Performance Assessment of Hetero-Junction Intrinsic Thin Film (HIT) Photovoltaic Module by Machine Learning Methods

B.E. Project Report-A

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Certificate

This is to certify that, the project report-A titled
"Performance Assessment of Hetero-Junction Intrinsic Thin Film (HIT) Photovoltaic Module by Machine Learning Methods"
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and is submitted in the partial fulfilment of the requirement for the degree of

Bachelor of Engineering
(Electronics Engineering)
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Abstract

A hetero-junction intrinsic thin film is a solar cell made up of ultra-thin amorphous silicon and high-quality mono-crystalline silicon. It has a pyramid surface on its front which increases the absorption of sunlight. The performance of hetero-junction intrinsic thin-film photovoltaic module using real I–V (current-voltage) characteristics is affected strongly by the operating environment. Solar irradiance is very much affected by changes in the environment. Clouds also have a large impact on the solar irradiance received by a PV cell. In this project, we will be investigating the effects of sudden fluctuating of the environmental conditions on power output and model temperature of a HIT (Heterojunction with Intrinsic Thin layer) module while considering in-plane irradiance, ambient temperature, and the module efficiency parameters using the Random Forest Regression machine learning algorithm. Results obtained from the algorithm will be analyzed to achieve a better understanding of the performance changes and the behaviour of the power output and model temperature, under random effects caused by different environmental conditions. The suggested algorithm is not limited to a specified module technology and region.

Keywords:
HIT Film, Photo-voltaic cells, Solar irradiance, Random Forest Regression, Environment

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Chapter 1

Introduction

A photovoltaic (PV) cell, also known as a solar cell, is an electronic component that generates electricity when exposed to photons, or particles of light. This conversion is called the photovoltaic effect, which was discovered in 1839 by French physicist Edmond Becquerel. It was not until the 1960s that photovoltaic cells found their first practical application in satellite technology. Solar panels, which are made up of PV cell modules, began arriving on rooftops at the end of the 1980s. Photovoltaic capacity has been growing steadily since the start of the 21st century, led by the construction of huge solar farms.

A photovoltaic cell is comprised of many layers of materials, each with a specific purpose. The most important layer of a photovoltaic cell is the specially treated semiconductor layer. It is comprised of two distinct layers (p-type and n-type) and is what converts the Sun's energy into useful electricity through a process called the photovoltaic effect. On either side of the semiconductor is a layer of conducting material which "collects" the electricity produced. Note that the backside or shaded side of the cell can afford to be completely covered in the conductor, whereas the front or illuminated side must use the conductors sparingly to avoid blocking too much of the Sun's radiation from reaching the semiconductor. The final layer which is applied only to the illuminated side of the cell is the anti-reflection coating. Since all semiconductors are naturally reflective, reflection loss can be significant. The solution is to use one or several layers of an anti-reflection coating to reduce the amount of solar radiation that is reflected off the surface of the cell. Solar cells can be arranged into large groupings called arrays. Solar cells in much smaller configurations, commonly referred to as solar cell panels or simply solar panels, have been installed by homeowners on their rooftops to replace or augment their conventional electric supply.

Solar photovoltaic (PV) module temperature has a strong impact on the module efficiency, which affects the energy yield of the entire PV system. The increase in module temperature not only decreases the output power of the PV module but also accelerates its degradation process. As the module temperature increases, there is a marginal increase in short circuit current; however, the open-circuit voltage of the module decreases significantly, which ultimately reduces the output power of the module.

The wind is one of the important variables influencing environmental parameters that also affect the temperature of the module, whose effect ultimately gets translated into the performance of the PV module. It plays a vital role in reducing the temperature of the PV module, which enhances its performance. The magnitude of temperature reduction due to air circulation around the PV module depends not only on the wind speed but also on wind direction concerning the orientation of the PV module. These models were formulated by considering the relationship between module temperature with some meteorological parameters, such as in-plane irradiance, ambient temperature, wind speed, and wind direction.

Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity, which can be done with or without using independent MPPTs (maximum power point trackers) or, specific to each module, with or without module-level power electronic (MLPE) units such as microinverters or DC-DC optimizers. Shunt diodes can reduce shadowing power loss in arrays with series/parallel connected cells.

Chapter 2

Literature Survey

Photo-voltaic modules are being used widely used in today's world. They are of many types. One of them is Hetero-Junction Intrinsic Thin Film module. They are the most advanced and efficient form of photo-voltaic module available in the market. However, they are still affected by the environmental conditions they are working in. Environmental factors like wind speed, sunlight, weather, etc. affect the performance of the module. Wind flow around the module affects its temperature significantly, which ultimately influences the module output power. In the previous works like "Wind Effect Modeling and Analysis for Estimation of Photovoltaic Module Temperature" done by Dr Dhiraj Magare along with other researchers, the prediction of the module temperature and maximum power output was done using the linear regression method of machine learning. However, since machine learning has evolved vastly in the past years, researchers are constantly finding new methods to make the prediction more accurate. They are also constantly looking for ways in which the module can deliver more power efficiently.

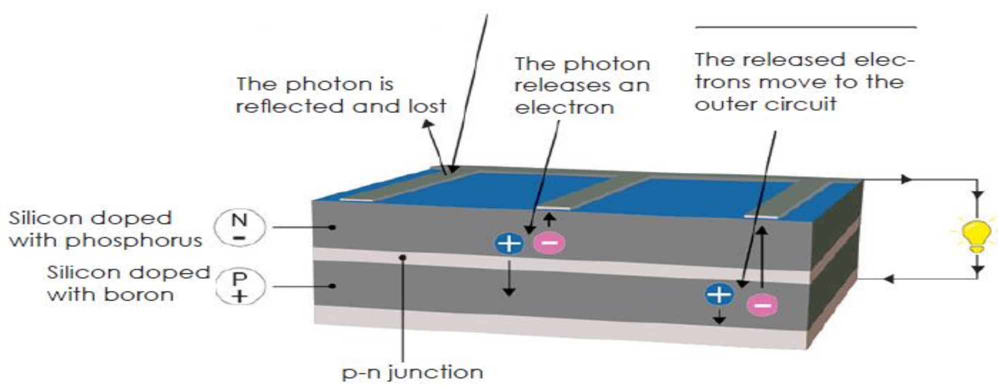
Chapter 3

Working of Photovoltaic Cell

A photovoltaic cell is made of semiconductor materials that absorb the photons emitted by the sun and generate a flow of electrons. Photons are elementary particles that carry solar radiation at a speed of 300,000 kilometres per second. In the 1920s, Albert Einstein referred to them as "grains of light". When the photons strike a semiconductor material like silicon, they release the electrons from its atoms, leaving behind a vacant space. The stray electrons move around randomly looking for another "hole" to fill.

To produce an electric current, however, the electrons need to flow in the same direction. This is achieved using two types of silicon. The silicon layer that is exposed to the sun is doped with atoms of phosphorus, which has one more electron than silicon, while the other side is doped with atoms of boron, which has one less electron. The resulting sandwich works much like a battery: the layer that has surplus electrons becomes the negative terminal (n) and the side that has a deficit of electrons becomes the positive terminal (p). An electric field is created at the junction between the two layers.

When the electrons are excited by the photons, they are swept to the n-side by an electric field, while the holes drift to the p-side. The electrons and holes are directed to the electrical contacts applied to both sides before flowing to the external circuit in the form of electrical energy. This produces direct current. An anti-reflective coating is added to the top of the cell to minimize photon loss due to surface reflection.



Photovoltaic Cell Efficiency

Since most of the energy in sunlight and artificial light is in the visible range of electromagnetic radiation, a solar cell absorber should be efficient in absorbing radiation at those wavelengths. Efficiency is the ratio of electrical power produced by the cell to the amount of sunlight it receives. To measure efficiency, the cells are combined into modules, which are in turn assembled into arrays. The resulting panels are then placed in front of a solar simulator that mimics ideal sunlight conditions: 1,000 watts (W) of light per cubic meter at an ambient temperature of 25°C. The electrical power produced by the system, or peak power, is a percentage of the incoming solar energy. If a panel measuring one square meter generates 200 W of electrical power, it has an efficiency of 20%. The maximum theoretical efficiency of a PV cell is around 33%. This is referred to as the Shockley-Queisser limit.

