed for maximum power point tracking in PV system hence this would further increase the efficiency of the system [1].

Energy scheduling is also an important concern for household applications which is affected by heating of different equipment, therefore, the overall cost should be minimized according to heating concern related to the appliance. Therefore this system supports all equipment's of different heating effects and it offers the overall low cost. A various control algorithm has been proposed to minimize the overall cost of the system with including the heating effects[2].Changes in solar irradiance are the main concern stability of SPV systems because this changes with time and the output power of SPV depend on the solar irradiance. Then there is a need of effective architectural analysis to protect the overall system. The Mars scenario was chosen because of data available and adaptability in the various techniques. All required components cost was assessed by estimating the total dry mass of the system, therefore, the best value solution has been obtained by using multi-attribute utility theory [3].

Nowadays the investigation of metamorphic monolithic InGaP/GaAs dual- junction (2-J) solar cells on Si substrates is the matter of concern. The dislocation density varies within the range of 105 to 107, this can be found between each cell .In order to achieve maximum potential an optimal cell has been investigated for mitigating the loss by taking shading effects. The main components of the design are front grid spacing and sheet resistance for higher consideration and the switch has a conversion efficiency of 33.11 % for 2-J InGaP/GaAs. This technology is used for low cost system, therefore, an optimum designed has been obtained through small area consideration [4].The solar photovoltaic system is developing fast nowadays with an effective share of electricity generation for this world. SPV system is a clean source of continuous, vast and reliable energy source to meet up the present energy scenario in the world. Various technologies have been made by different industry only for increasing the efficiency of the solar photovoltaic system. The third generation provided the solution of desensitized solar cell, which is a very effective technology. This technology offers the less expensive system in comparison with the Si-based photovoltaic system. To enable use of this technology worldwide a long-term stability is necessary. It has a different phase and it accelerated optical stress analysis is required to understand the mechanisms' degradation of DSSC parameters such as efficiency, open circuit voltage, and short circuit current. The experimental data are planned to determine the advantages and disadvantages of this technology [5].

The SPV pumping system comprises of dual inverter fed open-end winding induction motor. It requires low PV bus voltage in comparison with conventional type inverter. This could reduce the voltage rating of capacitors as well as semiconductor devices. It is used for cost reduction of PV system. By using this, an integrated control algorithm has been developed for maximum power point tracking, V/f control, and the sample-averaged zero-sequence elimination. While the MPPT algorithm ensures the extraction of maximum power from the PV source, the V/f control improves the motor pump performance. The sine PWM algorithm has been used to avoid the zero sequence components and it improves the overall performance of PV system. Solar photovoltaic energy has developed rapidly in past decades and the variability of the power production is an important matter of concern in spite of increasing the installed capacity of the system. The variability of the power production depends on short time effects like cloud shadowing and long term effects such as dust accumulation, aging effect etc. These effects may cause large changes in the power production in PV system. Hence data is needed to check the effects and to develop the effective PV system[7].There is the possibility of employing the water heater and HVAC for regulation of load but energy management for other loads is critical [8]–[10].For regulation of loads, the water heater is added with HVAC in the system. The HVAC system which is powered by solar system and water heating system has many advantages such as the quiet operation of solar energy [11]–[15].The solar system and wind system are popular because they are both clean and cost effective sources and do not require any fuel, unlike biomass, fuel cell stack etc. [16]–[18]. Nowadays the problem of electricity generation is increased which drives the need for cost effective solutions [19]. Many surveys have been focused on two-stage and single stage PV-powered pumping systems [20]–[23].So there is a need of a cost-effective system for small scale industry and commercial buildings.

In this proposed work, PVsyst software is used for calculation of different data. PVsyst software can easily estimate the production for an early study of installation. It is a project design tool for study, sizing and hourly simulation and gives result in a complete printable report. This software allows the user to accurately analyse the different configurations and to evaluate the results and recognize the best possible solution.

In this paper, grid-connected solar PV system design is described in Section II. In Section III, cost analysis of grid connected and off grid solar photovoltaic system are presented. In section IV, optimal scheduling is described. Results and discussion are described in Section IV. Finally, concluding statements are presented in Section V.

