Short Term Forecasting of Photovoltaic Module Using Machine learning

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A thesis submitted to the Department of Electrical and Electronic Engineering in partial
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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract

The objective of this study is to analysis and observe the performance of the photovoltaic (PV) modules in different environmental conditions by applying machine learning algorithm . There were two PV Modules , one is cleaned and other one is dusty . Real-time data from each sensor is effectively collected from November 2019 to February 2020, and prediction has been done on 2 different days from march month of 2020 from the weather station situated in Gabtoli. In this study short term performance analysis has been done with different error calculation. Result shows that, the performance depends on the volume of training dataset. In this study two artificial neural network models has been used to train and test the data of PV module output and assess the short term performance.

Keywords: Short Circuit Current; Temperature; Wind Speed; Humidity; Solar Irradiance;

Dedication

This thesis is dedicated to our beloved parents who raised us to be the persons we are today, who were always there for us whenever we needed them, and who constantly support us with their love and kindness.

Acknowledgment

All thanks to Almighty Allah, who made it possible for us to complete our thesis work in time without any significant obstacle. We want to thank and show our heartiest gratitude to our honorable supervisor Dr. Md. Mosaddequr Rahman Professor of Brac University, for his incomparable guidelines, as well as his continuous support and motivation throughout the thesis work. We are immensely grateful for his dedicated involvement at every step, professionalism and precious guidelines which paved the pathway to the completion of this thesis work.

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List of Acronyms

SP	Solar Panel
ANN	Artificial Neural Network
I_{SC}	Short Circuit Current
PV	Photo voltaic

Chapter 1

Introduction

1.1 Introduction

The sun provides more than enough energy to meet the whole world's energy needs, and unlike fossil fuels, it won't run out anytime soon. As a renewable energy source, the only limitation of solar power is our ability to turn it into electricity in an efficient and cost-effective way. At the point when one utilizes solar energy, no ozone depleting substance outflows are discharged into the air. The solar resource is enormous. According to the US Department of Energy, the amount of sunlight that strikes the earth's surface in an hour and a half is enough to handle the entire world's energy consumption for a full year. Just 18 days of sunshine on Earth contains the same amount of energy as is stored in all of the planet's reserves of coal, oil, and natural gas. And, once a system is in place to harness the solar resource and convert it into useful energy, the fuel is free. As an inexhaustible CO2 free power source, the ecological effect of solar energy is significantly lesser than other available power generation techniques. The effect is predominantly identified with the production and supply of the exceptional materials and metals that are required to deliver solar panels. Nowadays renewables, specifically wind and photovoltaic, are cheaper than conventional energies in much of the world. The main renewable technologies – such as wind and solar photovoltaic – are drastically reducing their costs, such that they are fully competitive with conventional sources in a growing number of locations. Economies of scale and innovation are already resulting in renewable energies becoming the most sustainable solution, not only environmentally but also economically, for powering the world. Bangladesh has one of the world's largest domestic solar energy programs. The World Bank and other development organizations, along with the private sector, are working with the government to bring affordable, solar-powered electricity to places where the traditional grid doesn't reach. Small-scale solar home systems now provide electricity to more than 4 million households and about 20 million people in rural areas, roughly one-eighth of the country's population. The program has also introduced 1,000 solar irrigation pumps and 13 solar mini-grids. From the National Solar Energy Roadmap 2021-2041 (draft) there is explained the current of solar energy development and plans. The government has taken many initiatives to use this energy efficiently.