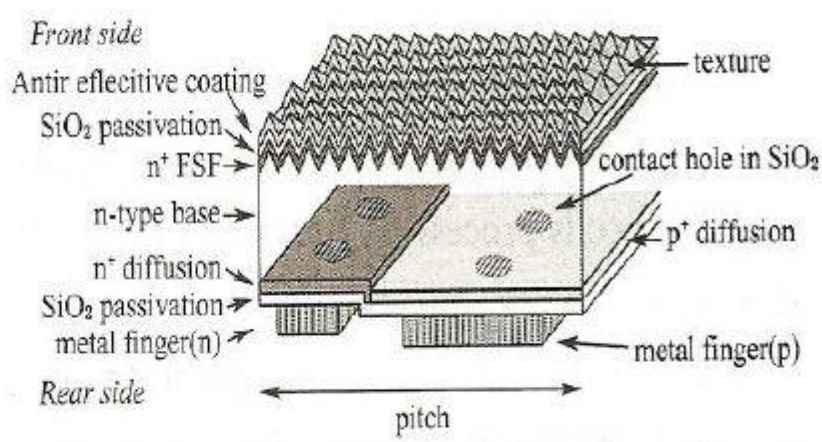
In real life, the amount of electricity produced by a cell, known as its output, is based on its efficiency, the average annual sunshine of the surrounding area and the type of installation. Incident solar radiation varies significantly, measuring 1 megawatt-hour per square meter per year (MWh/sq.m/y) in the Paris area versus roughly 1.7 MWh/sq.m/y in southern France and nearly 3 MWh/sq.m/y in the Sahara Desert. This means that a solar panel with a 15% efficiency rating will generate 150 kWh/sq.m/y in Paris and 450 kWh/sq.m/y in the Sahara.

Chapter 4

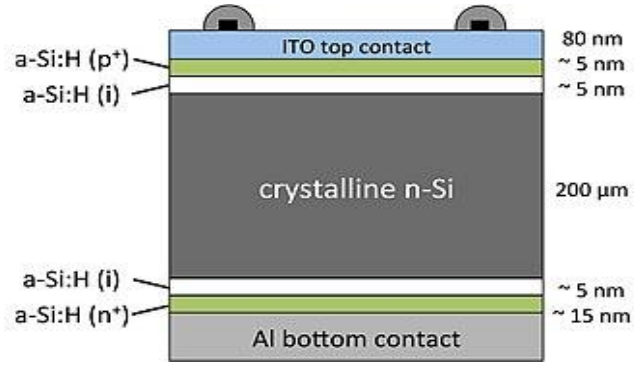
Structure and Fabrication of HIT

HIT is the abbreviation of Heterojunction with Intrinsic Thin-layer, which means intrinsic thin-film heterojunction. Since HIT has been applied for a registered trademark by Japan's Sanyo Corporation, it is also called HJT or SHJ (Silicon Heterojunction solar cell).

Heterojunction solar panels are composed of three layers of photovoltaic material. HJT cells combine two different technologies into one: crystalline silicon and amorphous “thin-film” silicon. The top layer of amorphous silicon catches sunlight before it hits the crystalline layer, as well as the light that reflects off the below layers. However, monocrystalline silicon, the middle layer, is responsible for turning most of the sunlight into electricity. Lastly, behind the crystalline silicon is another amorphous thin-film silicon layer. This final layer captures the remaining photons that surpass the first two layers. Using these technologies together allows more energy to be harvested as opposed to using them individually, reaching efficiencies of 25% or higher. The figure below shows the basic structure of a HIT solar cell, which is characterized by a pi-type a-Si: H film (film thickness 5-10 nm) on the light irradiation side and an n-type a-Si: H film (film thickness 5- l0nm) sandwiching a crystalline silicon wafer, forming transparent electrodes and collector electrodes on the top layers on both sides to form a HIT solar cell with an asymmetrical structure.



