

EASTERN ILLINOIS UNIVERSITY

Solar Energy Modeling for Residential Applications

5953 SUSTAINABLE ENERGY RESEARCH

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INTRODUCTION

Solar Photovoltaic system is a power system designed to use solar power to generate electricity by means of photovoltaics. It basically converts sun's radiation into usable electricity. PV is an arrangement of several components of solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, mounting and cabling accessories required to set up the system. PV systems are basically used for residential and commercial applications. They range from small, rooftop mounted or building integrated systems with capacities from a few to several tens of kilowatts, to large utility scale power stations of hundreds of megawatts.

PV systems operate silently without any moving parts or environmental emissions. A rooftop system regenerates the invested money for its manufacturing and installation within 0.7 to 2 years and produces about 95 percent of net clean renewable energy over 30-year service lifetime. Due to exponential growth of industry, prices for PV systems have rapidly declined in recent years.

Research Question

This research was taken up to design, analyze and validate the residential scale solar PV system using open resource models like PVWatts which use the geographic location based modeling. The objective was to run the model with certain assumed climatic and meteorological variable for the location of Charleston and then validate the energy output to the recorded energy output in the real world conditions taken from the solar array panels located at Center for Clean Energy Research and Education at EIU. The following objectives have been achieved from this research:

- 1) Design of residential scale solar PV system using PVWatts.
- 2) Analysis of the energy output under the influence of Variables like Snow, Soiling, Shading for 6 different iterations of the Model.
- 3) Comparison of model output with the energy generated at the same location for same surface geometry of panels in real world conditions.
- 4) Analysis of model energy output with respect to energy generated for the annual year of 2015, semiannual averages of 2014 and 2016.

PVWatts Model

NREL's PVWatts Calculator is a web application developed by the National Renewable Energy Laboratory (NREL) that estimates the electricity production of a grid-connected roof- or ground-mounted photovoltaic system based on a few simple inputs. To use the calculator, you provide information about the system's location, basic design parameters, and system economics. PVWatts calculates estimated values for the system's annual and monthly electricity production, and for the monetary value of the electricity.

PVWatts is suitable for very preliminary studies of a potential location for a photovoltaic system that uses crystalline silicon or thin film photovoltaic modules. The production estimates that PVWatts calculates do not account for many factors that are important in the design of a photovoltaic system. If using PVWatts to help design a system, you should work with a qualified professional to make final design decisions based on an assessment of the system location and using more detailed engineering design and financial analysis tools.

To get started with PVWatts, type an address, zip code, or geographic coordinates for the system's location. PVWatts uses this information to automatically identify solar resource data available at or near the system's location. The location may be anywhere in the United States, or in some other parts of the world.

The calculator estimates the monthly and annual electricity production of a photovoltaic system using an hour-by-hour simulation over a period of one year. To represent the system's physical characteristics, PVWatts requires values for six inputs:

- System DC size
- Module type
- Array type
- System losses
- Array tilt angle
- Array azimuth angle

The system design assumptions can be refined with three optional advanced inputs:

- DC to AC size ratio
- Inverter efficiency
- Ground coverage ratio

PVWatts makes cost of electricity estimates based on three assumptions about the economics of the system:

- System installation cost
- Average annual retail cost of electricity
- Whether the system is installed on a residential or commercial property.

The System Info inputs describe the physical parameters of the photovoltaic system. It is only needed to provide basic information about the photovoltaic array. PVWatts makes assumptions about modules, inverters, and other parts of the system so you do not need to provide detailed information about the system. PVWatts uses a set of assumptions that are appropriate for flat-plate photovoltaic systems with typical crystalline silicon or thin-film modules. PVWatts results are not appropriate for systems using some types of thin-film modules, concentrating collectors, or for modules using novel cell technologies or module designs.

