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De-carbonization of the campus

Seasonal Energy Storage & Conversion Technology.

Vaasa 2021

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1 Abstract

Increasing energy generation with non-renewable sources has created a major problem of global warming which is gradually affecting the nature and human lives. This has raised an alarming situation which requires immediate need to shift from carbon producing energy generation to a cleaner energy solution. Finland is considered to be fifth most sparsely populate country in Europe. About half of the energy consumption and carbon emission in Finland is related to the Finland's industrial sector and the other half is related to public, private sector and household buildings. The aim of this study is to assess the feasibility of PV adoption at the University of Vaasa campus by machine learning technique and propose a design of PV system with suitable energy storage system.

2 Introduction

Increasing energy generation with non-renewable sources has created a major problem of global warming which is gradually affecting the nature and human lives. This has raised an alarming situation which requires immediate need to shift from carbon producing energy generation to a cleaner energy solution. Under the Paris agreement, countries are marching toward environmental friendly economies to protect the future of the Earth and generations to come. Electricity production by non-renewable resources, such as oil and gas, is considered to be one of the main reasons of global warming in the energy sector. In order to minimize the effects of carbon change, it is necessary to minimize the carbon emission in the energy sector (Elisa Papadis, 2020).

Rapid increase in population growth and electricity consumption has increased the demand of electricity generation (Jamal Faraji, 2020). Finland is considered to be fifth most sparsely populate country in Europe. About half of the energy consumption and carbon emission in Finland is related to the Finland's industrial sector (Alireza Aslani, 2013) and the other half is related to public, private sector and household buildings. In order to reduce carbon emission at distribution level, for household and public buildings, distributed energy resources can help to mitigate the carbon emissions in Finland.

In this report, a study is conducted to de-carbonize University of Vaasa campus. University of Vaasa is located in the city of Vaasa on the west coast of Finland. Vaasa city has dominant winter seasons ranging from six to eight months, followed by summers lasting short period of time. Average yearly temperature of Vaasa is 3.9^{o} C and the warmest of temperature touched in Vaasa is about 15.6^{o} C. Coldest month of January in Vaasa city can reach up to -7.2^{o} C (WeatherBase, n.d.). University of Vaasa occupies a large area on the west coast. Total area of university campus is approximately 20,000 m^2. Campus is occupied with buildings such as Tritonia, Technobothnia, and Luotsi buidlings. Buildings occupies a total area of 17,000 m^2.

Adopting renewable generation at University campus level can make the Vaasa campus self-sufficient and would play its part in carbon emission reduction. One proposed solution is to adopt renewable resources such as solar Photovoltaic at the Vaasa campus. But since Vaasa is a colder region with few months of summer and sun energy, this would however require studies to be conducted to acquire the feasibility report for such distributed energy generation at the Vaasa campus. However, solar PV is considered for this study, as according to a research, PV has better efficiency in cold temperatures (A.Shuklaa, 2017).

In this study a machine learning technique is adopted to forecast photovoltaic generation at the Vaasa campus and present practicality of PV technology in Vaasa. Gradient boosting regression model is used in this study. Gradient boosting regressor use decision trees to solve the problem. It works in a way that it modifies the sample by setting sample to negative gradient and keeps the distribution constant (Helmbold, 2002). It uses gradient descent to minimize the loss. The regressor calculates the difference between the prediction and known value. The difference remaining is known as residual.

The goal of this study is to assess the feasibility of PV adoption at the University of Vaasa campus. Machine learning model is trained with single PV module generation dataset and weather data. Trained model with 91.2% accuracy is used to predict the PV energy generation at University of Vaasa campus. Based on the forecasted PV power outputs a proposed array of rooftop PV panels are implemented at the campus building and energy storage system is also suggested to store PV energy for later use in order to decarbonize University of Vaasa campus.

3 Materials and methods

Solar photovoltaic conversion technology is based on energy conversion from light energy, coming from sun, to electrical energy. This phenomenon is also known as photovoltaic effect. For the process of this conversion solar cells are used which are made up of semiconductor material, doped with different materials, in a pattern to form a pn-junction. The pn-junction is responsible for creating a constant artificial electric field (Francesco Calise, 2019) by extracting energy from photons of solar light. Most common form of semiconductor material used in photovoltaic cells is silicone mainly due to its abundance, however, other semiconductor materials such as germanium, gallium arsenide, and selenium can also be considered in manufacturing PV panels.