At present, 90% individuals of Bangladesh have access to electricity with per capita energy generation at around 464kwh. Around 62 off-network rooftop solar projects with a generation capacity of 14.36 MW and 50 on-grid projects with a generation capacity of 26.45 MW have been finished and run by public and private sectors till October 2019. In Bangladesh, the leading export sector is RMG which expects to reach $50bn in trades by 2021. To meet the increasing energy demand in Bangladesh, the Government has just propelled "500 MW Solar Power Mission" to promote the administration's Power System Master Plan (PSMP), Bangladesh can produce 635 MW (17.3%) from the solar rooftop, and the annual generation will be 860GWh which will decrease around 576,200 tons of CO2 emission. The generation of photovoltaic panels is sensitive to certain meteorological parameters such as wind speed, humidity, temperature, raindrops, solar radiation, etc. Linear regression machine learning algorithm for forecasting data that has been collected from two MonoSilicon PV modules to find a more accurate one-day forecast that can be very important for both commercial and non-commercial users as PV array generation is still uncertain. So, in this article, we tested forecast data over the course of a day by examining data from an entire month using a machine learning algorithm that takes into account several weather parameters**.**

1.2 Literature Review

Solar energy systems/power plants do not produce air pollution or greenhouse gases. Using solar energy can have a positive, indirect effect on the environment when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment. Burning fossil fuels increases the presence of greenhouse gases like carbon dioxide and methane in the atmosphere, contributing to the greenhouse effect that is heating our planet faster than ever. As a result, rising global temperatures cause glaciers to melt, sea levels to rise, which in turn causes a number of disasters such as tornadoes, frequent floods, extreme heat and drought. On the other hand, generating electricity from solar panels does not produce greenhouse gases and thus helps to slow climate change. The photovoltaic process that transforms sunlight into electricity doesn’t require any fuel and has no variable costs. Moreover, numerous researchers and students are working with greater enthusiasm due to the increasing demand for energy and the reliability of solar energy. In that case different kinds of research and projects are running to develop this field. Researchers are doing thesis on this to get better idea on solar energy use. In several renowned conferences and journals papers many books and thesis papers has been published. The future of this solar, the design, different theoretical results based on research and projects, practical investigations enriching this solar energy field day by day.

Solar PV power is safe and dependable; it produces no noise or pollution, is less limited, has a low failure rate, and requires no maintenance.

It is critical in addressing the escalating energy crises and environmental pollution.

Since the energy crisis of the 1970s, every country in the world has focused more on the development of PV power generation, with the United States' Million Solar Roofs Initiative, Japan's Sunshine Program, Germany's Million Solar Roofs Program, and China's Bright Project for Western Provinces Without Electricity serving as examples of PV power technology development.[1]

As the price of fossil fuels fluctuates, renewable energy is fast gaining relevance as a source of energy. It is consequently vital for engineering and technology students to grasp and appreciate the technologies related with renewable energy at the educational level. Solar energy is one of the most widely used renewable energy sources. The most abundant source of energy is solar energy. It is available both directly and indirectly as solar insolation and wind energy.

The sun emits electromagnetic radiation, which is a source of energy. It has a potential of 178 billion megawatts (MW), which is over 20,000 times the global demand. Some solar energy causes water to evaporate, resulting in rainfall and the formation of rivers, among other things. Some of it is used in photosynthesis, which is necessary for life on Earth to exist. Man has attempted to harness this endless source of energy since the dawn of time. However, until now, only a tiny percentage of this energy has been tapped.[2]

A solar power plant simulation model with a dual-axis tracking mechanism has been developed.

The time of day has an effect on the amount of electricity generated by statically and dynamically positioned solar cell modules. The efficiency of using solar tracking systems has been demonstrated by the writers. The gain in energy efficiency of the solar installation from the implementation of a dual-axis tracking system was estimated to be 33.37 percent using simulations in MATLAB / Simulink. The designer (researcher) can predict the possible power generation of the developed solar power station using this model, which allows him to have more objective information for the analysis of economic efficiency, based on available meteorological data in a short time without financial investments.[3]

The Orenburg region has ideal circumstances for the development of solar energy, with 2200 hours of sunshine each year (about 92 days) .In the period 2015-2019, eight solar power stations (SPS) were constructed and placed into service in the region. Solar panels that are set at a certain angle of inclination and are pointed to the south are known as stationary solar panels