The advanced parameters are assumptions that you can change when you have additional information about your system. For most analyses, you can ignore the advanced parameters and use their default values. The advanced parameters are:

- **DC-to-AC Size Ratio** defines the inverter's AC size as a function of the array's DC size. The default value is 1.1.
- **Inverter Efficiency (%)** is the inverter's DC-to-AC conversion efficiency. The default value is 96%.
- **Ground Coverage Ratio** describes the spacing between modules in the array. The default value is 0.4.

Draw your system feature

If you are not sure what DC nameplate size to use for the system size, you can use the map tool to roughly approximate the size based on the roof or ground area available for the array at the system location. The map tool calculates a value for the DC nameplate size and populates the System Size input with the value.

Click the map tool to display a Google map of the area surrounding the latitude and longitude from the solar resource data. Find the system site on the map, and click each vertex of

a polygon to draw an outline of the area over the roof or ground where the array will be installed, and click save to finish.

PVWatts estimates the size based on the area of the polygon and the nominal conversion efficiency for the module type you selected (Standard = 15%, Premium = 19%, and Thin Film = 10%). The map tool does not detect roof angles or ground slope, and it does not account for the tilt and azimuth angles of the photovoltaic array, or for potential shading by roof vents or other structures. For an array with a tilt angle of zero and a flat roof, the polygon you draw will roughly approximate the roof space available for the array. For a steeply pitched roof, however, the shape of the polygon is likely to underestimate the actual roof area.

PVWatts Results

The monthly solar radiation reported is the total irradiance incident on the tilted surface (plane of array) in kilowatt-hours per square meter per day. PVWatts calculates the monthly and annual values from the hourly plane of array irradiance values.

The total amount of electricity generated by the photovoltaic system for each month. PVWatts calculates these monthly totals by adding up the hourly values for each month. Because these values are based on typical year solar resource data, they represent the system's typical monthly generation over a period of many years, not the monthly generation for the months of a particular year.

The value of the electricity generated by the grid-connected photovoltaic system, assuming that the electricity service provider values all of the electricity at the average cost of electricity purchased from the System Info page. This is appropriate for a grid-connected system that either sells all of the electricity it generates, or whose entire electricity output goes toward meeting the building's electric load and displaces electricity purchases that the building would otherwise make.

The energy value is the product of the total electricity generated in each month (kWh) and the average cost of electricity purchased from utility (\$/kWh). It does not represent a situation where the electricity customer buys electricity at one price and sells it at a different (typically lower) price, or where electricity prices vary with time (time-of-use pricing) or consumption.

The station identification table displays information about the solar resource data. It is to be noted that the latitude and longitude are for the solar resource data site, which is likely to be different from the system location's latitude and longitude.

Weather Data Source

The name of the solar resource dataset.

Latitude

The latitude from the solar resource data.

Longitude

The longitude from the solar resource data.

DC System Size

The system's nameplate size or rating in DC kilowatts. PVWatts assumes that this value is at standard test conditions (STC) of 1,000 W/m² of solar radiation and 25°C photovoltaic cell temperature. PVWatts also assumes that the system uses flat, non-concentrating modules with crystalline silicon photovoltaic cells.

System Losses

The system losses percentage, representing conversion losses other than the inverter. The system's equivalent nameplate AC rating, equal to the DC rating divided by the DC to AC size ratio.

Array Type

A description of the array's tracking and mounting options.

Array Tilt

The array's tilt angle from horizontal.

Array Azimuth

The array's orientation from due North. A value of 180° represents an array facing due South (toward the equator in the Northern Hemisphere. (Does not apply to two-axis tracking.)

DC to AC Size Ratio

The ratio of the photovoltaic array's DC rated size at standard test conditions (STC) to the inverter's AC rated size.

Inverter Efficiency

The inverter's nominal DC-to-AC conversion efficiency.

Ground Coverage Ratio

The ratio of total module area to the area of the surface (roof or ground) occupied by the module for one-axis tracking self-shading calculations. The Economic Comparison results show the cost per unit of electricity with and without the photovoltaic system. A Cost of Electricity Generated by System less than the Average Cost of Electricity Purchased from Utility is an indication that installing the photovoltaic system may reduce the cost of meeting the building's electricity requirement.