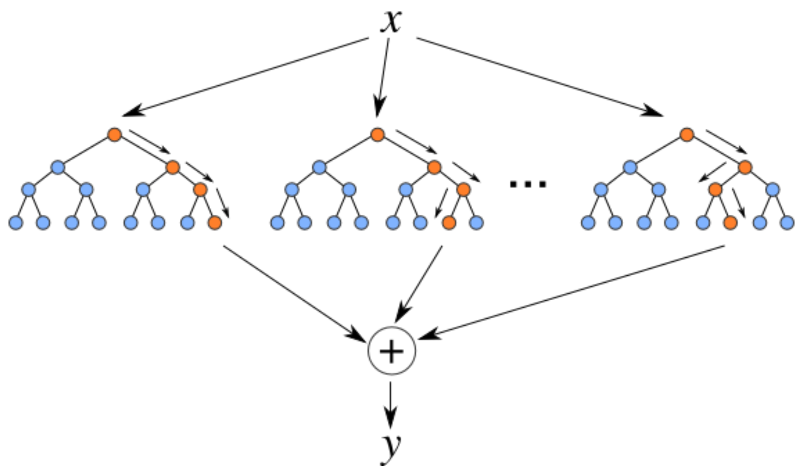
HJT combines the best qualities of crystalline silicon with those from amorphous silicon thin-film to produce a high-power hybrid cell that surpasses the performance of the industry's go-to technology, PERC. Because the HJT manufacturing process requires four fewer steps than PERC technology, there is potential for significant cost savings. While PERC has been a popular option in the industry for many years, its complex manufacturing process cannot compete with HJT. In addition, PERC does not offer HJT's high-temperature performance benefit.



