Design and Cost Analysis of a Solar PV system (A Case Study)

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ABSTRACT

The world is facing an increase in environmental pollution basically as a result of combustion of conventional energy sources. India currently depends on conventional energy to supply power to her teaming population. Due to this, the energy generated does not meet demand. Consequently, power supply is erratic and areas isolated from the main cities lack power supply. Therefore, the need to develop a non-conventional source of energy generation such as solar cannot be over emphasized. A photovoltaic system that can increase energy output and/or supply power to isolated areas of the country is a good choice, considering the abundance of solar radiated energy in India. In this work as PV system model is designed to work either as a standalone PV system or as grid integrated and payback period is calculated for the same. The developed model may be useful in the prediction of PV cell behaviour under different physical and environmental parameters. The result obtained showed the maximum power output and the corresponding maximum voltage of solar module. Study results demonstrate that, under complex irradiance conditions, the power generated by the new configuration is enhanced than that of the traditional configuration. The solar PV system can be widely used in many consumer applications, such as PV vests for cell phones and music players.

Index Term— Complex illumination, partial shading, photovoltaic (PV) solar cell power converter, solar array, Solar Radiation, Photovoltaic Panel, Maximum Power Output.

1. INTRODUCTION

Currently in India, the use of renewable energy is sparingly used to support conventional source of energy, this has led to over reliance on energy generated diesel power plants, dam's powered plants and coal powered plants in India. Because of this most isolated areas do not have sufficient power or no power at all in cases where the transmission lines are not assessable. A high penetration of solar energy known as photovoltaic (PV) energy in India will result in Power being evenly distributed to all parts of the country, Reliable power supply, Reduce the rate pollution of the environment, Increase in the amount of power generated in the country, Power supply to isolated areas of the country where it will cost more to build transmission line to such areas.

The intensity of solar radiation reaching earth surface which is 1369 watts per square meter is known as Solar Constant. It is important to realize that it is not the intensity per square meter of the earth's surface but per square meter on a sphere with the radius of 149,596,000 km and with the sun at its center. The efficiency of a PV device is dependent on the spectral distribution of solar radiation.[9]

The evaluation of PV devices is generally done with reference to a standard spectral distribution. There are two standard terrestrial distribution defined by the American Society for Testing and Materials (ASTM), direct normal and global AM1.5. The direct normal standard corresponds to the solar radiation that is perpendicular to a plane directly facing the sun. The global corresponds to the spectrum of the diffuse radiations. Radiations which are reflected on earth's surface or influenced by atmospheric conditions are called diffuse radiations. To measure the global radiations an instrument named pyranometer is used.

Solar radiation assessment is a critical activity for setting up solar projects. The quality of the resource also impacts the type of technology which may be used at a specific place for solar power generation. The measurement of this data should ideally be undertaken at the micro level through site specific ground based weather monitoring stations over a period of time (preferred time is between 12 to 18 months).

A micro level of assessment is required to assess solar resource attractiveness of the proposed site. This shall include assessment of parameters like

a) Global Horizontal Solar Radiation

b) Diffused Horizontal Solar Radiation

c) Direct Normal Solar Radiation

d) Wind Speed/Direction

e) Rain Accumulation

f) Air Temperature

g) Atmospheric Pressure (SLP)

h) Relative Humidity

Solar panels produce electricity from sunlight. The first solar panel-powered satellite was launched in 1958 by Hoffman Electronics. A solar panel consists of number of photovoltaic (PV) solar cells connected in series and parallel. These cells are made up of at least two layers of semiconductor material (usually pure silicon infused with boron and phosphorous). One layer has a positive charge; the other has a negative charge. When sunlight strikes the solar panel, photons from the light are absorbed by the semiconductor atoms, which then release electrons. The electrons, flowing from the negative layer (n-type) of semiconductor, flow to the positive layer (p type), producing an electrical current. Since the electric current flows in one direction (Like a battery), the electricity generated is DC.

A photovoltaic array (PV system) is an interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by a single module is not enough for commercial use, so modules are connected to form arrays to supply the load. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads lights etc. the modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current.

There are huge works, research, thesis, implementation, design consideration and Improvement on solar technologies is going on around the world as well as in our country. That is why we have more than company doing business, implementation and research on solar technologies, University students around the globe working with solar system.