Average Cost of Electricity Purchased from Utility

The price at which the electricity service provider purchases electricity generated by photovoltaic system, or the value of electricity purchases displaced by the system. This is equal to the input value on the System Info page. This value represents the cost per unit of the electricity that would be purchased to meet the building's electricity load without the photovoltaic system.

Cost of Electricity Generated by System

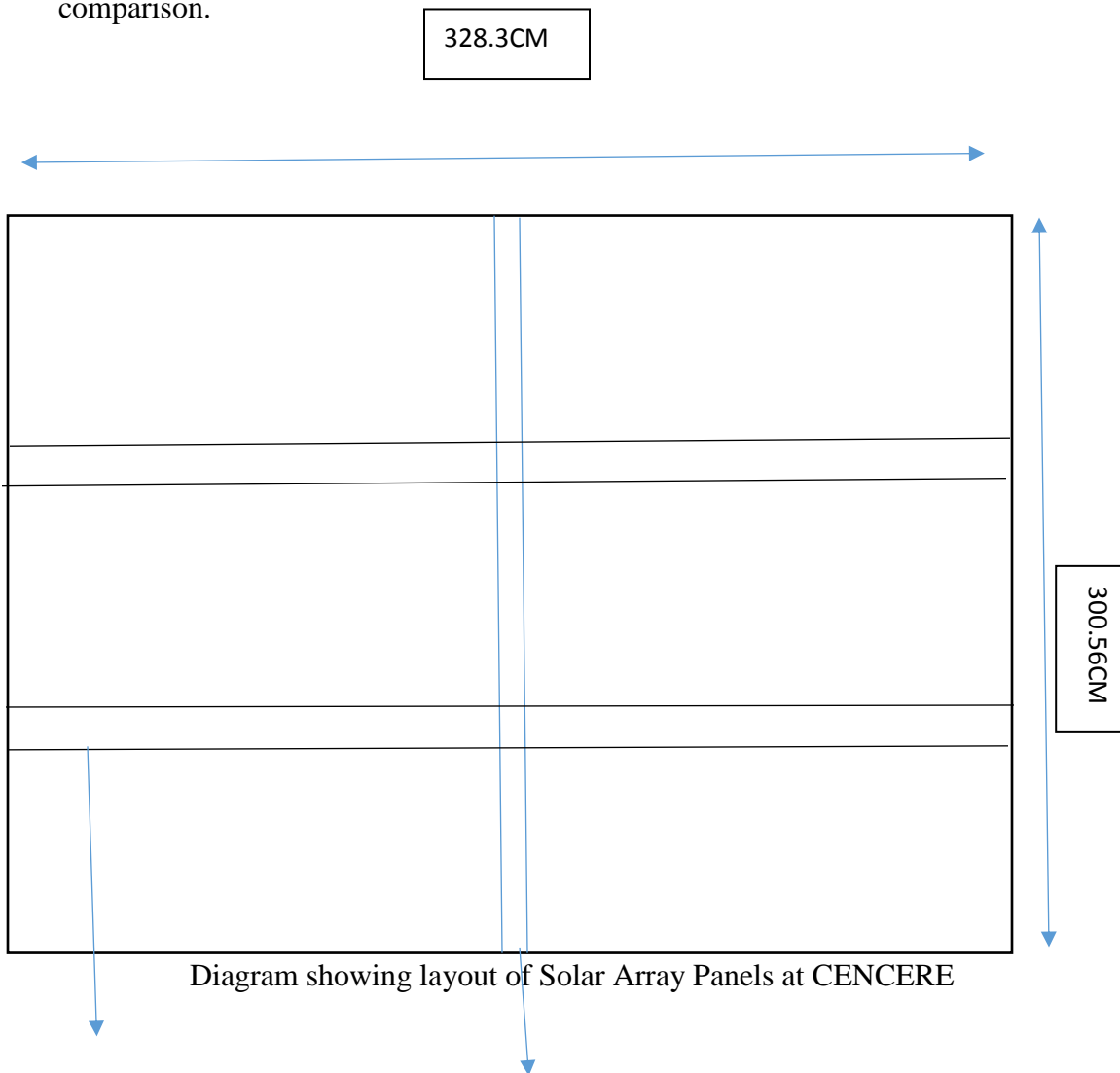
The photovoltaic system's cost of generating electricity, or levelized cost of energy. This value is equivalent to the cost of installing and operating the system over its life, accounting for the value of incentives and cost of debt. This value represents the cost per unit of electricity generated by the system