2. Grid Connected Solar PV System Design

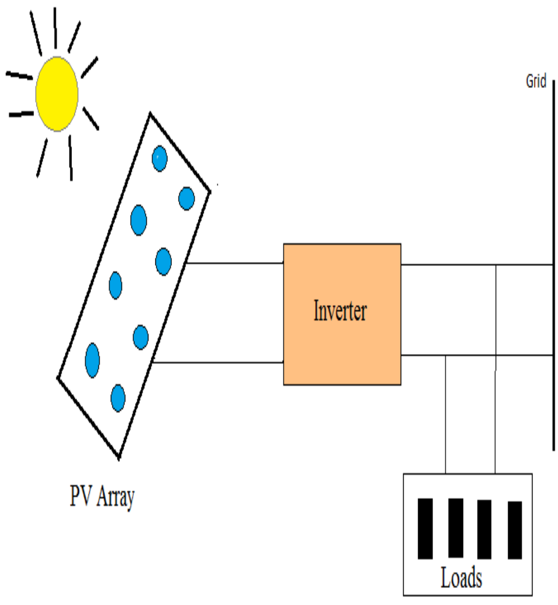

Fig. 1. Grid Connected Solar PV System

The solar system design is based on system type, site location, area, solar irradiance etc. The basic components of PV system are solar charge controller, inverter, PV modules as shown in fig 1. For Grid connected systems, there is no need of storage device i.e. battery so initial cost of the system would be reduced. To design a grid connected solar PV system for the commercial use, the following steps are required.

A 10 kW PV system connected to the grid via an inverter is assumed. The I-V relationship of the photovoltaic system is

$$I = I_{pv} - I_0\left[exp\left(\frac{V + IR_s}{A\,kT_w}\right) - 1\right] - 1\frac{V + IR_s}{R_{sh}} \tag{1}$$

$$I_{pv} = G[I_{sc} + k\left(T_w - T_{ref}\right) \tag{2}$$

$$I_0 = I_s(\frac{T_w}{T_{ref}})^3 \exp\left\{\frac{qE_G\left(\frac{1}{T_{ref}} - \frac{1}{T_w}\right)}{kA}\right\} \tag{3}$$

These equations are used to design the PV system. The system will be powered by $12V_{dc}$, 315W PV module.

2.1. Power consumption demand per day

The power consumption demand depends on the connected loads.10 kW SPV system is considered for small scale industry or commercial building and the grid-connected SPV system gives the yearly saving.

The net PV panels energy needed=10kWh/day

2.2. Sizing of PV panel

The number of PV panels required can be calculated by taking overall power required and the watt rating of PV panel. By including this two parameters actual requirement of PV modules can get.

The number of PV panels required=10000/315

=31.74

Actual requirement=32 modules

So 32 modules of 315 W are needed for the grid connected PV system. 315 W modules are readily available so to achieve 10 kW output SPV system, 32 modules are connected.

The PV Model specifications are:

$$P_m = 315.3\,W$$
$$V_{mpp} = 37.20V_{dc}$$
$$V_{oc} = 45.30V$$
$$I_{sc} = 9.01A$$
$$I_{mpp} = 8.45A$$

Efficiency/cells area=17.99%

Efficiency/module area=16.12%

Hence the efficiency per module area is 16.12% consequently 32 modules are needed to generate 10kW power output. This system is economical as well as reliable since the solar output is used to feed the grid via an inverter. Whenever solar power is not available then grid will supply electricity to the respected load. Table 1 shows the PV module Specification for equivalent circuit parameters and table 2 shows the size description of PV module.

Table 1. PV module Specification for equivalent circuit

Parameters	**specifications**
R shunt	350 ohm
Rsh(G=0)	1400ohm
R series model	0.36ohm
R series max	0.37ohm
R series apparent	0.55ohm
Gamma	0.906
IoRef	0.02mA
muPmax fixed	-155 mV/°C
muPmax fixed	-0.41/°C

Table 2. Size description of PV module

Module-Length	1922mm
width	992mm
thickness	40mm
weight	23kg
Cells-In series	72
In Parallel	1
Cell area	1.752m2

2.3. Design of the Inverter

Inverter size depends on the total watts of all appliances therefore for safety concerns the inverter should be accurately rated hence 2 inverters are used with 5kW capacity each. Table 3 shows the inverter specification. PWM algorithm is used to control the output of the inverter. The output of inverter should be constant for better performance and high efficiency of switching devices, Auto-tuning has been used for the inverter circuits.