(SP).The angle of inclination of the SP in the Orenburg region is commonly believed to be 51° in the winter and -41° in the summer. A two-coordinate solar tracker is being developed at Orenburg State University (OSU) for the solar module (400 W), which follows the sun along the X and Y coordinates based on data analysis from two pairs of LDR sensors. A fixed solar module of equivalent capacity has been commissioned to assess the effectiveness of the solar tracker. According to statistics from the HSS and IMC, using solar tracking devices for SPS in the Orenburg region results in a large increase in power generation, especially in the winter.

The solar tracker with multiple axes has enhanced power generation by 36.3 percent (in clear weather).[4]

Despite the fact that Bangladesh has a variety of renewable energy sources, due to its geographical position, solar energy is the most viable alternative.

Throughout the year, the average daily solar radiation fluctuates from 4-6.5 kWh/m2 with a pleasant sunny hour. On the solar panels at the Institute of Energy, University of Dhaka, Dhaka-1000 (90°33' E longitude and 23°77' N latitude), this experiment and data collecting were carried out. For the scurrility, two sets of panels were chosen, one mono-crystalline and the other polycrystalline. The arrays are oriented in a southerly direction with a set latitude tilt angle. The efficiency reduction for monocrystalline couple (M1and M2) and polycrystalline couple (M3 and M4) panels are27.17% and 20% respectively on 6th March, 2020.Because of the rain on February 14, 2020, both clean and dirty panels' efficiency and performance ratios have become comparable. By the end of February 2020, the performance ratios of dusty panels had plummeted. After the experiment, it was discovered that efficiency decreases as the amount of dust on the surface of PV solar panels increases, and that efficiency decreases as the temperature rises. When the temperature of PV solar panels climbs beyond 40°C, the efficiency of the panels decreases dramatically. Solar photovoltaic panel cleaning has become a serious concern in Dhaka due to the city's high pollution levels.[5]

Dust on photovoltaic modules affects their efficiency by lowering their transmittance, which reduces the amount of effective solar insolation reaching them. According to studies, the tilt angle of the solar collector, exposure length, site climate conditions, wind movement, and dust qualities all affect dust or minute particles. Soiling can result in a large amount of loss, since it can limit transmittance by up to 40%. In high-dust-density areas, a daily cleaning cycle is advised. Low-latitude areas, even if they have a modest dust density, should have a daily cleaning cycle since their tilt angle is lower, resulting in more dust deposition. In mid-latitude regions, the tilt angle will be mild, resulting in decreased dust accumulation rates, requiring only weekly cleaning. Dust will not be a major issue in high latitude regions because panels will be close to vertical, but snow will be a major issue that must be addressed promptly.[6]

Dust storms have a direct impact on solar radiation and, as a result, solar energy plant performance. The influence of dust storms on PV energy systems varies greatly depending on how far a given location is from the region's active dust sources. On two PV testing locations, two cases of 48-hour-old dust cloud impacts were investigated. When compared to the day before the dust hit, the results revealed a wide range of variability, with the power output changing from +14.4 percent to 37 percent.[7]

For all solar energy uses, accurate predictions of global sun radiation are critical. A variety of solar radiation models are used to estimate solar radiation. This paper examines a number of papers that use ANN models in depth. The ANN model is found to have good prediction accuracy, with correlation coefficients ranging from 0.97 to 0.99.The extensive study concludes that studies utilizing the ANN model produce better results than papers using standard regression methods, and that these methods have numerous advantages over traditional approaches.[8]

A strategy has been designed to make the most of solar energy, and a Simulink model has been created following training. The maximum power is predicted using advanced artificial neural network technology that takes into account the variance in sun irradiance and temperature input levels. When the aim was zero, the performance of an artificial neural network was 9.251210.

The proposed approach is used to track the greatest powerpoint of a solar panel in 2.