METHODOLOGY

The following methodology was used to run the model

- The solar array panels at REC were measured and their dimensions including gaps were recorded.
- Actual geometric surface area of two arrays used for power generated was calculated to be 20 square meter.

- The DC system size for the geometric surface area of 20 square meter panels was manually computed to be 2.9KW.
- The geometric surface area thus calculated has been input into PVWatts model along with various other variables like DC System size, system losses, Tilt, Azimuth and other advanced parameters.
- After input variables were given, the model was run to generate the output.
- Many number of iterations on the model were run changing the input variables like Snow, Shading, soiling to understand the performance of model behavior under different conditions.
- The best of 6 iteration outputs were taken for further analysis and comparison.



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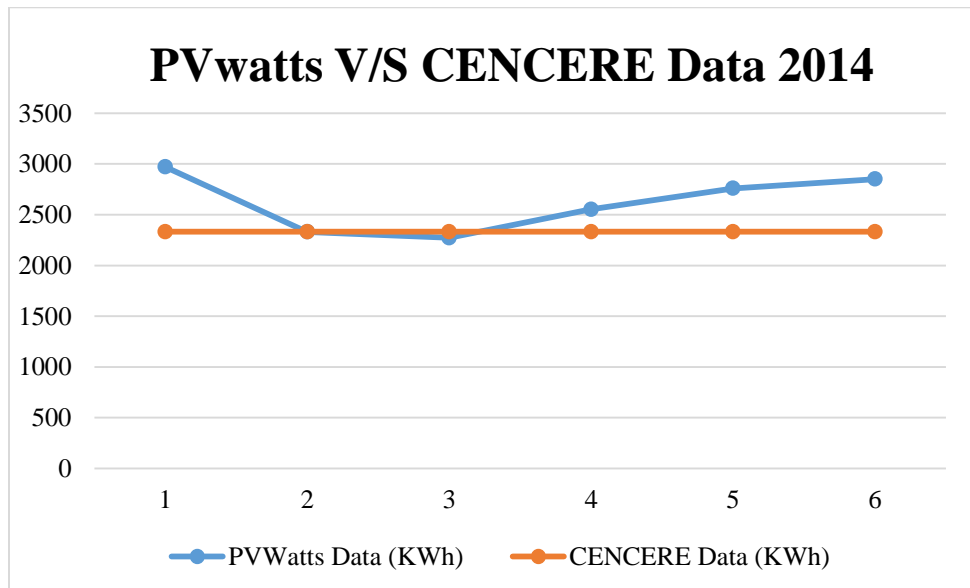
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RESULTS

- The semiannual (May to December) data for the year of 2014 against 6 best iterations of model gives the following results.