Various types of mounting of solar panel can be done depending on the location and system. These include pole mounting, ground mounting, building integrated photovoltaic (BIPV) and roof mounting [4, 5]. Pole mounting may be at the top of the pole, pole side or special mounted to continuously change direction in order track maximum sunlight path. Roof mounting is the preferred, but where there is insufficient space at the roof to accommodate the number of panels required, ground mounting may be adopted in residential estates and for few commercial applications in isolated and/or secured places. BIPV though more expensive, is a unique kind of mounting where the PV modules are placed on the building surface, vertical walls or at the atriums to blend with the building architecture. This makes the house more beautiful; provide shedding for improved cooling system in very hot places as well as protection.

Roof mounting is two types - pitched roof mount and flat roof mount. Pitched-roof mounting is difficult because depending in the orientation and angle; proper mounting has to be done. Need to fix the tilt angle for the optimum output. We cannot hope all these categories a roof can match. That is why there are 3 types of roof mounting. They are- Flush mount, Angle mount and Fin mount.

2. PHOTOVOLTAIC SYSTEM DESIGN

For the design purpose roof-top area of BBSB Engg. College is taken as a case study. There are three possible configurations of solar PV system. Each of these configurations has its own advantages and disadvantages. System requirements determine which type of system configurations has to be used. In this work, two possible configurations, the first one is grid connected solar PV system without battery and the second one is stand-alone solar PV system with battery. When the demand is high then the system will deliver energy same as a grid connected solar PV system without battery as described. But when the demand is low or in an off day the battery can store energy by solar panel through charge controller. This stored energy can be used as backup for gloomy day or at night.

A typical solar PV system consists of solar panel, charge controller, batteries, inverter and the load.

2.1 Charge Controller

The charge controller is an electronic device whose function protects the battery to avoid overcharging or excessive discharge. When battery is included in a system, the necessity of charge controller comes forward. In a bright sunny day the solar cells produce more voltage that can lead to battery damage.

2.2. Batteries

To store charges batteries are used. Mostly used batteries are nickel/cadmium batteries. There are some other types of high energy density batteries such as- sodium/sulphur, zinc/bromine flow batteries. But for the medium term batteries nickel/metal hydride battery has the best cycling performance. For the long term option iron/chromium red ox and zinc/manganese batteries are best, our battery is 32MWh.

2.3 Inverter

The inverters are responsible for transforming the DC electricity from the photovoltaic panels into AC electricity to be sent to each transformer. The same inverters have a microprocessor, responsible for ensuring a sinusoidal wave with minimal distortion. It also incorporates batteries to regulate the power factor according to the needs. Solar panel generates dc electricity but most of the household and industrial appliances need ac current. Inverter converts the dc current of panel or battery to the ac current. We can divide the inverter into two categories. Stand alone and Line-tied or utility-interactive.

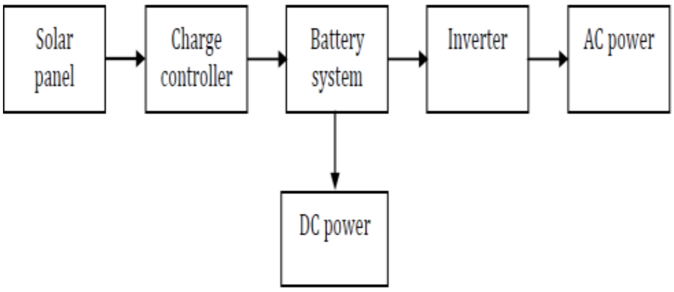

Figure 1: Block diagram of a typical solar PV system

2.4. System Sizing

We will select the number of PV module can be installed in the selected area. The no. of inverter, combiner box and other equipment's is needed to complete the whole designing. We will also find that.

2.5. Number of Module Selection

The no of module can be accommodate on both roof top and facade can be calculated by the following formula,

No. of module accommodation = Total usable area/area of a selected PV module

2.6. PV Array Design

To design the array there are some parameter to check. The most important thing is to choose proper inverter and combiner box so that, they can withstand the PV modules' voltage and current.

Su-kam 10kW inverter's MPPT voltage range= 250-850 V

Su-kam 250Watt module's open circuit voltage =37.8 V

12 module in series = 37.6* 12 = 453.6 V

This is within the inverter's MPPT voltage range. We didn't put more modules due to safety.

Module's maximum power voltage = 30.7 V

Inverter MPPT voltage range: 250-850V.

(100-500V)/12 = (module maximum power voltage = 30.7).

So, power maximum power voltage is in the inverter's voltage range.