Table 3. Inverter Specification

Parameter	**Specifications**
Minimum MPP voltage	360V
Maximum MPP Voltage	500V
Absolute max PV voltage	500V

Power Threshold	25W
Grid Voltage	230V
Nominal AC power	5kW
Maximum AC power	6kW
Nominal AC current	22A
Maximum AC current	33A

2.4. Array Design for optimizer

The Number of optimizers in series is equal to 8 and 1 string has 8 modules so for optimum design this system is preferred
PNom=2520 W
No of string in parallel=4
Phnom Ratio=1.01
Area=63m^2

2.5. Geographical location

The geographical site is very important where solar system has to be installed. It is necessary to collect data from different centers, Delhi has been chosen for this installment. Latitude is 28.6°N and longitude is 77.2°E.

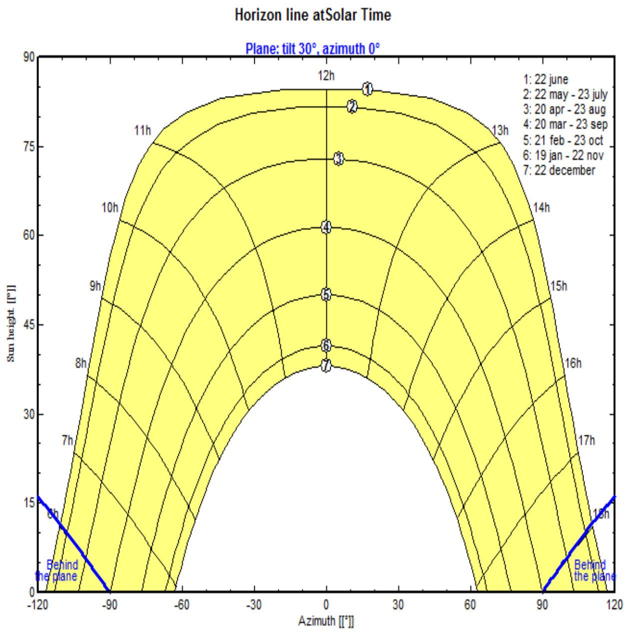

Fig. 2. Sunlight versus azimuth angle with different change in Month

Altitude=219m
Albedo factor=100%
Diffuse factor =1
Albedo Fraction=1.00
Thus sunlight versus azimuth angle graph is shown in fig 2.with a change in a different month. This graph shows that sunlight varies with a change in a month as well as with the change in azimuth angle.

3. Optimal Scheduling for Grid Connected PV System

Optimal Scheduling is very necessary for efficient operation. If PV source is generating power more than the required by load, the excess energy is sold back to the grid by using Smart Energy Meters.At night, solar power is not available, therefore during this time interval load is satisfied by grid power. The flowchart for optimal scheduling is shown in fig 4.