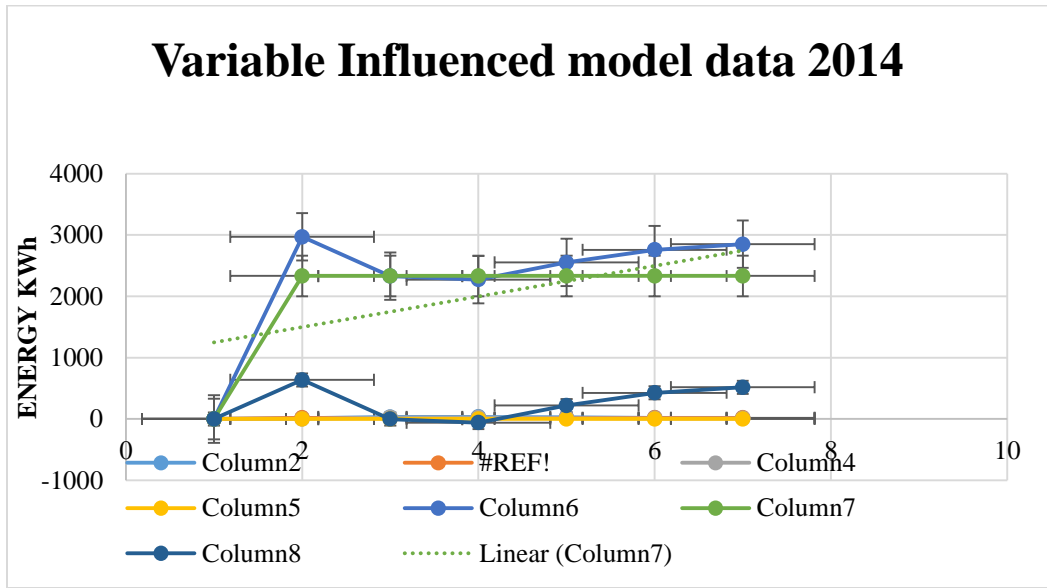
DC System size (Kw)	System Loses (%)	Tilt(Angle)	Snow	Soiling	PVWatts Data (KWh)	CENCERED ata (KWh)	DELTA (Kwh)
2.9	14	20	0	2	2970	2332	638
2.9	32.67	20	24	1	2330	2332	-2
2.9	34.56	20	25	1	2272	2332	-60
2.9	26.11	20	14	2	2553	2332	221
2.9	20.13	20	10	1	2759	2332	427
2.9	17.52	20	8	1	2850	2332	518

Table showing difference of energy from PVWatts model and CENCERE data with different variables.



Graph showing PVWatts data and CENCERE data for 6 iterations

- The nearest observed values for the model and the data generated is observed to be -2KWh, -60KWh, and 221KWh for the year 2014. The model predicted the nearly same output as the CENCERE data on the second iteration indicating the efficiency of the model.



Graph showing influence of variables for 6 iterations

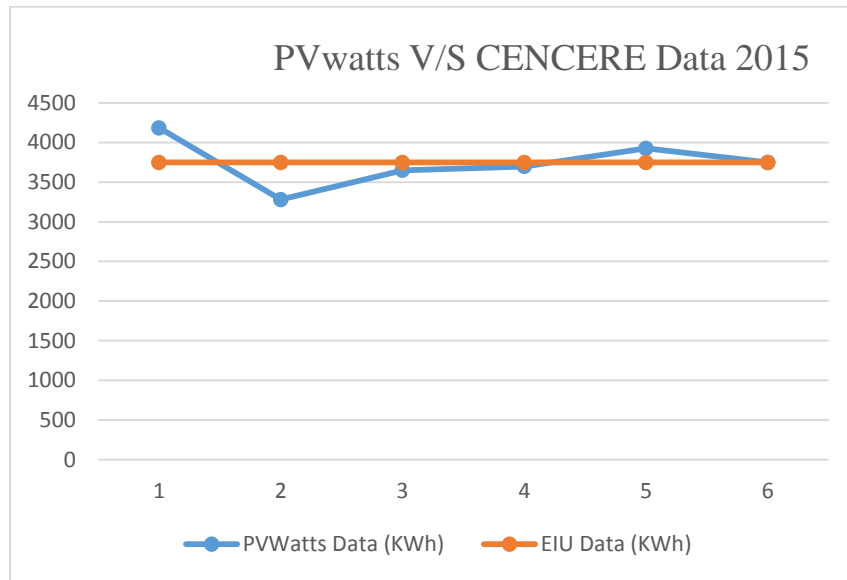
2015

- The annual data for the year of 2015 against 6 best iterations of model gives the following results.

