Solar Energy Prediction using Meteorological Variables

Devangi Solanki, Utsav Upadhyay, Siddhi Patel, Reema Chauhan, Shubhangi Desai
Department of Electrical Engineering
Sarvajanik College of Engineering and Technology
Surat, India
Email: uutsav58@gmail.com, devangi3196@gmail.com

***Abstract*— The remarkable increase in per capita power consumption worldwide has drawn attention towards the required growth in renewable energy sector in order to bridge the gap between overall demand and supply. Solar power has been the fastest growing source of energy throughout the world outstripping all other forms of power generation. Though Solar PV system is recognized as promising renewable energy technology it is burdened with few uncertainties and drawbacks. To make interconnected grid system more resilient it is necessary to do solar energy generation forecast which is under acceptable limits. This paper presents a solar energy prediction model consisting of a mathematical model which enables to compute the amount of solar energy generation for next seven days (including present day) by considering weather data and plant specifications. The factors that affect the solar energy generation are ambient temperature, solar irradiance, efficiency of panels, and efficiency of plant components like: inverter, cables, type of PV module installation etc.**

The graphical results indicate the fine parallelism between predicted results and actual output concluding high accuracy except for the climate situations observed such as partly cloudy or overcast and during plant malfunctioning in terms of string failure.

Keywords—solar energy prediction, renewable energy, energy management, forecasting modelling, photovoltaic.

I. INTRODUCTION

India has abundant solar energy having sunshine time more than 3650 hours every year. PV system is perhaps the most efficient way to exploit the pollution free solar energy which does not consume any fuel which is available everywhere irrespective of geographical location. Solar power is a propitious resource that has the competence to deliver efficient, reliable and easily accessible energy. Nevertheless, the energy reaching earth's surface is associated with altering solar radiation. One of the main impediments to solar energy adoption above its susceptibility to weather is the intricacy in predicting its availability. By harnessing solar power efficiently, the dependence on fossil fuels and environmental degradation can be significantly diminished. In order to best utilize solar energy, a well grounded evaluation and prediction process is required. To amalgamate PV system into power grid, solar energy forecast is necessary to oversee grid load dispatch.

In PV systems, the energy generated is not easily predictable as it is dependent on various external parameters especially weather conditions. Hence the accuracy of solar energy generation forecast utilizing weather data is of significant interest. Different approaches for forecasting the energy generated from PV systems have been proposed. They are based on statistical methods such as linear regression and autoregressive moving average and machine learning methods such as Neural Networks (NNs), nearest neighbor and Support Vector Regression (SVR). Most of the previous work was focused on developing general prediction method for all types of weather conditions. This paper presents a mathematical model of solar energy prediction consisting of an equation which enables to compute the amount of solar energy generation for next seven days by considering weather data and plant specifications.

The dataset consists of three different types of data: 1) Weather data consisting of forecasted temperature for seven following days.2) Plant Data: first part consist of plant specifications and the second part is meter data which consists of parameters of the PV system including PV energy which is to be forecasted.3) Solar Radiation data which consists of the Minimum, Maximum, Average and Instantaneous values of Solar Irradiance. To visualize performance of mathematical model, comparison is carried out in form of graph between forecasted and measured PV energy values. Solar energy forecast leads to economical and operational benefits, improved unit commitment and dispatch efficiency, reduced reliability issues and reduce curtailment of renewable energy generation.

II. MATHEMATICAL FORMULATION

This mathematical model enables to compute the amount of solar energy generation by considering weather data and plant specifications. The factors taken into consideration are module temperature and its derating factor, solar irradiance, panel efficiency, type of installation and overall plant losses. In order to make mathematical model more reliable, performance factor and radiation reflection factor has been taken into consideration.

$$\mathrm{OEP} = a * b * c \ \text{kWh/day} \qquad \ldots(1)$$

$$a = \eta * \mathrm{Pf} * \mathrm{Rf} \qquad \ldots(2)$$

$$b = I * n * l * b \qquad \ldots(3)$$

$$c = \{1 - \gamma(\mathrm{T} - \mathrm{Tr})\} \qquad \ldots(4)$$

978-1-5386-5995-3/18/$31.00 ©2018 IEEE

Where,

OEP = Output Energy Predicted (kWh/day)