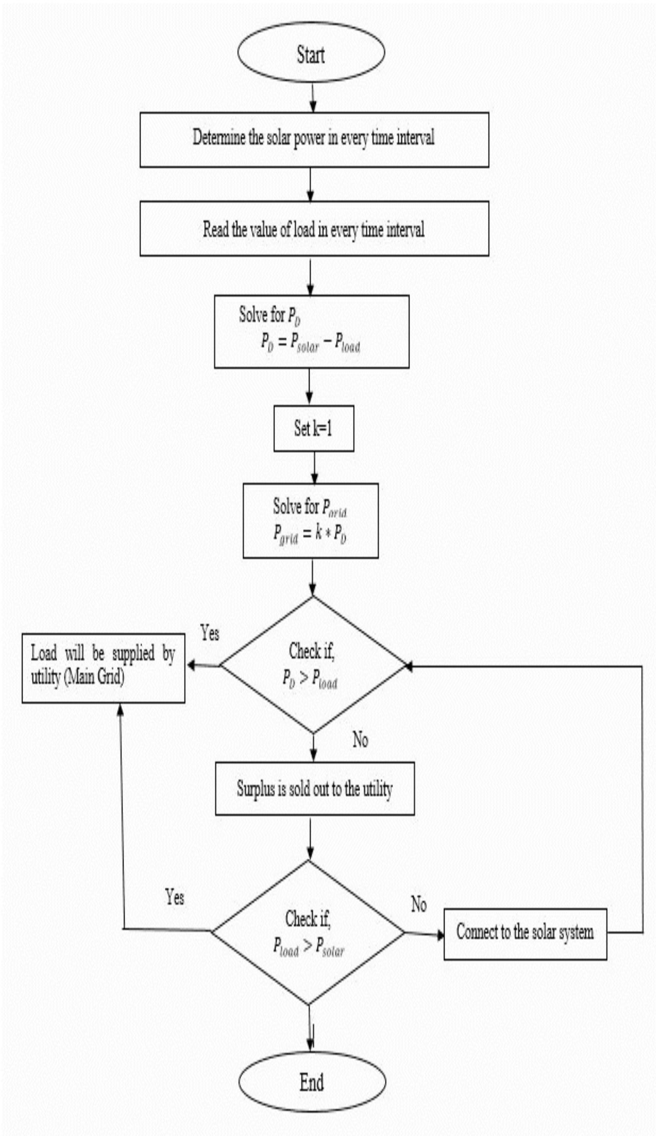

Fig. 3. Flowchart for Optimal Scheduling

The process of optimal scheduling for grid-connected PV system is described as below.

Step 1- Monitor the outputs of the solar system.
Step 2- Monitor the load of the system
Step 3- Calculate the Surplus Power by

$$P_D = P_{solar} - P_{load}$$

Step 4-Set the value of k is equal to 1 for the lossless system.
Step 5- Calculate the grid power by

$$P_{grid} = k * P_D$$

Step 6- If, $P_D > P_{load}$ then load will be supplied by utility otherwise surplus is sold out to the utility. If solar power is greater than load, then surplus power is sold to the utility.
Step 7- If,$P_{load} > P_{solar}$, then move to step 8 otherwise load will be supplied by the solar system and move to step 6.
P_D is the surplus power , P_{solar} is the generating form the solar sources , P_{load} is the load power and P_{grid} is the grid power.

Finally, the optimal scheduling can be achieved in the grid-connected PV system.

4. Cost Analysis of Grid Connected and Off-Grid Solar Photovoltaic System

The overall cost of grid-connected PV system and off-grid PV system are calculated to find the cost-effective solution. In the grid connected system when the generating power from the PV system is more than the demand then this surplus power will be sold out to the utility. The Cost analysis has been done by taking all the cost of a different component of the system, setting, wiring and other misc. charges. The off-grid system comprises of the inverter, PV panel, battery, charge controller etc. This system has a higher cost because extra components are needed to meet the desired demand because if the battery is not connected then this system would not work properly.The rating of the inverter should be chosen according to power feed to the grid if grid power is low then lower rating inverter is sufficient otherwise, the cost would be increased. Power consumption requirement per day is 10 kW. To achieve a cost-effective system, 32 PV modules and 2 inverters with 5kw capacity each are used to generate 10kW power output. 180 Ah Batteries having a cost of 200000 INR (2996.48 USD) are used for off-grid PV system.

Table 4. Overall cost of off-grid PV system

Particular	Company	Quantity	Investment(INR)
PV Modules	Hanwha solar	32	526702.17
Inverter	Su-Kam	2	149600
Battery	Exide	-	200000
Battery charge Controller	-	-	50000
O and M	-	-	10500
Setting, wiring, other misc	-	-	63980
MPPT Controller	Generic	-	26000
		Total-	1026782.17

The cost of battery and charge controller is approximately equal to 250000 INR for this 10kW system. Then the overall cost would be an Overall cost for off grid system=1026782.17 INR as shown in table 4.
Table 5 shows the Overall cost of grid-connected PV system.The cost of energy = 2.12 INR per unit hence grid connected SPV system is cost effective solution for proposed work. If this system is not connected to the grid then the cost of battery and charge controller would be added to the overall cost of the system. Therefore the overall cost of energy would increase. This work shows that the off-grid SPV system is costly in comparison with grid connected SPV system.