Solar modules are build up by combining number of solar cells. These solar modules can consist of 36 solar cells modules (12V) and 72 solar cell modules (24V). Cells in individual modules can be connected in series, to increase the output voltage of the module, or the cells can be connected in parallel to increase the current output of module with same voltage of each cells (Ahmad, 2017). Similarly, number of modules can be connected in series or parallel to maximize the output power at same current (series-connection) or same voltage (parallel-current) respectively. In this study, datasets of single PV module consisting of 72 cells obtained from IEEE DataPort (Mussetta, 2020) is used to train machine learning model. By the help of trained model and Vaasa weather data, PV generation by a single module is forecasted.

3.1 Energy storage for PV system

Renewable energy, specifically wind and solar, are variable sources of energy generation which are highly dependent upon the varying wind and sun energy nature. Due to their intermittent nature and fluctuations renewable energy generation units cannot operate as a standalone in power system. To make renewable units function efficiently one solution is to adopt energy storage systems along with renewable generations (Montaser Mahmoud, 2020) .

Energy storage systems can be categorized into mechanical, electrochemical, electrical and thermal energy storages. It can be further classified into short term and long term storages. Some example of storages include flywheel energy storage, Super capacitors, pumped-hydro and many other. Each type of storage system has its own benefit and its integration with generating units depends upon the application for which it is desired.

Electricity generated by PV system can be used in reducing the overall electricity consumption of university campus by utilizing the electricity produced by PV panels integrated with battery energy storage system (BESS). This type of integration will supply electricity to the university campus and reduce the overall electricity consumption. However, the second proposed energy storage for this study is photovoltaic thermal (PVTs) coupled with heat pump and ground heat exchanger which is described in a study as solar assisted ground source heat pump (SAGSHP) system (Naranjo-Mendoza, 2019) . SAGSHP system reduced the electricity consumption by heating domestic buildings.

3.1.1 PV system with BESS

BESS converts energy from electricity and stores it in the form of chemical energy. Batteries with various materials are available which can be used to store energy such as Lead-acid, Li-ion, and Cadmium-mercury. One of the battery which is widely used in industrial application is the Lithium-ion battery. They have very high response time, energy & power density, longer shelf-life and low shelf discharge. In most of the grid energy technologies and application, lithium-ion battery is used as energy storage device

Adopting BESS as energy storage with PV integration can reduce peak hour’s electricity consumption by the university campus. During low electricity consumption BESS can store electricity from the PV system and during high load hours, when university is open for students, BESS can supply sufficient power to the university campus to reduce electricity consumption by the grid. One common BESS can be adopted for the entire university which stores energy and supply power to the university campus.

However, for this integration it is necessary that PV is generating enough electricity throughout the year so investment cost (for BESS and PV system) is returned with profit and electricity import from grid is reduced. Resulting in de-carbonization of the University campus. In order to study the PV generation in summer and winter, machine learning technique is used to forecast hourly PV generation in January and June, 2020 of the Vaasa city; presented in the results section.

3.1.2 PVT with heat pump and ground heat exchanger

Photovoltaic thermal (PVT) is a hybrid system which can generate electrical energy and thermal energy from solar energy. In this proposed energy storage system, PVT is integrated with heat pump and ground heat exchangers (boreholes) (Naranjo-Mendoza, 2019). PVT produce both electrical energy and thermal energy. Electrical energy is consumed by the heat pump, in order to transfer heat to ground heat exchangers or directly to the buildings.

Ground heat exchanger can store heat seasonally in an underground earth energy bank (containing boreholes). Integrating ground heat exchanger with PVT will allow to store energy in summers and supply heat energy in winters for heating university buildings. This will result in reduction of electricity consumed for heating purposes in winters by University of Vaasa building.

In this study, the forecasted electricity generation by the PV system can be used to evaluate the consumption of heat pump. However, PV thermal is different from PV as it cools down PV cells by transferring heat and increase electricity production. It is assumed in this study that electricity generated by PV and PVT is almost same under similar weather conditions.

3.2 PV power forecasting Datasets

Forecasting electricity generation by machine learning requires datasets to train the models. Datasets used are at 10-minutes time interval. Actual measurement of single PV module dataset (2017-2018) is obtained from IEEEDataPort which is measured at SolarTech Lab, Politecnico di Milano, Italy (Mussetta, 2020). The dataset contains 1 minute time interval PV module power production and weather data of Politecnico di Milano, Italy. Initially, with this dataset a gradient boosting regression model is trained for the month of January, 2017.