η = Efficiency of panels (%)

n = Number of panels (constant)

l = Length of each panel (m)

b = Breadth of each panel (m)

I = Irradiation (kWh/m^2)

Pf = Performance factor (constant)

γ = Temperature coefficient (%/°C

-0.47% / °C, for silicon crystalline panels

T = Module temperature (°C)

Tr = Reference temperature (°C), 25ºC

Rf = Radiation reflection factor (constant)

For any healthy PV system, output energy can be predicted using above equation (1).

A. Significance and impact of factor taken into consideration

1. Efficiency of panels: (η): The solar panel energy conversion efficiency is expressed as a percentage of the module output power (watts) over the input sunlight energy (irradiance in W/m^2) and the surface area of the solar panel (in m^2). The efficiency obtained in mono-crystalline panel is 13% to 15% and for polycrystalline panel is 18%. It is studied that high quality solar panels maintains their rated efficiency, but lesser quality solar panels loses up to 3% of efficiency during their initial exposure to sunlight. Other factors including energy conversion losses, wiring inefficiencies and module heating are unavoidable which typically decrease efficiency by about 14 percent. Mono-crystalline silicon module having 17% efficiency is taken into consideration for evaluation of mathematical model.
2. Area of Panel: The plant specifications provide number of panels and dimension of panels. Area of panel is obtained from the product of number of panels, length of each panel and breadth of panel in m^2. Panel taken into consideration has dimensions 1.96*0.92 m^2 and product of dimension of one panel and total number of panels results into total surface area of panel.
3. Irradiance: Irradiance is a measure of the amount of sunlight falling on a given surface. The symbol I is used to denote irradiation and its unit is W/m^2. Hourly irradiation values for each sunshine hour has been obtained from NASA website and taken into consideration. With the change in the time of the day the energy received from the Sun by the PV panel changes. The voltage and current both being a function of the light falling on the cell, there exists a complex relationship between irradiance and output energy. However, on an overcast day i.e. at lower insolation levels these mechanisms show an increasing percentage of the total energy being generated. Too much insolation causes saturation of cells and the number of free electrons or their mobility decreases greatly. With the increasing solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies. The angle of the sun, passing clouds, hazy weather, and air pollution can affect irradiance levels. However, the total energy received by the system from the sun remains relatively constant from year to year. It's a fact that the weather changes every day, and the earth's position towards the sun changes throughout the year. That means that a solar panel at a fixed location may produce 55 W at noon in December and 110 W at noon in June. Similarly, the same panel may produce 130 kWh per year in one geographic location and only 105 kWh in another. In both situations, the production difference is largely because of differing amounts of sunlight.
4. Performance factor: It is observed that due to occurrence of certain losses, the energy actually delivered to the electricity grid is less than the energy produced by the PV modules. So in order to make our equation more reliable, we have considered performance factor which subtracts the estimated system losses such as losses in cables, power inverters and dirt (sometimes snow) on the modules.
5. Temperature Coefficient represents the rate at which the panel will underperform at each increase or decrease in degree Celsius (°C). This value, which is normally given in the form of negative percentage, reveals the impact of temperature on the panel. Solar panels are power tested at 25^0C, so the temperature coefficient percentage illustrates the change in efficiency as it goes up or down by a degree. For example if the temperature coefficient of a particular type of panel is -0.5%, then for every 1^0C rise, the panels maximum power will reduce by 0.5%.So on a hot day, when panel temperatures may reach 45^0C, a panel with a temperature coefficient of -0.5% would result in a maximum power output reduction of 10%. Conversely, if it was a sunny winter's morning, the panels will actually be more efficient. Each type of solar cell has a different temperature coefficient as detailed below: Both mono- crystalline and polycrystalline cells have a temperature coefficient between -0.45% to -0.50%, amorphous based thin film panels have between -0.20% to -0.25% and hybrid solar cells currently on the market sit in the middle with a temperature coefficient between -0.32% when tested under standard laboratory conditions, where ambient temperature is set to 25°C.Experimental results showed that the most significant changed by temperature is voltage which decreases with increasing temperature while output current slightly increase by temperature. The closer the temperature coefficient is to zero, the better the panel will perform when the temperature rises.
6. Module temperature: Temperature plays another major factor in determining the solar cell efficiency. As the