Table 5. Overall cost of grid-connected PV system

Particular	Company	Quantity	Investment(INR)
PV Modules	Hanwha solar	32	526702.17
Inverter	Su-Kam	2	149600
O and M	-	-	10500
Setting, wiring, other misc	-	-	63980
MPPT Controller	Generic	-	26000
		Total-	776782.17

The analysis shows that the saving of 250000 INR can be achieved with the same capacity of the grid-connected system .Battery and battery controller is the necessary part of the off-grid SPV system and this may increase the overall cost of the system. Therefore the grid connected system is the cost-effective solution to satisfy the future demand. Power consumption at night is around 1 kW therefore at this period grid supplies the energy.If generating power from the PV system is more than the demand then surplus power will be sold out to the utility. If any source is not available then the system automatically shift on the main grid. Therefore an idea of PV grid connected system and control the grid automation system have been given. The battery back-up system is necessary to achieve cost effectiveness in locations such as the U.S. where the utility imposes a high surcharge on net-metering back to the utility, but this is not case in India. The Ministry of New and Renewable Energy (MNRE) started a national consultation on net metering for grid-tied PV systems, where officials from secretaries of state regulatory commissions and officials from state power department came together to achieve an action plan with practical solutions for the introduction of net metering. If the solar photovoltaic system generates more energy than is consumed, they may be got or paid for the excess energy contribution to the utility over the same time.

5. Results and Discussions

Solar grid connected system is the most cost effective.The proposed 10 kW Grid connected system has a load of around 10 kW hence by installing this system the cost of energy would be 2.12 INR per unit.

The 10 kW grid-connected system will provide 40 units per day. The Small Scale industry/Commercial Building consume about 80 units (assume) in a day. The cost of a 10 kW system in 2017 is approximately 776782.17 INR without battery. The lifetime of a typical solar system is 25 years. So, the system would cost the 31071.28 INR per year. These 40 units of electricity in a day don't need to buy from the grid. At a grid power price of 6 INR (In Delhi, India) per unit of electricity bill will reduce. The cost of 40 units from grid is equal to 87,600 INR. Therefore, it shows the saving of 56528.72 INR per year. Meanwhile, at some period of time when the solar generating power is more than the load demand then this power will be sold out to utility, this will further gives the saving. So this is cost effective solution for generating the electricity.

On the other hand, the cost of a 10 kW off-grid system in 2017 is approximately 1026782.17 INR with battery. Therefore, this system would cost the 41071.28 INR per year. The cost of 40 units from grid is equal to 87,600 INR. Therefore, this system shows the saving of 46528.71 INR per year. This work shows that grid-connected SPV system is cost effective solution for electricity generation in comparison with off- grid connected SPV system.

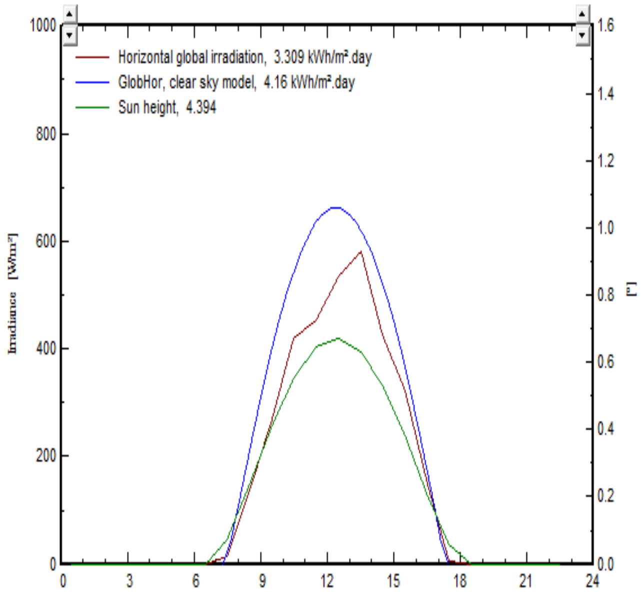

Fig. 4. Hourly graph sun height

The hourly graph shows that solar irradiance changes with time as shown in fig 4.so that solar system doesn't give same output at all time so there is need of MPPT controller. MPPT controller gives constant output irrespective with the solar irradiance. The cloudy atmosphere changes the irradiance so it is difficult to achieve the same irradiance throughout the year.

