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SOLAR EFFICACY: MODELING, SIMULATION AND COST OPTIMIZATION OF A GRID CONNECTED PV SYSTEM FOR COMMERCIAL BUILDING

Faculty Advisor
Vinay Kumar Gupta
Electrical Department
Medi-Caps University
Indore(M.P.), India

Author I
Ambuj Jain
Electrical Engineering
Medi-Caps University
Indore(M.P.), India

Author II
JitendraSinghai
ElectricalEngineering
Medi-Caps University
Indore(M.P.), India

Author III
SurbhiBhawalkar
Electrical engineering
Medi-Caps University
Indore(M.P.), India

Abstract— *For almost three decades, tapping the energy from the sun has always had a great potential but there has been many obstacle.Technology cost is found to be one of the main obstacles so far. The paper analyses the installation ofphotovoltaic solar power plant for a commercial building in Indore (Longitude 77 50'east and latitude 22 44'north), Madhya Pradesh, a central region of India. In this paper, modeling & simulation of proposed solar power plant of Medi-Caps University (Q Block) has been done to analyses the result of the plant before installation. It can also been seen as the general guide for maximizing the life of the PV solar power plant and how to effectively use the cost to optimize the plant overall potential.*

Currently the building (for which the solar power system is being designed) depends completely on the grid for all its energy requirements, thus a hefty payout is made every year to State Electricity Board. Solar power plant offer both an environmental and economic benefit, especially at universities or at any other commercial sites where energy consumption is high. Basically, the plan is to shift to solar energy so as to minimize the expenditure and the dependency on the grid.

Keywords: *Photovoltaic Solar power plant, Cost optimization, MPPT, Payback Period, MATLAB Simulink.*

I. INTRODUCTION

At the mention of global warming, Analysis show that, from 1880-2012, average temperature on earth has increased by 0.85^0 C[1], and it is prognosticated that by the end of 21^{st} century this will reach to 3.7^0 C[2]. India is relatively new entrance in renewable energy industry which can be seen in its energy generation mix, where fossil fuel counts for almost 63.6% of total energy produced.Solar accounts for approximately 8% (i.e. 34045 MW) of the total energy mix.[3]In year 1956, the first solar modules were available commercially. The cost,however, was far from the reach of average people.

Why solar? As it is clean and green energy, it is more reliable source of energy with unlimited potential, it has proven to be affordable and ongoing research is making it more affordable and efficient, it is best suited for Indian condition as its tropical climate and location, also utilization of abundant wastelands in the country for solar plant set up and if there is constrain of area we can even use rooftop alternative.

PV technology or solar photovoltaics converts the solar radiation (sun's energy) in electricity using semiconductors that exhibit the Photovoltaic effect.

There are basically 3different type of solar panels

a) Monocrystalline
b) Polycrystalline
c) Amorphous Silicon/ Thin Film.

Solar cells are made by polysilicon with ingots and wafers which then make a modules or panels.

Solar PV system are generally divided into

a) On grid (grid connected) solar power plant,
b) Off grid (independent of grid) solar power plant,
c) Hybrid solar PV system.

Components in a solar PV system are solar panels, inverter, mounting structure, DC\AC cables, LA kits, earthing kits and a bi-directional meter.

Concept of grid connected solar power requires a reference voltage from an incoming grid connection to generate output from a solar system. The voltage and frequency of solar power system is synchronized with the voltage and frequency of incoming feeders, the broad range of voltage is defined by the solar inverter, an installed solar system shall be automatically disconnected if the grid fails/power outage(Global anti-islanding norms), a grid connected system can be connected either at LT level or at HT levels (Specially in industrial solar requirements).

Load calculation:

To design a solar power plant, load calculation is of most importance. To calculate the load we must know the power consumption of each device which is being used, but in our case we did not get the permission from the authorities. So we opt for another approach i.e. the sanctioned load.

Transformer rating = 500KW
30% of 500KW = 150KW (as per government norms)
Previously installed plant = 75KW
Therefore we are left with just 75KW plant capacity.

II. RESEARCH AND DESIGN

Photovoltaic cells converts the solar radiation (sun's energy) in electricity. But the configuration of photovoltaic modules in solar power plant is not as simple as it sounds, and is not viable way to examine and understand its working and thus a model is designed initially to study the performance of the solar power plant in real world without really investing a single penny in the project. The model solves real world problem safely and efficiently. A photovoltaic module is basically an interconnection of a number of solar cell in series and parallel formation, and the series and parallel combination of these PV modules adds up to form a solar power plant. A single diode model (also known as '5 parameter model') which is an equivalent circuit of the practical PV cell, is used to understand the basic working of the PV cell.