The method was used to a 40 Watt PV panel, and the network calculated that the maximum power at varying irradiances and temperatures of 300C was roughly 39.62 Watt. Tracking time is less than the conventional methods and there are no perturbations and small oscillations. [9]

Solar energy production is influenced by a variety of environmental factors such as sun position, weather, and PV panel characteristics, among others, but on a gloomy day, cloud movement becomes the most important component in solar energy production. This paper employs many deep convolutional neural networks to explore various temporal and capturing the cloud movement pattern and its effect on solar energy generation using weather forecast data.

In a persistent model, the error rate was 21%, and using the SVR model, it was 15.1 percent, but utilizing convolutional neural networks, the error rate was 11.8 percent.[10]

A thesis group from BRAC University's Department of Electrical and Electronic Engineering evaluated both the dual and single-axis sun tracking systems to determine which would be most useful. The results demonstrate that there are no significant differences between dual and single-axis sun tracking systems, with differences of 3.96 percent and 3.44 percent with a variance of 0.52 percent between dual and single axis with and without the cloud effect.

1.3 Scope of the work:

Solar energy field is now a vast area for research. New methods, technologies need to be used here for our better future. Here we are using ANN method for our research and got results on how solar radiation, solar energy need gets affected and its impacts. Based on this work our next step can be how we can store this energy without any loss and how we can amplify this energy. And also, we will work to prevent the facts that cause the loss of this energy. Overall, this renewable, endless and environment friendly energy is our big target to consume the full energy we get everyday. [11]

"Design of a Solar Powered LED Street Light: Effect of Panel's Mounting Angle and Traffic Sensing" was presented in the 2013 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology. This paper discusses the cumulative energy outputs of panels Wh/m2/day varying different seasons for three different mounting angles ($\theta = 0°, 23.1° \& 46.5°$). During the summer period, the solar photovoltaic module delivers the highest energy output exceeding 1000 W/m2 but during winter energy output is low. The solution to this problem resolves through changing the mounting angle of the solar module.[12]

1.4 Aim & Objective

The primary aim of this research is to examine the climate parameters impact on solar modules, conjointly to examine the dust impact on the solar modules output energy. In addition, there is a vision to foresee the yield of solar photovoltaic modules depending on the weather parameters by utilizing the Artificial Neural Network approach. The main objective of this study was to examine the effects of climate parameters on the solar modules, as well as to examine the impact of dust on the energy output of the solar modules. In addition, there is a vision to predict the performance of solar power modules based on meteorological parameters using an artificial neural network approach. Temperature, wind speed, humidity, barometric pressure and solar surface radiation are considered as environmental parameters, where short circuit current is the output parameter of solar modules. Temperature, humidity, wind speed and barometric pressure data are collected using various sensors integrated into a combined system, known as a weather station. On the other hand, the solar module's surface irradiance is measured by theoretical calculation. Real-time data from each sensor is effectively collected from November 2019 to February 2020. The artificial neural network models are trained with data extracted from each sensor and check the expected output based only on the input weather parameters.

1.5 Thesis Organization

The book is organized as follows. Chapter 1 gives a general presentation followed by the foundation and the targets of the work. Chapter 2 shows the theoretical foundation of the following thesis topic. Chapter 3 and chapter 4 presents the description of the software used and graph of experimental and predicted analysis also provides the theoretical analysis for both clean and dusty solar panels over the four months datasets. Chapter 5 shows the prediction analysis of the short circuit current ,,results , error . In the end, Chapter 6 provides the conclusion of the work and offers future research work proposals