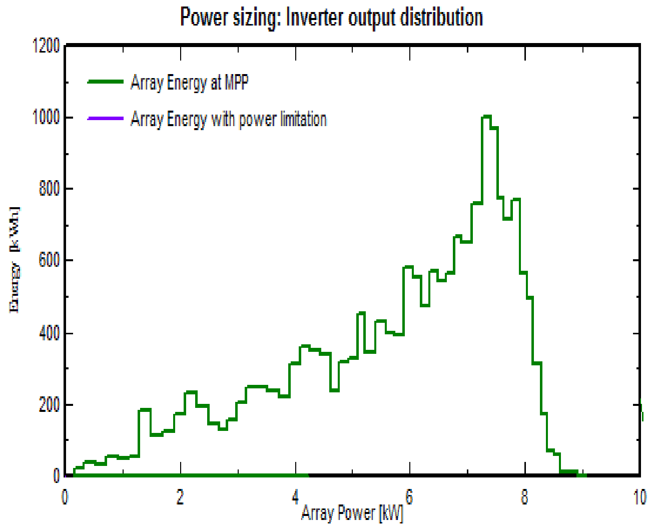

Fig. 5. Array Energy at MPP for Inverter

Fig 5 shows the Array Energy at MPP for Inverter. Inverter output energy changes with array power and this depend on MPPT controller without MPPT controller inverter gives less output irrespective of output load. MPPT is a very important component to achieving maximum output from the PV photovoltaic system.

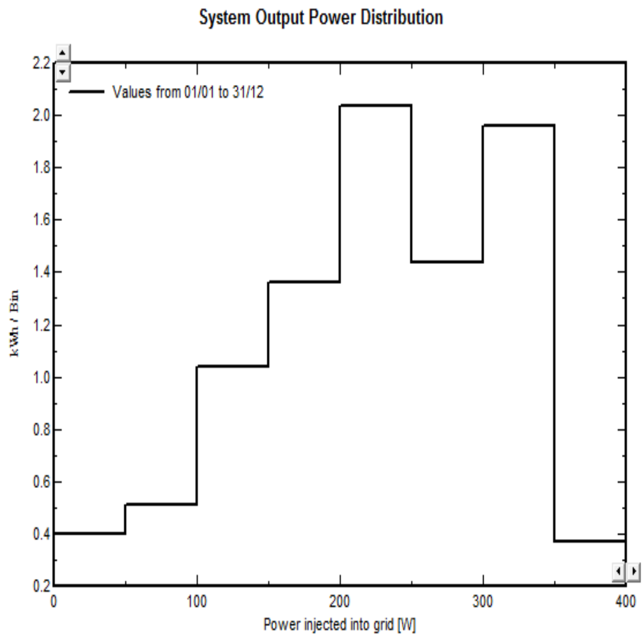

Fig. 6. Output power distribution during year

Output power injected into the grid as shown in fig 6varies throughout the year because the solar irradiance change and this may affect the output power generated by the PV system. Mainly the study includes the data for one year and the all the information about the solar irradiance. This may be generated by PVsyst software itself based on latitude and longitudinal information of the site.

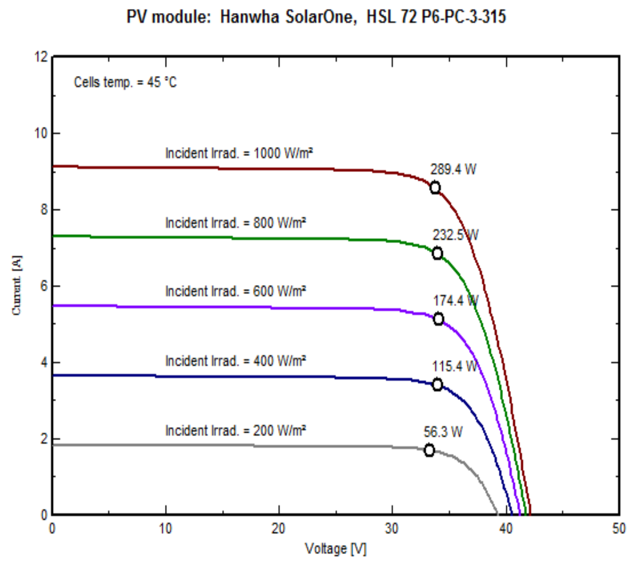

Fig. 7. PV Module Graph Current Versus voltage

Fig 7.shows the output voltage and output current of solar modules. If incident irradiance changes then output voltage and current also changes. Output parameters of PV modules depend on the solar irradiance. Solar irradiance changes with time so output parameters also change. The solar system is cost effective solution for long term says 25 years system just like this system gives a saving of the huge amount per year.