Datasets from Italy was used because no actual measurement data was found for power generation by PV module at Vaasa or Finland. Since the machine learning model is trained with only weather features containing global horizontal irradiance (W/m2) and ambient temperature (^{o}C). Accurate prediction is possible if only these features of Vaasa weather data can be given to the model for predicting PV power generation. Required features of weather data from Vaasa's weather station was not found from Finnish meteorological institute (Institute, 2021), a nearest possible alternative weather data from Jyväskylä airport (Jyväskylä lentoasema) is used to predict PV generation in the city of vaasa.

4 Results

In this study for de-carbonization of University of Vaasa campus a rooftop PV with energy storage system is proposed. For evaluating the practical implementation of PV system and considering the energy storage for Vaasa region a machine learning technique is carried out which is used to forecast PV generation. Based on the results obtained a PV system for University of Vaasa can be designed and suitable energy storage is proposed.

To train the machine learning model, a PV module dataset is used with 10-minutes time interval. Dataset consists of features such as temperature, windspeed, and solar irradiance. By using gradient boosting regressor's feature selection, important features are selected to train the machine learning model. Ambient temperature and global radiation were found to be most important features which are used train the model. The model was trained with January 2017 actual measurements of a PV module (with 250-450 W maximum power) measured in Italy and achieved an accuracy of up to 91%.

Name	Cross validation score	Test score	Training score
Gradient boosting regressor	91.2%	92.2%	88.7%

Table 1 Accuracy score GBR model

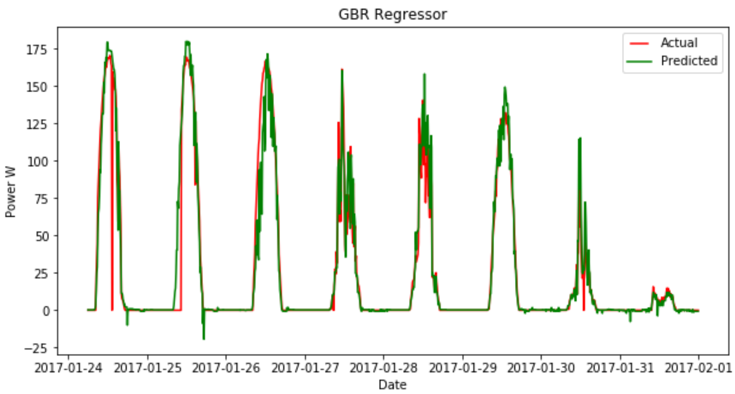

Figure 1: January 2021 last week forecast

Vaasa’s approximate weather datasets from the city of Jyväskylä was used to predict the PV module power generation in winter and summer. For winter January dataset was used and for summer May dataset was used. The machine learning model was capable of medium term forecasting, ranging from 10-minutes to one month PV module generation forecasts.

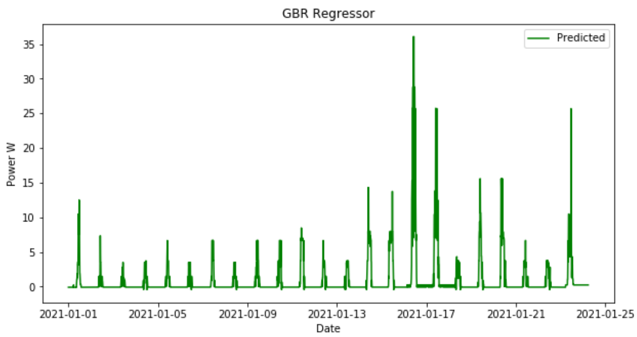

Figure 2 : Vaasa January 2021 forecast

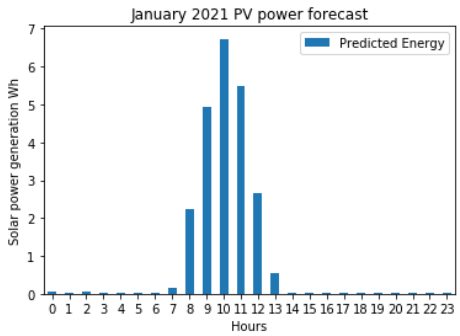

Figure 3: average PV production (Jan 2021)

During winters, or specifically January, power produced by a PV module is forecasted to be very low. An average hourly generation for January 2021 shows peak PV module power generation to be approximately 7Wh (figure 3). whereas, during summers the PV generation can have a peak power generation of about 132 Wh (figure 5).

