Performance evaluation of the 600kW grid-tied solar photovoltaic system in Strathmore University

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Abstract

This paper presents the performance of a 600kW a grid – tied system installed at Strathmore University. The plant has two systems, a 420kW and 180kW connected to two independent transformers. The system is composed of 2,400 solar panels and 30 inverters. The solar PV modules are spread over the rooftops of six buildings within the university. Of the 600kW, 20kW has been taken away for a hybrid system that is used for training at the Strathmore Energy Research Center (SERC). The daily energy generation data for three years is used to identify the Performance Ratio (PR) and Capacity Utilization Factor (CUF) of the 600kW system. The performance analysis is then compared to a range of PR and CUF values for well performing grid – tied plants.

Introduction

In June 2014, Strathmore University commissioned a 600kW grid-tied solar PV system, geared towards self – consumption and exporting excess power to the national grid. The system is located on the roof-top of six buildings at Strathmore Campus in Madaraka Estate, Nairobi. The system is connected to the grid at 415V in two places, namely Mvule House and Keri House behind the Medical Centre.

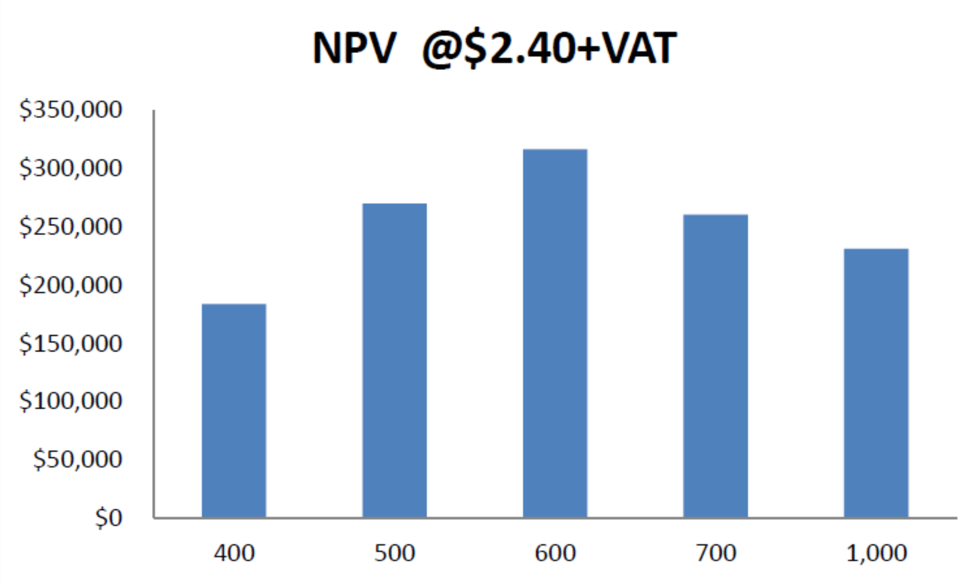
Several factors were important in the decision to invest in a solar PV power plant at the University:

- Awareness and knowledge of the University's senior management about solar PV technology and its financial sustainability aspect.
- The University's location within the "Solar Belt" giving it an advantage in tapping daily solar power throughout the year due to the average insolation of 4-6kWh/m2/day, without the need for sun tracking.
- The existence of a green energy facility, set up by the French Development Agency (SunRef), offering project financing at concessional rates with a very generous pay-back period.
- Additionally, the existing feed-in-tariff provided by the 2006 ERC regulations, allows for a grid-connected system without storage which the possibility of selling its excess power to the utility.

The minimum plant size eligible for the Feed in Tariff (FiT) regime in Kenya is 500kW, thus, this represented the smallest size that the University could consider. To arrive at an optimal plant size design, modeling tools were applied to various plant sizes. The sizing analysis was undertaken via two models, namely:

- System Advisor Model (SAM) -a renewable energy application designed by the National Renewable Energy Laboratory, an agency of the US Government);
- A financial model in Excel that takes some of the results from the R model to calculate Net Present Value (NPV) of systems of various sizes.

Figure 1



The figure above shows how the NPV varies as system size changes. Beyond 600kW the financial losses from energy exported to KPLC at a lower price than the Levelized Cost of Electricity (LCOE) reduces the savings achieved by Self Consumption (SC) of PV energy. A system that is too small will not reap all possible savings from avoiding purchasing electricity from the Utility at $0.225. From these two models, the clear optimized size for maximum returns was 600kW.

This paper focuses on analyzing the Performance Ratio (PR) and Capacity Utilization Factor (CUF) of the installed plant. The performance ratio (PR) is the ratio between the actual energy generated and the calculated energy generated of a PV plant. It is also known as the quality factor of a PV plant. The capacity utilization factor is the ratio of the actual amount of energy generated to the maximum amount of energy that can possibly be generated by the PV plant.