DC System size (Kw)	System Losses (%)	Snow	Soiling	Tilt (Angle)	PVWatts Data (KWh)	CENCERE Data (KWh)	DELTA (Kwh)
2.9	14	0	2	20	4184	3747	437
2.9	34.89	25	3	20	3279	3747	-468
2.9	25	25	3	20	3649	3747	-98
2.9	24.01	15	2	20	3697	3747	-50

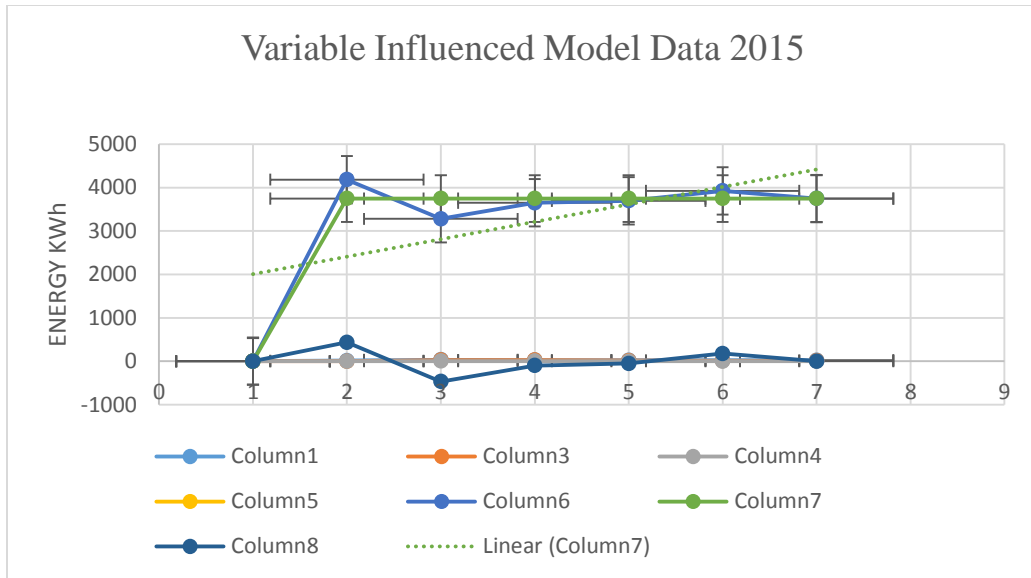
2.9	22	12	1	20	3926	3747	179
2.9	23	12	1.2	20	3747	3747	0

Table showing difference of energy from PVWatts model and CENCERE data with different variables.



Graph showing PVWatts data and CENCERE data for 6 iterations

- The nearest observed values for the model and the data generated is observed to be - 98KWh, -50KWh, and for the year 2014. The model predicted the exactly same output as the CENCERE data on the last iteration indicating the efficiency of the model.



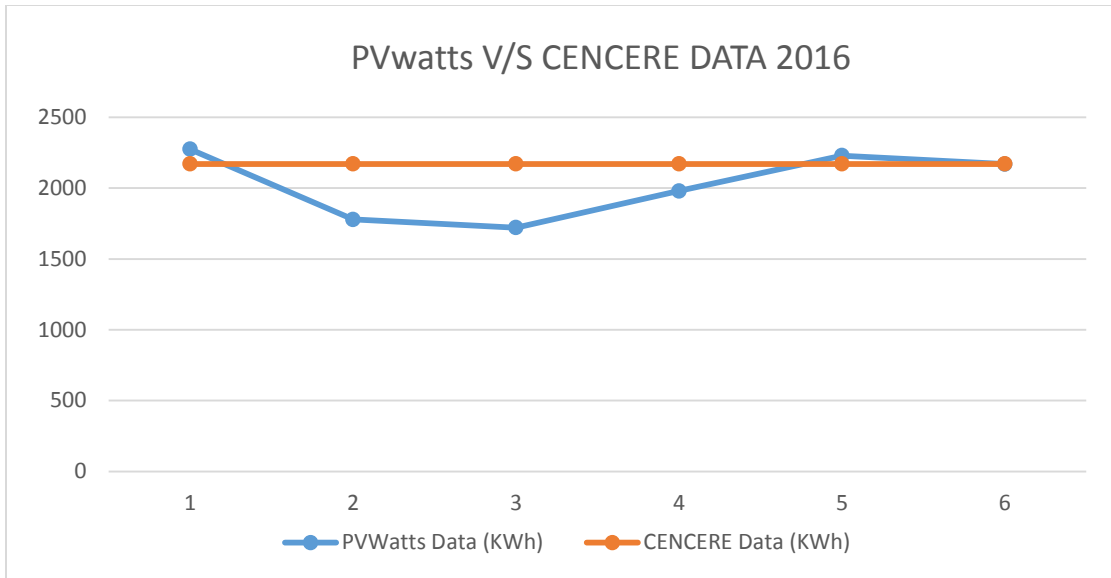
Graph showing influence of variables for 6 iterations