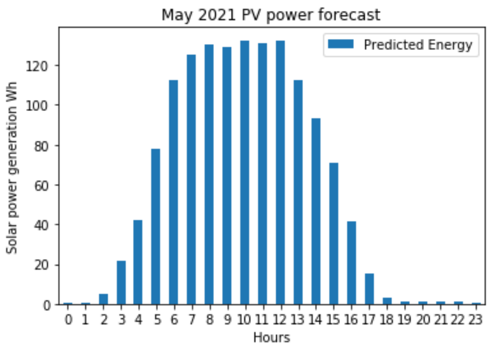

Figure 4: Average PV production (May 2021)

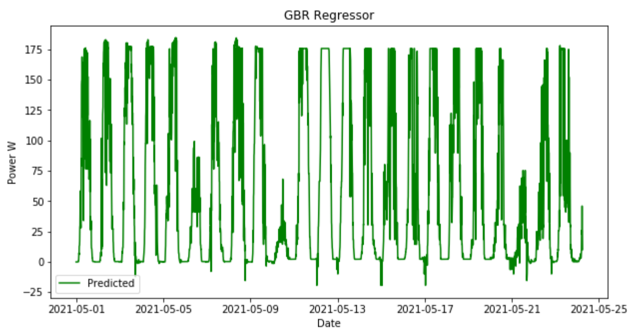

Figure 5: Vaasa May 2021 forecast

4.1 Design of University of Vaasa PV system

A University of Vaasa rooftop PV system can be designed based on the forecasted power of single PV module. Supposing a total number of 17 PV modules are grouped to form a PV array. Three PV arrays are proposed at Terahovi building, Tritonia and Luotsi building.

Area covered by the PV array system can be calculated. An average size of a 72 cell PV module is 3.25 feet x 6.42 feet = 20.865 ft^2 or 6.36 m^2. A total area covered by a PV array on a rooftop of a single building will be 17 PV module x 6.36 m^2 = 108.12 m^2 of area.

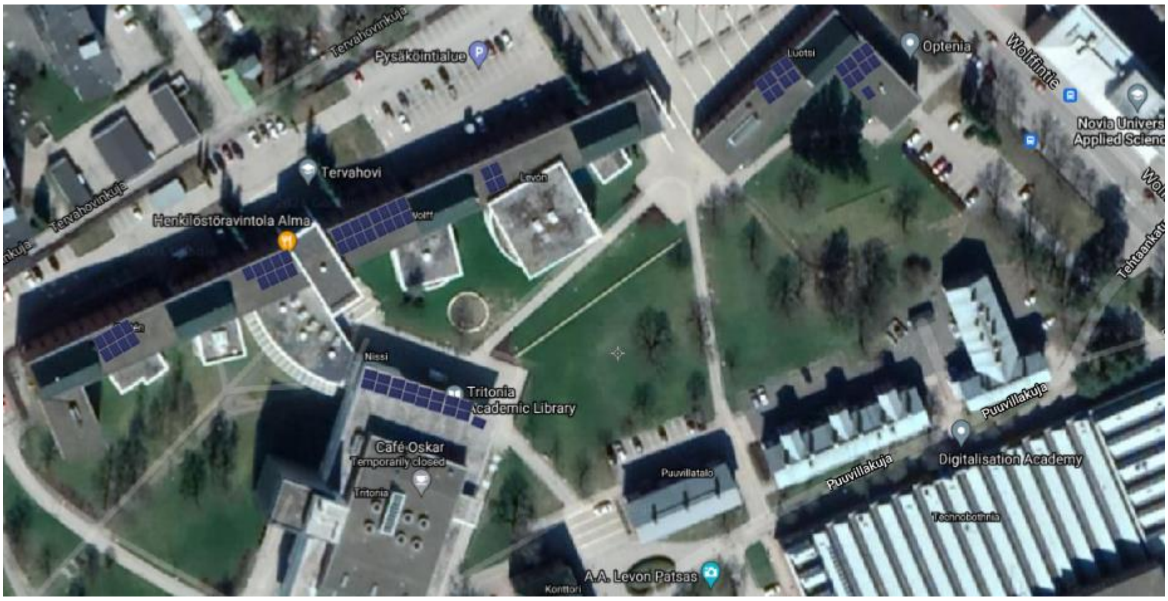

Figure 6: Proposed rooftop PV system with 3 PV arrays of 17 PV panels on three buildings

Peak power produced by a single PV module in winter is forecasted to be 7 Watt. If a PV system is designed based on this data, negligible amount of power is produced. Array peak power of a single building would be 7 watt x 17 PV module = 119 W. Considering the derating of array as 0.77 and daily sunshine hour of 3.5 hours (based on forecasted data), total dc power output of PV array would be 119 watt x 0.77 x 3.5 = 320.71 watt.