Data for the years 2015, 2016 and 2017 is collected form the portal of Solar Edge Monitoring System. There are 30 Solar Edge inverters, each is rated at 20kW. Each inverter is connected to a string of 80 250W PV modules. Monitoring is made possible by the use of solar optimizers. Each solar optimizer is connected to two PV modules, and sends information about the PV module to the inverter. Analysis of this data gave a PR of 68.27% and a CUF of

14.96% in the year 2015. In 2016 the values were a PR of 64.26% and a CUF of 14.09%. Finally in 2017 PR was 62.82% and CUF was 13.77%.

The results were compared to similar installations in India and were found to be within the calculated ranges in this region.Daily power production is between 2.0 to 2.8 megawatt hours and is monitored at every inverter. On average, generation begins at 7:00 am to 6:00 pm. There is more demand for electricity during the weekdays as compared to weekends and holidays.

The high costs of electricity in Kenya, averaging \$0.225/kWh presented an opportunity for getting a mortgage to install the solar system and use the savings in electricity to service the loan. This is very much similar to stopping paying rent and entering into a leasing agreement such that at the end the period the solar system belongs to Strathmore and the provision of electricity until its end of life span is “free”

Methodology

Data on energy generated by the plant in Megawatt hours has been collected by the Solar Edge monitoring system from day one. The monitoring system captures data from all inverters in the system. From the system one is able to get the daily energy generation data and the period of generation. The data is made available from the portal either on a daily, monthly and yearly basis. A period of three years, 2015, 2016 and 2017 was considered in this study. This is because the system began generation in late June 2014, therefore there was no data for the first half of the year. In order to consider 3 complete years, data from 2018 was not included either.

Data collected was utilized to calculate the Performance Ratio (PR) and Capacity Utilization Factor (CUF) of the plant. Performance Ratio and Capacity Utilization Factor are both functions of atmospheric and electrical factors and can be determined as shown below.

Performance Ratio (PR)

Performance Ratio shows the amount of energy that is available for sale to the utility after deducting losses in the system and the energy that is consumed during the plant’s operation. An ideal Solar PV plant operating at ideal conditions has a PR of 100%. It is however not possible to have a PV plant operating at 100% PR value as they do not operate in ideal conditions and uncalculated for losses occur. This therefore shows that the closer the PR value is to 100%, the more the PV plant is operating efficiently. The PR value is usually taken in a duration of time ranging from a day to a year. In this paper the PR value is taken annually.

$$Performance\ Ratio = \frac{Actual\ Energy\ Generated}{Calculated\ Energy\ Generated} \times 100\%$$

Where $Calculated\ Energy\ Generated = Annual\ Global\ Horizontal\ Irradiation\ (GHI) \times Area\ of\ the\ PV\ modules\ surface \times PV\ module\ efficiency$

Global Horizontal Irradiation (GHI) is the total amount of radiation from above that is measured on the solar PV module's surface that is horizontal on the ground. It is given in kWh/m^2. For Strathmore University, the Annual GHI is 1921 kWh/m^2. The area of the PV modules surface for the installed plant is 3920.4 m^2 and the PV module efficiency is 15.27%.

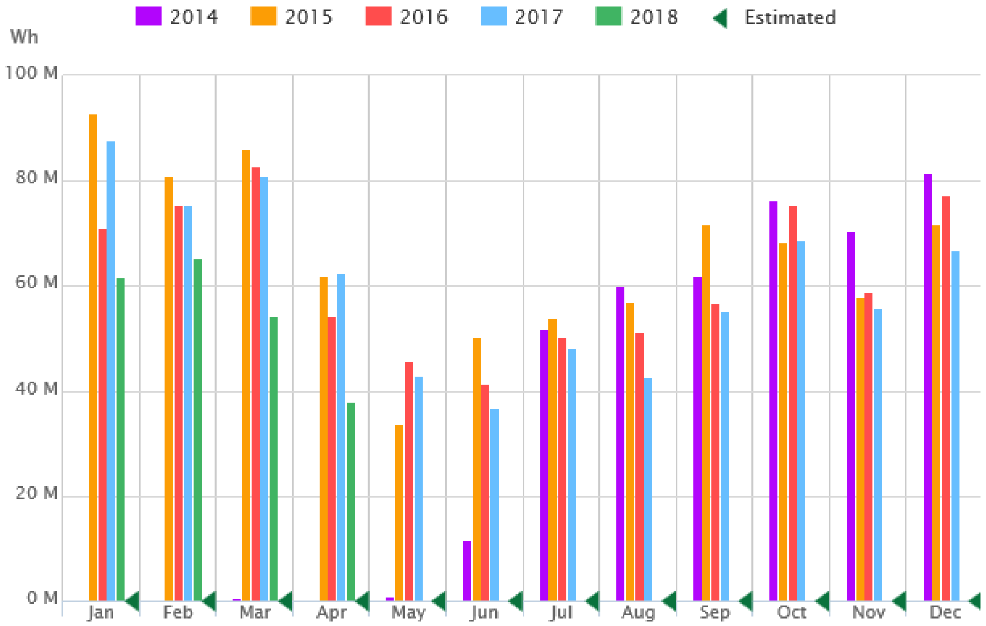
Capacity Utilization Factor (CUF)

Capacity Utilization Factor gives the ratio of the actual energy generated from a Solar PV plant to the maximum energy that could be generated when the plant runs for 24 hours in all 365 days of the year.

$$Capacity\ Utilization\ Factor\ (CUF) = \frac{Actual\ Energy\ Generated\ (kWh)}{Plant\ Capacity\ (kW) \times 24hrs \times 365days} \times 100\%$$

Results

Figure 2



From the data, it was noted that the highest generation occurred in the first third of the year (January, February, March and April), followed by the last third period (September, October, November and December) and the lowest generation occurred in the middle third period of the year (May, June, July and August) as shown in figure 2.