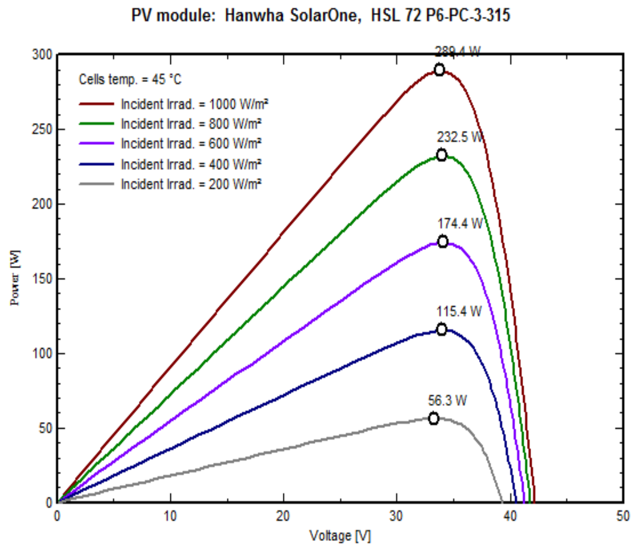

Fig. 8. Power Versus Voltage

Maximum power of PV modules depends on the output voltage and current, as shown in fig 8 which, depends on the solar irradiance so maximum power depends on the solar irradiance this is an important factor of PV modules. This shows the power limitation curve for different voltage depending on the solar irradiance. If solar irradiance is high than maximum power would be achieved easily without MPPT controller but due to the constraint of the solar system, this irradiance is not constant all the time so MPPT becomes a necessary component of any solar photovoltaic system.The efficiency of PV modules also depends on incident global. Fig 9 shows that efficiency is 17.1 % for incident global is 600W/m2 with temperature 10°C.Similarly, efficiency is 17.8% for incident global is 600W/m2 with temperature 25°C.

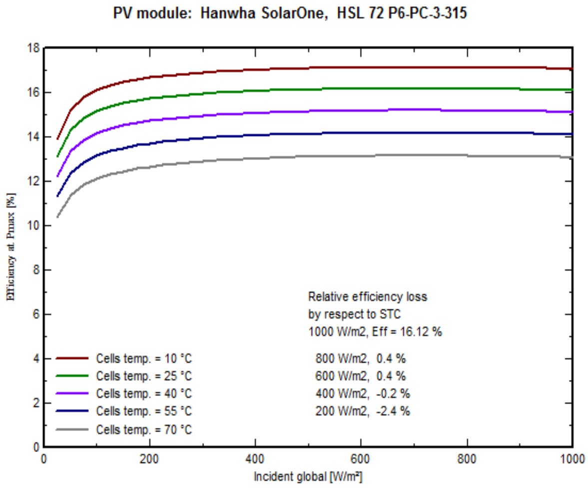

Fig. 9. Efficiency versus Irradiance

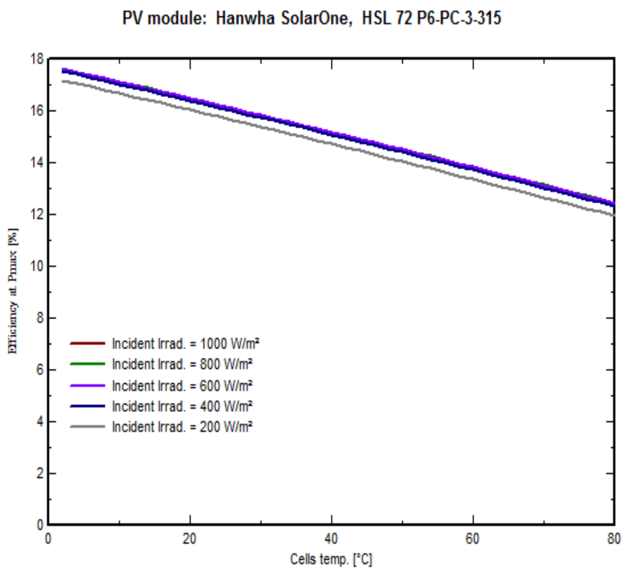

Fig. 10. Efficiency Versus Temperature

Efficiency also depends on of PV modules temperature it may change with time as shown in fig 10. By using MPPT controller maximum power can be extracted. MPPT controller set the maximum power point by setting the voltage and current. Closed loop system is used with some controller so voltage and currents remain constant and the output of the system gives maximum power. This grid-connected system shows that overall cost of the grid connected system is reduced by 250000 INR.