temperature increases the rate of photon generation increases thus reverse saturation current increases rapidly and this reduces the band gap. Hence this leads to marginal changes in current but major changes in voltage An interesting fact about solar power is more the warmer solar cells get, the less efficient they become. The hotter the cell material is, the more resistance there is and the slower the electrons can move through it. This means that production goes down because not as many electrons can get through the circuitry in the same amount of time as before. Temperature acts like a negative factor affecting solar cell performance. Therefore solar cells give their full performance on cold and sunny days rather on hot and sunny weather.

7. Radiation reflection factor: sunlight falling upon panels is never absorbed completely and maximum 9% of radiation is reflected or refracted back so this factor makes equation more reliable by deducting energy losses due to reflected radiation.

III. Analysis and Results

In this mathematical model, two grid-connected PV systems having rating of 270kW and 500kW were studied. To predict solar energy generation plant specifications such as system efficiency, plant area and weather parameters consisting of daily irradiation and forecasted temperature for each sunshine hour was obtained and taken into consideration to compute amount of solar energy to be generated in next

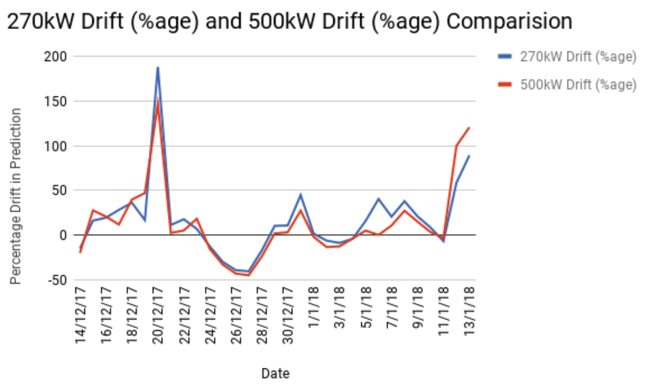

Figure 1 Drift comparison of both the plants under clear sky and opaque cloud covers.

seven days.

Generation for both the plants was examined for certain weather conditions including peak monsoon days having average temperature 20°C,stormy days, sunny winter days having average temperature 25°C and during spring season with average temperature 30°C in order to study impact of variation in temperature on system efficiency. It is observed that a sunny winter days yield more energy compared to hot spring days due to temperature derating when module exceeds 25°C.

Solar irradiation data was fetched from the NASA's meteorological web portal. Although it is considered as the most accurate weather source, undetermined cloud location can lead to an error in the obtained data. It is observed that sky during the state of opaque cloud cover (OCC) i.e. partly cloudy, mostly sunny and overcast lead to 20% bias in it. [1]

Days mentioned in the Table 1 are OCC days and rests of the days were Clear Sky days. As it is also observed from the Fig 1, for those same days, the PV output was greatly impacted as well as it showed a drastic drift in predicted results.

Table 1 Sky observation at plant-site

Date	Sky
18/12/17	Passing Clouds
19/12/17	Scattered Clouds
20/12/17	Partly Sunny
25/12/17	Passing Clouds
26/12/17	Passing Clouds
27/12/17	Passing Clouds
31/12/17	Low Clouds
12/1/18	Overcast.
13/1/18	Overcast.

Predicted results were then compared with the actual PV outputs. Fig 2 and Fig 3 shows the graphical comparison of it for 270kW plant and 500kW plant respectively. Except for the hindsight cloudy or bad weathers, both the graphs shows parallelism with drift less than 30%.