2016

- The semiannual data for the year of 2016 (January to June) against 6 best iterations of model gives the following results.

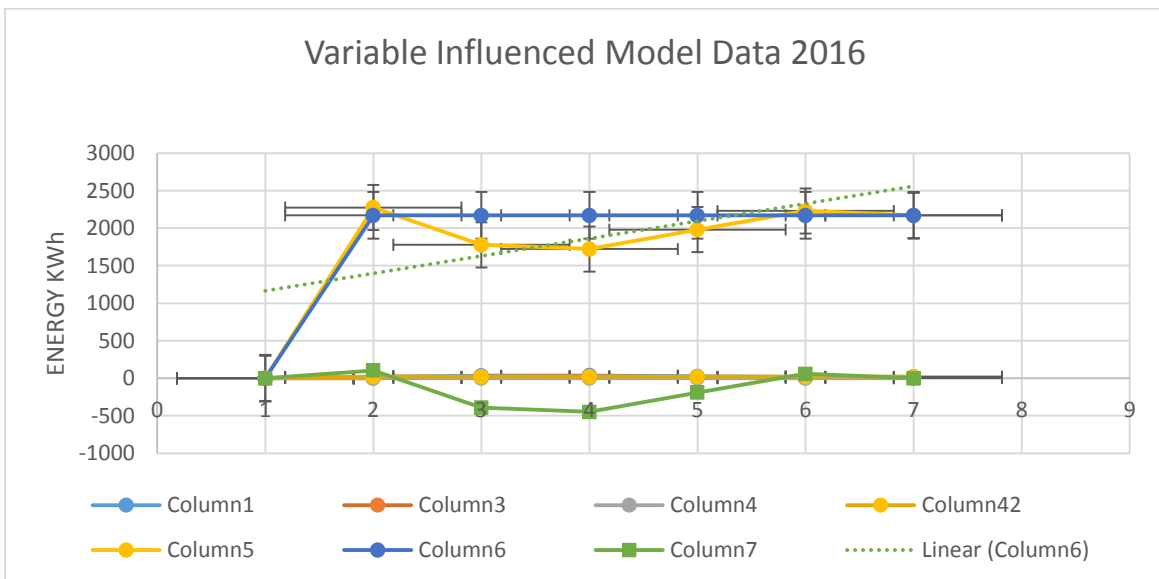
DC System size (Kw)	System Losses (%)	Snow	Soiling	Tilt(Angle)	PVWatts Data (KWh)	CENCERE Data (KWh)	DELTA (Kwh)
2.9	14	2	2	20	2274	2170	104
2.9	32.64	20	2	20	1778	2170	-392
2.9	34.89	25	2	20	1721	2170	-449
2.9	25	15	2	20	1980	2170	-190
2.9	15.6	5	1	20	2229	2170	59
2.9	17.94	6	2	20	2169	2170	-1

Table showing difference of energy from PVWatts model and CENCERE data with different variables



Graph showing PVWatts data and CENCERE data for 6 iterations

- The nearest observed values for the model and the data generated is observed to be - 1KWh, 59KWh, and 104KWh for half the year of 2016. The model predicted the nearly same output as the CENCERE data on the last iteration indicating the efficiency of the model.