Su-kam 10kW inverter's current rating:

Inverter's rated voltage = 400 V

Maximum current: (10000/400) = 25 A

At 694.96 W/m2 maximum short circuit current = 8.14 A

If we put 3 parallel string (1 string consist of 12 series module) = 3*8.14 = 24.42 A

We cannot put more string, because if there is rise in a weather condition with low temperature and high isolation excessive current can flow. For safety considering 35% excessive current = 32.9 A

This is also in inverter's capacity SMA SCCB-10 combiner box maximum input fuse rating = 600 V, 20A

This is also can withstand 3 parallel strings each consist of 12 series modules. Therefore, our chosen PV array design is 3 parallel strings of each consist of 12 series modules for 1 combiner box and 1 inverter. As we need to arrange 620 modules we need 17 configurations.

2.6.1. Number of inverter calculation

No of inverter = Total no of module / (no. of module in series in a string*no. of parallel string) = 620 / (12*3) = 17.

We will need combiner box is equal to the number of inverter. So, we will need 17 combiner boxes.

2.6.2. Wiring arrangement

Rated short circuit current is 8.63 A from the PV module. If there is an effect of higher insulation and lower temperature access current can flow. To prevent these to happen the safety factor is considered. Average isolation at Fatehgarh Sahib city is 694.96 W/m2. Therefore, maximum short circuit current will be = 8.14 A

For 3 parallel string = 3*8.14 = 24.42 A

Considering 35% safety factor Maximum current rating is 33 A. So, we have chosen 33A rating wiring.

2.6.3. Photovoltaic system and energy storage

The main benefit of integrating storage with renewable energy is the capability of shifting the peak demands using charging/discharging (charging when the excess electricity is stored, discharging when there is a peak demand). The storage can be charged from the renewable sources or from the grid. The demand on the grid can be met with the renewable sources (wind, solar) or energy storage or both.

The other benefits are:

a. Mitigation of short-term solar power intermittency and wind gust effects and minimizing its impacts on voltage, frequency, and power fluctuations in power system.

b. Lowering the transmission and distribution costs by increasing the confidence in renewable distributed generation.

c. Improving power system stability and reduction of harmonics.

2.6.4. Characteristics of Energy Storage System

Energy storage plays a crucial role not only in maintaining system reliability but also in insuring energy efficiency and power quality. The functions of an energy storage system vary from its applications. The role of storage in power system determines the size and type of storage used. The problem is to analyze the domain of application of the storage system.

With an appropriate choice of storage parameters, the storage unit may be used as multifunctional device, able to solve a wide number of problems. The combination of storage with storage connected PV system is beneficial.

There are different applications that an energy storage system can fulfill:

• Generation capacity deferral

• Frequency control

• Integration with renewable generation

• Load leveling

• Transmission line stability

• Distribution facility deferral

• Transit system peak

• Reliability, power Quality, uninterruptible power supply

3. SOLAR PHOTOVOLTAIC DESIGN

Figure 2 shows the block diagram of the PV module

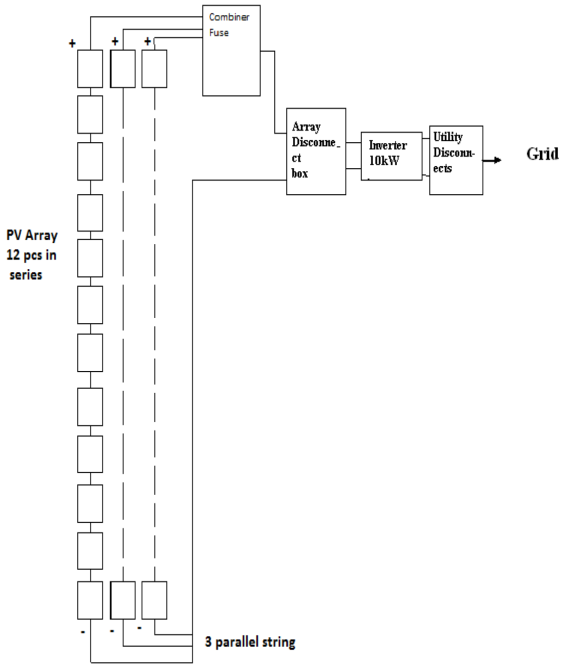

Figure 2: Block diagram of designed Solar PV system

3.1 Cost Calculation

To implement the proposed solar PV system for BBSBE College, we need to have a clear concept on the implementation cost. In these consequences, we have calculated the approximation cost in rupees. Table below shows all components that we have required implementing a solar PV system. These components are: PV modules, inverters, combiner boxes, and surge arrestors, lightning rod, mounting, meters, wiring .also we have to consider the transportation, installation, and LC and maintenance costs. We have considered this as the 40% of all components costs. After doing calculation the total cost stands around 22627676.4.