Table 6. Monthly Data

Months	GlobHor kWh/m^2	T Amb ℃	Globlnc kWh/m^2	GlobEff kWh/m^2	EArray kWh
January	118.2	13.23	171.8	169.5	0.582
February	137.0	17.24	182.6	180.3	0.158
March	188.2	23.29	220.6	217.1	0.000
April	206.5	29.22	212.4	208.6	0.581
May	222.1	32.61	207.3	202.8	0.000
June	196.5	32.14	176.2	172.0	0.000
July	166.4	31.42	152.1	148.4	0.000
August	159.9	30.36	155.0	151.4	0.362
September	170.6	28.58	186.4	182.8	0.577
October	164.5	25.49	208.1	205.2	0.058
November	128.5	19.32	186.2	183.9	0.000
December	115.1	14.85	177.4	175.5	0.344
Year	1973.5	24.85	2236.0	2197.5	2.662

Hence Table 6 shows the monthly data of solar system the output vary with sunlight as well as the by changing the month of the year.

Table 7. Optical factors (Transport, IAM, shading)

Months	GlobHor kWh/m^2	Globlnc kWh/m^2	FTransp	FIAMBm	FIAMGI	FIAMShd
January	118.2	171.8	1.453	0.986	0.978	0.978
February	137.0	182.6	1.333	0.986	0.979	0.979
March	188.2	220.6	1.172	0.984	0.977	0.977
April	206.5	212.4	1.029	0.981	0.974	0.974
May	222.1	207.3	0.933	0.976	0.969	0.969
June	196.5	176.2	0.897	0.974	0.966	0.966
July	166.4	152.1	0.914	0.976	0.967	0.967
August	159.9	155.0	0.969	0.980	0.968	0.968
September	170.6	186.4	1.092	0.982	0.973	0.973
October	164.5	208.1	1.265	0.987	0.978	0.978
November	128.5	186.2	1.449	0.985	0.979	0.979
December	115.1	177.4	1.541	0.986	0.979	0.979
Year	1973.5	2236.0	1.133	0.983	0.974	0.974

Table 7 shows the optical factor throughout the year including the effect of shading and these are got from PVsyst software by loading different conditions. The FTTransp is 1.453 for January and 1.265 for October this shows that this factor also changes throughout the year. The FIAMBm is 0.986 for January and 0.987 for October. This factor does not change rapidly, this may be approximately constant throughout the year.

Table 8. System loss throughout the year (Detailed System losses)

Months	ModQual kWh	OhmLoss kWh	EArrMPP kWh	InvLoss kWh
January	-5.736	8.84	761.8	755.564
February	-5.907	10.31	783.2	782.209
March	-6.875	12.79	910.8	910.761
April	-6.424	11.82	851.2	851.169
May	-6.228	10.46	826.1	826.131

June	-5.388	7.78	716.1	716.071
July	-4.709	6.11	626.5	626.529
August	-4.813	6.59	640.0	639.959
September	-5.759	9.51	764.1	764.095
October	-6.441	11.95	853.3	853.312
November	-5.986	10.15	794.0	794.009
December	-5.855	9.40	777.1	774.331
Year	-70.122	115.71	9304.1	9294.139

This losses have calculated by the from PVsyst software for different load conditions. System losses i.e. modules losses, ohmic losses, array losses, and inverter losses decrease the overall efficiency of the system, the inverter losses is approximately equal to 1kW and total ohmic losses are very minimum as shown in the table 8. The overall effect of this losses can be minimized by taking good quality components.

*1 USD is equal to 66.75 INR as on 10th March 2017.

6. Conclusion

This work presents the optimal scheduling of Grid-Connected SPV system for economical and efficient operation to electrify the small scale industry/commercial building. . If generated power from the SPV system is more than the load demand then surplus power will be sold out to the grid otherwise load will be supplied by utility. Therefore an idea of renewable energy generation and control of grid automation system is proposed in this paper. Concerning the Grid-connected solar photovoltaic system and off-grid solar photovoltaic system that have been considered for solar power generation, the results indicate that the proposed grid-connected solar photovoltaic system is best suited for small scale industry/commercial buildings as presented above based on overall cost. In the proposed work, Grid-connected system shows the saving of 56,528.72 INR per year. Since the main concern of any small scale industry/commercial building is to reduce the overall cost of energy, therefore such systems can be electrified with SPV systems in grid connected mode for economic operation but at places where grid supply is not available the option of off-grid SPV systems can also be considered.

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