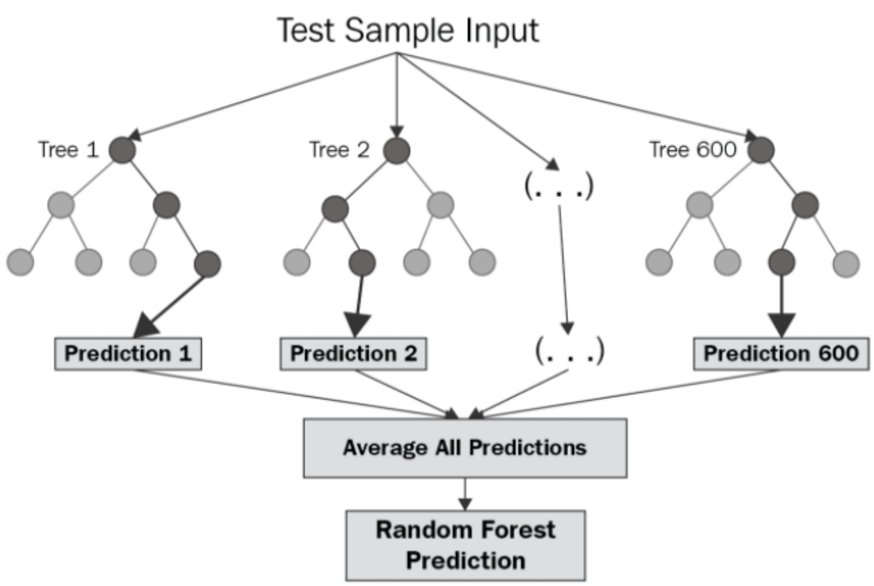
Fabrication of HIT cells

The details of the fabrication sequence vary from group to group. Typically, good quality, CZ/FZ grown c-Si wafers are used as the absorber layer of HIT cells. Using alkaline etchants, such as NaOH or $(CH_3)_4NOH$ the (100) surface of the wafer is textured to form the pyramids of 5-10µm height. Next, the wafer is cleaned using peroxide and HF solutions. This is followed by deposition of the intrinsic a-Si passivation layer, typically through PECVD or Hot-wire CVD. The silane (SiH4) gas diluted with H_2 is used as a precursor. The deposition temperature and pressure are maintained at 200^o C and 0.1-1 Torr. Precise control over this step is essential to avoid the formation of defective epitaxial Si. Cycles of deposition and annealing and H_2 plasma treatment are shown to have provided excellent surface passivation. Diborane or Trimethyl boron gas mixed with SiH_4 is used to deposit p-type a-Si layer, while, Phosphine gas mixed with SiH_4 is used to deposit n-type a-Si layer. Direct deposition of doped a-Si layers on the c-Si wafer is shown to have very poor passivation properties. This is most likely due to dopant induced defect generation in a-Si layers. Sputtered Indium Tin Oxide (ITO) is commonly used as a transparent conductive oxide (TCO) layer on top of the front and back a-Si layer in bi-facial design, as a-Si has high lateral resistance. It is generally deposited on the backside as well fully metallized cell to avoid diffusion of back metal and for impedance matching for the reflected light. The silver/aluminium grid of 50-100µm thick is deposited through stencil printing for the front contact and back contact for bi-facial design.

Chapter 5
Random Forest Regression



Random Forest Regression is a supervised learning algorithm that uses the ensemble learning method for regression. The ensemble learning method is a technique that combines predictions from multiple machine learning algorithms to make a more accurate prediction than a single model.



The diagram above shows the structure of a Random Forest. You can notice that the trees run in parallel with no interaction amongst them. A Random Forest operates by constructing several decision trees during training time and outputting the mean of the classes as the prediction of all the trees. To get a better understanding of the Random Forest algorithm, let's walk through the steps:

- Pick at random k data points from the training set.
- Build a decision tree associated with these k data points.
- Choose the number N of trees you want to build and repeat steps 1 and 2.
- For a new data point, make each one of your N-tree trees predict the value of y for the data point in question and assign the new data point to the average across all the predicted y values.

A Random Forest Regression model is powerful and accurate. It usually performs great on many problems, including features with non-linear relationships. Disadvantages include there is no interpretability, overfitting may easily occur, we must choose the number of trees to include in the model. The ensemble of decision trees has high accuracy because it uses randomness on two levels:

- The algorithm randomly selects a subset of features, which can be used as candidates at each split. This prevents the multitude of decision trees from relying on the same set of features, which automatically solves Problem 2 above and decorrelates individual trees.
- Each tree draws a random sample of data from the training dataset when generating its splits. This introduces a further element of randomness, which prevents the individual trees from overfitting the data. Since they cannot see all the data, they cannot overfit it.

Problem with Random Forest Regression:

When using a Random Forest Regressor, the predicted values are never outside the training set values for the target variable. The Random Forest Regressor is unable to discover trends that would enable it in extrapolating values that fall outside the training set. When faced with such a scenario, the regressor assumes that the prediction will fall close to the maximum value in the training set.

The solution is to build a deep learning model because neural nets can extrapolate or combine predictors using stacking.

Chapter 6

Conclusion and Progress

In Conclusion, we are using the Random Forest Regression method of machine learning to predict the maximum output power and the module temperature under the parameters by which the predictions can vary.

We have successfully managed to find the relations for module temperature and are yet to start training the data. We are still working on the relations for maximum power output.

Bibliography

[1] Dhiraj Magare, Oruganti Sastry, Rajesh Gupta, Birinchi Bora, Yogesh Singh and Humaid Mohammed, “Wind Effect Modeling and Analysis for Estimation of Photovoltaic Module Temperature”
[2] E. Skoplaki and J.A. Palyvos, “On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations”
[3] E. Skoplaki and J.A. Palyvos, “Operating temperature of photovoltaic modules: A survey of pertinent correlations”
[4] https://levelup.gitconnected.com/random-forest-regression-209c0f354c84
[5] https://neptune.ai/blog/random-forest-regression-when-does-it-fail-and-why
[6] https://www.planete-energies.com/en/medias/close/how-does-photovoltaic-cell-work#:~:text=A%20photovoltaic%20(PV)%20cell%2C,photons%2C%20or%20particles%20of%20light.
[7] https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics
[8] https://en.wikipedia.org/wiki/Crystalline_silicon
[9] https://m.solar-junction-box.com/new_detail/id/33860

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