Chapter 2

Theoretical Background

The world is almost at the verge of shifting the extraction of energy from non-renewable resources into renewable resources. In light of this venture, solar energy amongst all renewable resources is easily extractable with higher efficiency. The following thesis work is entitled as, "Outdoor Performance Analysis and Prediction of Photovoltaic Modules Using Machine Learning Algorithm", which requires a clear understanding of the theoretical fundamentals of the solar module. So, this chapter is focused on the theoretical overview of the solar panel considering the effect of various weather parameters on the energy output. Initially, the working mechanism of a solar module is discussed briefly along with the explanation of affiliated parameters such as short circuit current (I_{SC}), open circuit voltage (V_{OC}), ideality factor, fill factor, power, energy. These aforementioned parameters are analogous with the solar cell from the IV characteristics curve. Later on, it is described how the expected energy output from a solar module varies radically due to the change of patterns in the weather parameters such as humidity, wind speed, air pressure and temperature. In addition, the vital role of solar irradiance (W/m^2) on the solar module's output power is illustrated.

2.1 Solar Panel

2.1.1 Basic of Solar Panel

Solar energy is a potential option to cope up with present climate problems and dependency on fossil fuels by catching the sunlight and use it as a power source. Sun is the main source of solar energy. Solar panel converts the energy from the sun which is mainly photon into electricity. Solar panel in other word PV device is a semiconductor that convert energy from sunlight to electricity. PV device is combination of many particular solar cells, they are constructed of layers of silicon, phosphorous, boron therefore solar cells are nothing but p-n junctions Silicon and phosphorous provides negative charge and boron provides positive charge. Photon strikes the surface of the PV panel, the electrons of atomic orbit get knocked out by it and released in electric field which is generated by the pv cells by pulling these free electrons in directional current. The whole process is called 'Photovoltaic Effect' like a battery solar cells have two-layer positive layer and a negative layer which create an electric field. At the time when the sunlight hit the solar panel surface, the cells absorb the photon from the sunlight energy so generate electric current. This energy generated from the photons by hitting the surface of the solar panel release the electrons from their atomic orbits which released in the electric field created by the solar cells as a result free electron are pulled out in the directional current.

Table 2.1: Advantages and Disadvantages of the Monocrystalline, Polycrystalline and Thin-film Solar Panel:

Solar panel type	Advantages	Disadvantages
PERC	• Higher efficiency than (5%)Monocrystalline	• Costly
Monocrystalline	• High efficiency , over 20%	• Costly
Polycrystalline	• Low price	• Lower efficiency 15-17%
Thin-film	• Portable and flexible • Low weight	• Lowest efficiency • 2-3%less than crystalline silicon

Among all panel types, crystalline solar panels have the highest efficiency but costly

2.1.2 How Do Solar Panels Work?

Sun is a nuclear reactor. It generates photons, small energy packets. When a solar panel comes into sunlight, photons from sunlight hit a solar cell. Electrons in the atom energized and loose from it. By attaching positive and negative side of the cells of pv device in an electrical circuit, electricity produced by the flow of the electrons through the circuit. For producing electric field, solar cells in a PV device are precisely engineered with positively and negatively charged semiconductors sandwiched together. This electric field makes a path for the drifting electrons and force them to flow in a specific direction towards the conductive metal plates. This flow of electrons hit the metal plate and current channeled into wires, enabling electrons to flow as they would in other source of electric production [9].

2.1.3 Mechanism of Solar Panel

Solar cells are made of semiconductor materials must having a bandgap near to 1.5ev, like silicon. There are likely three types of material in terms of electricity flowing – conductor, insulator and semiconductor. When the correct voltage is applied, a conductor allows an electron to travel easily from one atom to another as there are no band gaps between the valence and conduction bands. Then there are some materials they do not pass electricity through them, called insulator. Plastic is a good example of that material. In the contrary, semiconductor materials shows both behavior of conductor and insulator. They can only allow to pass free electron under specific condition. There is a term named band, where the electrons in atoms are organized. Electricity generated when electrons transfer from the valanced band to the conductor band.