However, if we design our PV system based on May forecasted data, an average peak power of 132 watt is produced by a PV module. An array of consisting of 17 PV module will produce peak power of 17 PV x 132 watt = 2.244 kW. With 0.77 derating of array and 9 hours of sunshine, total dc power output of a single PV array would be 2.24kW x 0.77 x 9hours = 15.52 kWh of energy. Hence, a total of 3 PV arrays on rooftop of three buildings of University of Vaasa will produce 15.52 kWh x 3 = 46.56 kWh of energy.

Based on these calculation of power generated by a PV system, energy storage can be adopted. From calculations it can be seen that a PV system produces negligible amount of power in winters, integrating battery energy storage system with PV system in University of Vaasa will have no impact in winters as no significant power is produced by PV arrays in winters.

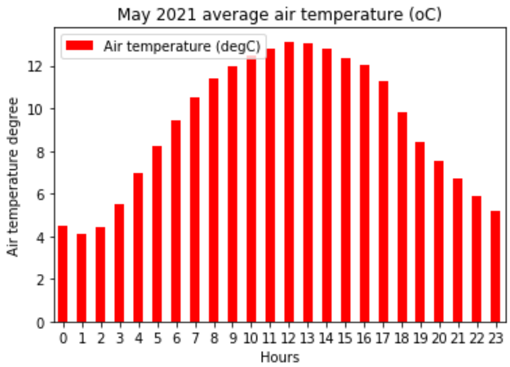

Figure 7: May 2021 average air temperature (^{o}C)

PV thermal system can be heated with air temperature up to an average peak of 12 ^{o}C based on May 2021 weather data. If we integrate ground heat exchanger with PVT system, during summer electricity can be consumed within the university premises and heat generated by a photovoltaic thermal can be stored in ground heat exchanger which can be used for heating university buildings in winters, thus making it a better energy storage solution.

5 Conclusion

In conclusion, a study is conducted to decarbonize the University of Vaasa campus by adopting rooftop PV system integrated with energy storage system. To evaluate the feasibility of such PV system and adoption of suitable energy storage at University of Vaasa, machine learning technique is used to forecast power generation of a PV module. With the help of 91.2% accurate gradient boosting regressor model, January and May 2021 PV power generation data is forecasted.

A design of a PV system is proposed in the study based on the forecasted PV module power generation. It was observed that during winter PV power generation is very low and PV array will produce peak power of 320.71 watt. However, in summers PV array can approximately produce peak power of 15.52 kWh. Based on these power outputs it is suggested that PV system integration with battery energy storage will be functional only in summer and is not considered to be an optimal solution for University campus decarbonization. Whereas, PV system with heat pump and ground heat exchange integration can be effective solution in summers as well as in winters.

However, the forecasted powers can be considered as approximate values as datasets used for training the model and predicting the values were not actual data of Vaasa city. For more accurate PV system design actual measure data of PV module and weather data in Vaasa can improve the accuracy of forecasting machine learning models which can help in adopting optimial energy storage system integration. Similarly using other accurate machine learning models such as teaching learning based optimization (TLBO) technique can also produce highly accurate and realistic results (Raj Kumar Sahu, 2021) .

Adopting PV system with optimal energy storage system at University of Vaasa will reduce energy imports from grid’s non-renewable energy. Self-sufficient university campus will reduce the cost of energy consumption by cleaner heating solution, reduce carbon emission and play a vital role in sustainable and low-carbon energy community. Hence, resulting in more cleaner and greener environment.

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7 Appendices (separately attached)

7.1 Appendix 1. Pv module data.csv

7.2 Appendix 2. January vasaa data.csv

7.3 Appendix 3. May vaasa data.csv

7.4 Appendix 4. Jupyter Notebook seasonal energy GBR model.ipynb