Graph showing influence of variables for 6 iterations

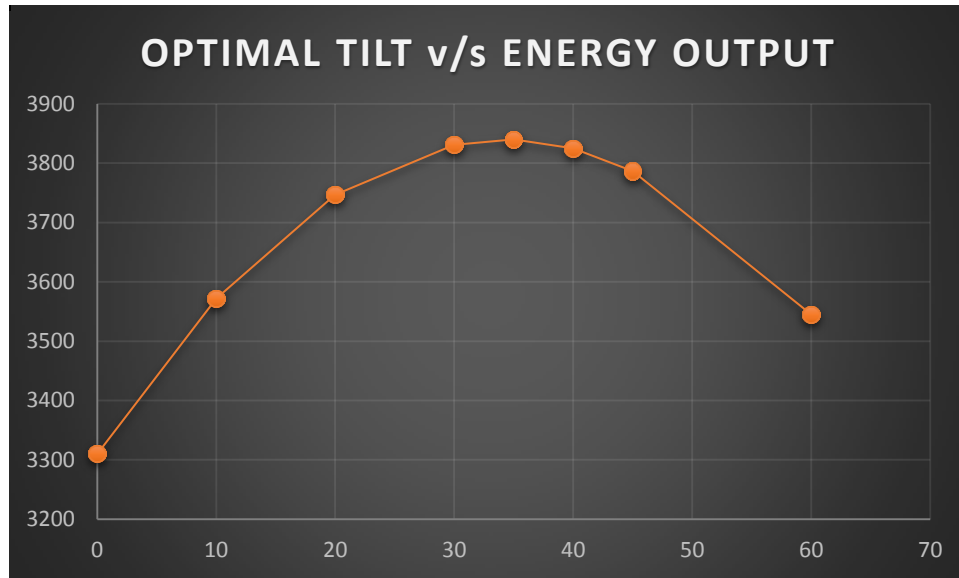
COMPARISION

- The data obtained from the iterations was validated using the energy output data generated by solar panels at CENCERE in EIU.
- The data set at EIU had the data recorded as follows
 - 2014 – May to December
 - 2015 – January to December
 - 2016 – January to June
- The best of 6 iterations were compared to the semiannual energy output of 2014, annual output of 2015 and semiannual energy output of 2016.
- The difference of energy is computed to observe the nearest possible scenarios for energy generation in real world scenario.
- The resultant data is plotted to graphs to show the most probable iterations depicting energy generated in near real world scenario.

OPTIMAL ARRAY TILT ANGLE FOR CHARLESTON AREA

System Losses (%)	Snow (%)	Soiling (%)	<u>Angle of Array</u> <u>(Degrees)</u>	PVWatts Output (KWh)
23	12	1.2	<u>0</u>	3310
23	12	1.2	<u>10</u>	3572
23	12	1.2	<u>20</u>	3747
23	12	1.2	<u>30</u>	3831
23	12	1.2	<u>35</u>	3840
23	12	1.2	40	3825
23	12	1.2	45	3787
23	12	1.2	60	3545

Table showing maximum energy production for optimal tilt angle at Charleston location



Graph showing Optimal Tilt v/s Energy Production

CONCLUSIONS

- The energy output generated by the model depicts near real world energy output.
- The energy output generated by the model in few iterations was negative indicating the variables assumed for input have considerable impact on the output by showing less energy generation possible than was recorded at CENCERE solar panels.
- Model holds good for scenarios with near real input variables applied under practically possible conditions.
- Tilt or angle of array is observed to have significant effect on the model.
- The optimal tilt angle is observed to be $10^{\circ} - 35^{\circ}$ for the Charleston area as shown in the graph.
- There is further scope for analysis using the generated data from model and recorded data at CENCERE.
- The major limitation of this study is the climate data set input into PVWatts model from Springfield location which is 85miles from Charleston.

REFERENCES

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