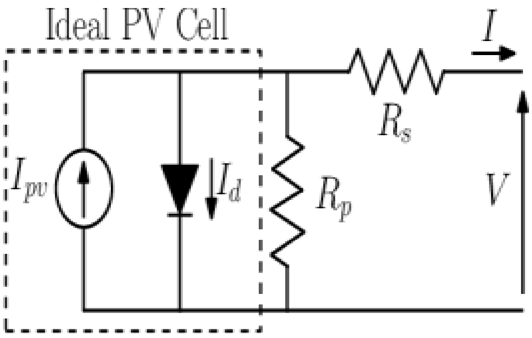

Figure 1Single Diode Circuit Diagram of Photovoltaic Cell[12].

A. Module Designing and Irradiance

There are various tools out thereto work with which can be used to mathematically model the PV modules,so as to get the most accurate understanding of it. We used MATLAB Simulink to study the PV cell/module with the help of the current equations[4, 5]. The mathematical modeling of PV module is continuously being updated enabling the research scholar to have the better understanding of its working. The currents equations are as follows-

Photo-Current

$$I_{ph} = [I_{sc} + k * (T - 298)] * \left(\frac{G}{1000}\right)$$

Saturation Current

$$I_0 = \left[I_{rs} * \left(\frac{T}{Tn}\right)^3 * e^{\left(\frac{q*Eg\,0*(\frac{1}{Tn}-\frac{1}{T})}{n*K}\right)}\right]$$

Reverse Saturation Current

$$I_{rs} = \left[\frac{I_{sc}}{e^{\left[\frac{q*Voc}{(n*Ns*K*T)}\right]} - 1}\right]$$

Current through shunt resistor

$$I_{sh} = \left(\frac{V + I \cdot Rs}{Rsh}\right)$$

Output Current

$$I = I_{ph} - I_0\left[e^{\left[\frac{q*(V+I\cdot Rs)}{(n*Ns*K*T)}\right]} - 1\right] - I_{sh}$$

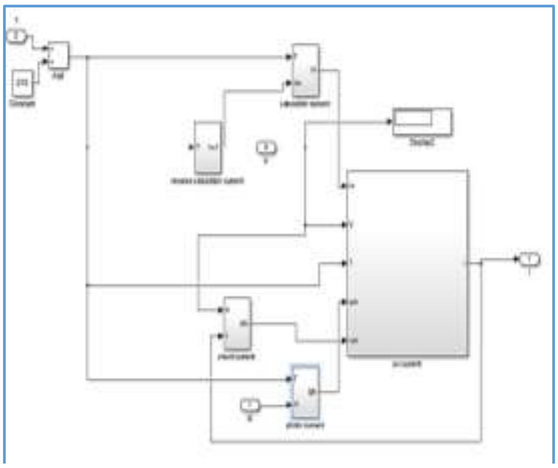

Figure 2 Output current equation of PV

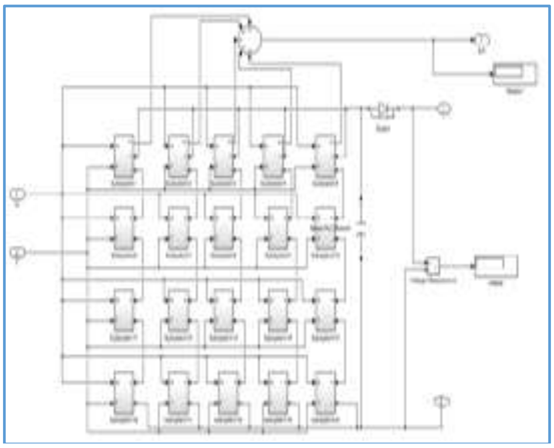

Figure 3 Connections for a 5kW PV Solar Power Plant

The solar energy available to PV module depends on a number of factors such as the amount of solar energy available at the location, temperature etc. Solar irradiation figures are used to plan the deployment of the solar power system. The solar irradiance or the incident solar energy depends on many factors-

$$H = \frac{24 \cdot k \cdot Lsc}{\pi} [\cos\delta \cdot \cos\varphi \cdot \sin\omega rs + \omega rs \cdot \sin\delta \cdot \sin\varphi] \left(\frac{\frac{kWh}{m^2}}{day} \right)$$

Where L_{sc} is the mean solar constant (= 1.37 kW/m^2)[6].The average solar irradiance at Medi-caps University is found out to be 5.5 kWh/m^2/day[7]. But the model is designed and tested for standard condition that is irradiance is set at 1000 W/m^2 and temperature is set at 25^0C.