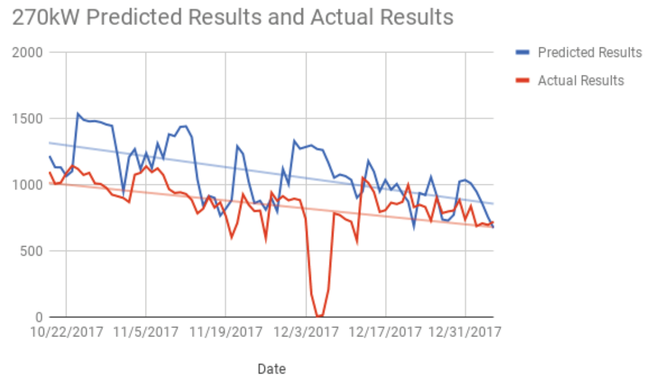

Figure 2 Graph showing comparison of Predicted Results and Actual Results of 270kW plant

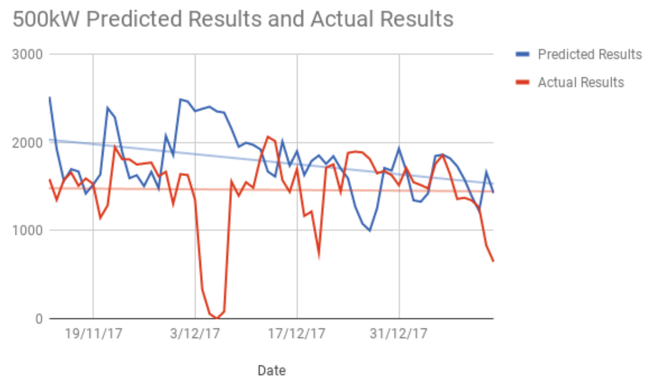

Figure 3 Graph showing comparison of Predicted Results and Actual Results of 500kW plant

IV. CONCLUSION

This paper has described why solar energy prediction is important and how it can be done using mathematical model considering weather variables and plant specifications. Analysis also showed generalized idea about the impact of temperature, irradiance, plant design and efficiency on the PV system output. It is observed that a sunny winter days yield more energy compared to hot spring days. Graphical analysis interprets that during normal weather days, model gives 70% accurate prediction for any healthy PV system but any uncertainty in weather condition results into vulnerability in mathematical model result just like in case of OCKHI Cyclone impacted days mentioned in figure 2 and 3 between 3rd to 7th Dec, 2017.

Acknowledgment

The authors are very much thankful to Prof. Tejas Patel for their invaluable technical guidance throughout the research. Likewise authors also acknowledge Surat Municipal Corporation, Surat, India for authorizing to study both the 270kW and 500kW solar plants and for their staff's helpful cooperation. Finally, two websites nasa.org and worldweather.com has provided the required forecasted weather data.

References

[1] Hall James and Hall Jeffrey, "Evaluating the Accuracy of Solar Radiation Data Sources", Solar Data Warehouse, February 2010.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[2] H. M. Ali, M. A. Zafar, M. A. Bashir, M. A. Nasir, M. Ali, and M. A. Siddiqui, "Effect of dust deposition on the performance of photovoltaic modules in Taxila, Pakistan," Thermal Science, pp. 46–46, 2015. http://www.doiserbia.nb.rs/ft.aspx?id=0354-98361500046A

[3] Navin Sharma, Pranshu Sharma, David Irwin, and Prashant Shenoy, "Predicting Solar Generation from Weather Forecasts Using Machine Learning", Smart Grid Communications (SmartGridComm), 2011 IEEE International Conference, Brussels, Belgium, Oct 2011. http://ieeexplore.ieee.org/abstract/document/6102379/

[4] Elke Lorenz, Johannes Hurka, Detlev Heinemann, and Hans Georg Beyer, "Irradiance Forecasting for the Power Prediction of Grid-Connected Photovoltaic Systems", IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 2, NO. 1, MARCH 2009

[5] David P. Larson, Lukas Nonnenmacher, Carlos F.M. Coimbra, "Day-ahead forecasting of solar power output from photovoltaic plants in the American Southwest", in press.

[6] Report IEA PVPS T14-01:2013, "Photovoltic and Solar Forecasting"