Table 1:Components and cost for solar PV system

Component	Description	Quantity	Cost in Rs
PV module	Su-kam SSP 250W	620	11780000
Inverter	Su-kam 10kw	17	3066800
Combiner Box	SMA SCCB-10	17	629850
Surge Arrester	-	17	17476
Lightning Rod	-	04	26000
Mounting	-		530000
Meters	-		14500
Wiring	-		98000
Transportation, installation, LC, maintenance	40% of all cost		6465050.4
Total Cost in Rs.			**22627676.4**

In this regard, we computed approximate cost in Rupees for each component is presented in Table. These components are: PV modules, inverters, combiner boxes, surge arrestors, lightning rod, mounting, meters and wiring. Also we have to consider the transportation, installation, and LC and maintenance costs.

The PV system is modeled to supply power to the load. Energy production in twenty five years in kWh is 812.13*25*365 which gives 7410686.25. The cost per unit of energy produced in twenty five years is 22627676.4/7410686.25=3.05 so we may be able to generate per unit of energy at 3.05.

We consider our proposed PV system life is 25 years. So, the cost per unit of energy by the designed system will be the total cost of the system as 22627676.4.

3.2 Pay back period

Annual consumption = 1644353 kWh

Total cost = 6*1644353

= 9866118

PV total cost = 3.05*1644353

= 5015276.6

Saving = 4850841.4

Payback period = Total cost/Saving per annum

= 22627676.4/4850841.4

= 4 .66

= 4years and 8 months (approx)

5. CONCLUSION

The proposed low cost stand-alone renewable photovoltaic energy utilization schemes is suitable for resort/village/estate electricity application in the range of (1500 watts to 50000 watts), mostly for water pumping, ventilation, lighting, irrigation and village electricity use in arid remote or isolated communities.

In this work as PV system model is designed to work either as a standalone PV system or as grid integrated. The total cost for the PV system module has been calculated (Table. 1). Finally the payback period is calculated which is 4 years and 8 months. The developed model may be useful in the prediction of PV cell behaviour under different physical and environmental parameters. The result obtained showed the maximum power output and the corresponding maximum voltage of solar module. So, solar energy for a college estate has been chosen as secondary energy source the developed model has been used for energy yield determination based on the experimental data of solar insulation which helps to determine the size of the PV system in the outdoor condition.

REFERENCES

[1] hou Xuesong,Song Daichun, Ma Youjie and Cheng Deshu, “Grid-connected control and simulation of single-phase two-level photovoltaic power generation system based on repetitive control,” Measuring Technology and Mechatronics Automation (ICMTMA), 2010 International Conference, vol. 2, May 2010, pp. 366 - 369.

[2] Liang Ma, Wang Ran and Zheng, T.Q., “Modeling and Control of 100 kW Three-phase grid-connected Photovoltaic inverter,” Industrial Electronics and Applications (ICIEA), 2010 the 5th IEEE Conference, July 2010, pp. 825 - 830.

[3] Rujia Men and Xiaoqing Han, “Optimum control and simulation for a grid-connected photovoltaic system,” Probabilistic Methods Applied to Power Systems (PMAPS), 2010 IEEE 11th International Conference, July 2010, pp. 431 - 435.

[4] H.W. van der Broeck, H.-C. Skudelny, and G.V. Stanke, “Analysis and realization of a pulse width modulator based on voltage space vectors,” IEEE Transactions on Industry Applications, vol.24, pp. 142-150, 2008.

[5] Calais, M., Myrzik, J., Spooner, T. and Agelidis, V.G., “Inverters for single-phase grid connected photovoltaic systems – an overview,” Power Electronics Specialists Conference, 2002. pesc 02. 2002 IEEE 33rd Annual, vol. 4, November 2002,pp. 1995 - 2000.

[6] Sera, Dezso, Teodorescu, Remus and Rodriguez, Pedro, “PV panel model based on datasheet values,” InternationalSymposium on Industrial Electronics, 2007. ISIE 2007. IEEE, November 2007, pp. 2393 - 2396.

[7] Altas, I.H. and Sharaf, A.M., “A photovoltaic array simulation model for matlab Simulink GUI environment,” International Conference on Clean Electrical Power, 2007. ICCEP '07, July 2007, pp. 341-345.

[8] Nasiri, A. “Integrating energy storage with renewable energy systems”, Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE, 10-13 Nov. 2008, pp. 18.

[9] DIKE, DAMIAN OBIOMA, “CHARACTERIZATION OF HIGH PENETRATION OF PHOTOVOLTAIC SYSTEM”,International Journal of Engineering and Applied Sciences, Oct. 2014, Vol. 5,No. 05.