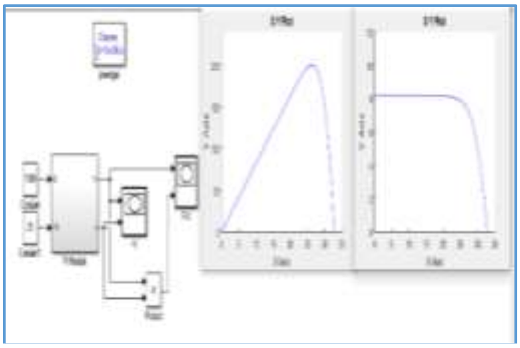

Figure 4 PV module and its P-V and I-V characteristics

B. MPPT and P&O Algorithm

MPPT (Maximum Power Point Tracking) is technique which is used to maximize the power extraction at all condition. In case of PV module there is a single operating point where maximum power can be drawn. The aim of MPPT is to keep the operating point of PV module at the MPP or hovering near or around that point.[8] The process of always maintaining the operating point of PV module near or around the MPP is known as MPPT.

Perturb & Observe (P&O) method or the Hill climbing method is used for MPP Tracking[9]. It is robust and commonly used method. P&O method may result in top level of efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

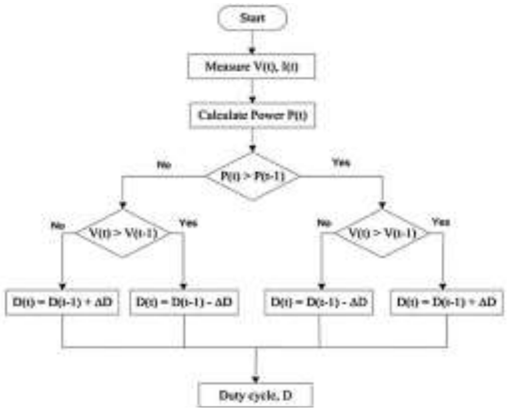

Figure 5 Flowchart of Perturb and Observe Algorithm[13].

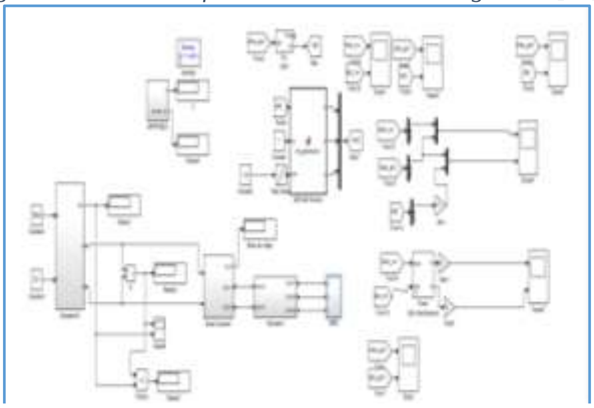

Figure 6 Complete Model of a grid connected Solar Power Plant

C. Payback Period

Payback period or the breakeven period is the time taken by which the initial investment made for the system will be recovered from the savings it makes. It helps in determining whether to go forward for the project or not.[10]

$$Annual\ financial\ benefits\ =\ (savings\ on\ bills\ +\ Incentives)$$

$$\text{Payback Period} = \frac{\text{Net Up front Cost}}{\text{Annual Benifits}}$$

III. IMPLEMENTATION

Cost optimization for a plant is a most important aspect for designing of any project .So how to optimize the cost?In case of the solar power plant it is more about maximizing the efficiency of the projecti.e. to increase the life of plant to perform at its peak efficiency. Hence maximizing efficiency and cost optimization are both interrelated and dependent on each other and there are some points that should be kept in mind while the installation of the project. Although it might increase the installation cost but it will eventually help in maximizing the overall efficiency of the plant for a substantial amount of time. These points are:

A) Length and cross section of the cable used*:*

This is one of the most left out point. The cable used should be of good quality and the cross section area of cables should also be kept in mind. The harsh way in which they are bend and starched will result in some wear and tear of the cable. Also the layout of plant should be such that it minimizes the cable length. And the tray which cover the cable must be of good quality, so as to protect the cable from the harsh weather conditions and it should have heat sync capability.