In the three-year period, the highest amount of energy generated is 93.013 MWh in January 2015. The lowest amount of energy generated is 33.613 MWh in May 2015. Since the plant began generation about 1 million kg of CO2 emissions has been saved by the plant. This is equivalent to 3,348 trees planted.

PR and CUF

In 2015, the performance ratio was 68.27%, and a CUF of 14.96%. In 2016, the performance ratio value is 64.26% and a CUF of 14.09%. In 2017, the performance ratio value is 62.82%. This value is lower than the PR in 2015 and 2016. The plant had a CUF of 13.77%. This value is lower than in 2014 and 2015. The values of PR and CUF obtained are within a range of good performing plants in India, that experiences almost similar temperature and irradiance conditions to Kenya.

Figure 3

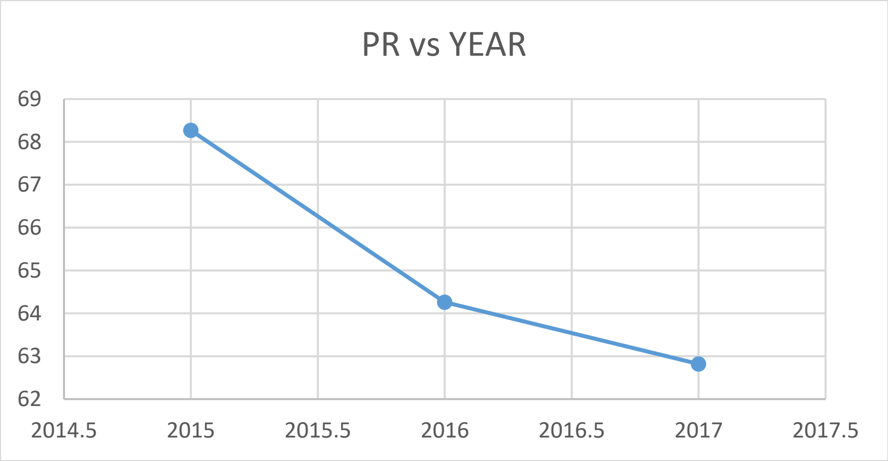
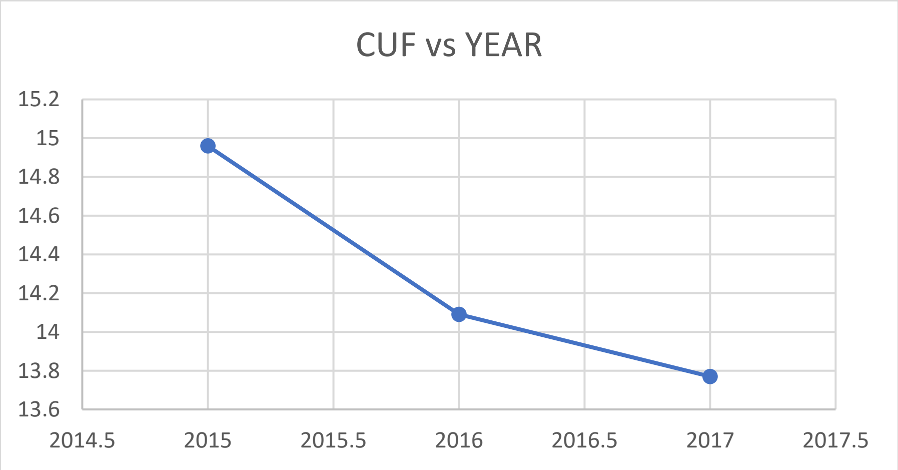


Figure 4



Conclusion

The performance of the 600kW system in Strathmore University was analyzed. Performance Ratio (PR) and Capacity Utilization Factor (CUF) reduces systematically over the three years period used to analyze it. Performance Ratio reduced by 5.87% in 2016 and by 2.24% in 2017. The total reduction in PR is 7.98%. Capacity Utilization Factor reduced by 5% in 2016 and by 2.27% in 2017. The total reduction in CUF is 7.95%. These is be attributed to three main reasons. There is a fast rate of failure of solar optimizers, therefore data from some PV panels is not recorded by the inverters. High temperatures that cause derating of the PV panels and the accumulation of dust on the panels that causes shading on the panels. Frequent maintenance practices will help improve greatly the performance of the system.

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