B) Propearthing and surge protection devices*:*

To avoid uneven potentials across the installation, protective earthing should be provided. Also the surge protection devices should be used so in case of any fault the system bears the minimum damage.

C) Inverter sizing:

The inverter sizing should be done in proper way so as to increase the overall reliability of the plant.

D) Angle of inclination*:*

The angle at which the panels are inclined significantly affects the output of the plant. For Indore city, the angle of inclination should be near or around 22^0.

E) Design of plant:

The area covered must be such that the solar panels can tap the maximum irradiance.

F) Monitoring system**:**

Although it has no direct impact on increasing the efficiency of plant, but regular monitoring will help in better understanding of the power generation from the plant which might be useful for future analysis.

By these points payback period can be as low as possible and it is being reflect on the result of the calculation of cost estimation.

IV. RESULTS

We have successfully modeled and designed the solar power plant for 'Block -Q'of Medi-caps university, Indore and have also put forward all the key points that should be kept in mind while designing the photovoltaic solar power plant for any commercial building so as to optimize the cost.

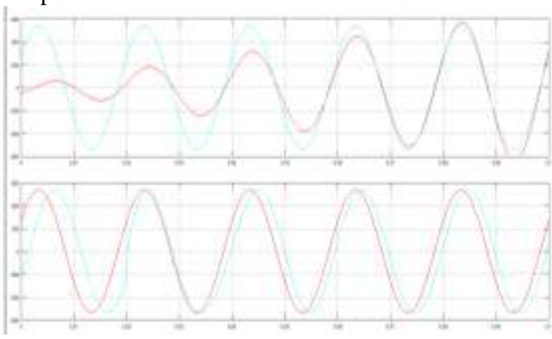

Figure 7 Synchronized Waveform of PV solar power plant and the Grid

Also we have calculated the payback period of the proposed plant and that has come out to be approximately 4years which is quite less for such a big plant. (Theoretically) and proved that it is more efficient.
The table below clearly depicts the calculation of the payback period. The following assumption were made before determining the payback period-

$$Electricity\ Tariff\ =\ 7.52\frac{INR}{kWh}$$

Yearly Tariff Rise=2%

$$Generation\ from\ 1kWp\ Plant\ =\ 4.00\left(\frac{\frac{kWh}{kWp}}{day}\right)$$

YEARS	1	2	3	4	5	6
Solar Generation (kWh)	1,09,500	1,07,310	1,06,559	1,05,813	1,05,072	1,04,337
Tariff (INR per kWh)	7.52	7.67	7.82	7.98	8.14	8.30
Benefits						
Savings (INR)	8,23,440	8,23,111	8,33,696	8,44,417	8,55,276	8,66,275
Costs						
CAPEX (INR)	30,00,000	-	-	-	-	-
O & M (INR)						20,000
Net Benefit by Year	**(21,76,560)**	**8,23,111**	**8,33,696**	**8,44,417**	**8,55,276**	**8,66,275**
Cumulative Benefit for Payback	(21,76,560)	(13,53,449)	(5,19,754)	3,24,664	11,79,940	20,46,215
Payback Period (Years)	**3.8**					

V. CONCLUSION

This paper presents the modeling of the photovoltaic solar power plant by using the mathematical equations. With the increasing energy demand, switching to photovoltaic solar power plant is the best way by which the dependency on grid can be reduced. Apart from, the installation of a 75kW solar power generation plant at Medi-caps University, Indore not only provide a self-sustaining way of producing power from the renewable source of energy (i.e. the sun)but also provides economic benefits,. I.e. it would save a gigantic amount of money (annually) that the university would spent on the bills over the course of time. Also the paper describes certain ways that might initially increase the installation cost but will surely increase the efficiency of photovoltaic solar power plant and will also account for increasing the life time of the PV solar power plant. In the course of time it would drastically cut down the CO_2 emissions of 2306 tonnes. This installation will be equivalent to planting of 3069 teak trees over the life time.[11].

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