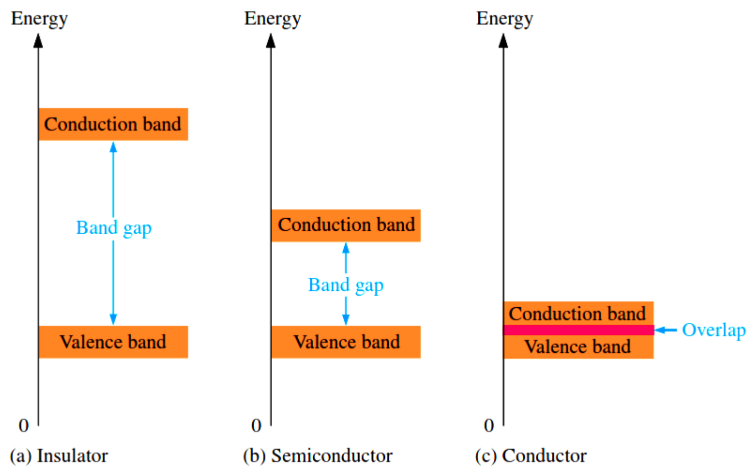

Figure-2.1: Bandgap visualization of Insulators, Semiconductors, and Conductor materials[10]

In the above figure, it is clear that the bandgap of insulator is very high, that's why the electrons can not pass through. In conductor, the bandgap is overlapping, so it is very easy to move electron through conductor. In semiconductor, the band gap is lesser than insulator, greater than the conductor. So, in proper condition, by providing enough energy in this type of material, the band gap can be overcome and valanced electron can move. Solar cells are made of two different kinds of silicon. The band gap of silicon is 1.12ev. [1]

When the sunlight hit the solar panel, deeply the p-n junction the light photons can easily goes through very thin p-type layer. The energy of photons supplies the needed amount of energy to make a number of electron-hole pairs. The incoming light causes the junction's thermal equilibrium to be broken. In the meantime, the depletion region's free electrons swiftly reach the n-type side of the junction. On the other hand, holes remained in the depletion region goes to the p-type side of the junction. Whenever the n-type side holds the free electron, they are not allowed to cross the junction as barrier potential is there. In the same way the newly created holes can not pass the barrier potential of the junction. With the time, the concentration of electrons gets higher in the n-type side and concentration of holes becomes more in p-type side of the junction. At that time, p-n junction acts like a small battery cell. A voltage is established referred as photovoltage. A minor current flowing can be detected across a small load with the junction. [2]

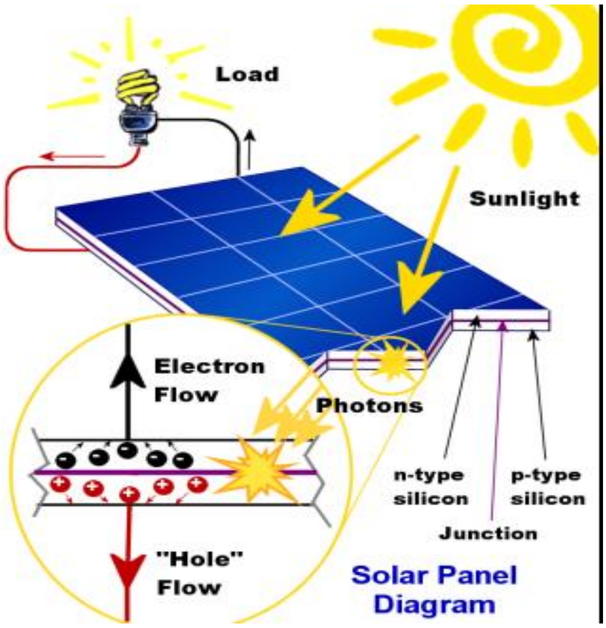

Figure 2.2: Solar Cell Mechanism

2.1.4 Solar Cell Characteristics

Single Diode Model

We are going to explain shortly in three section – single diode model, I-V characteristics and electrical characteristics of PV array. First of all, one diode model is the common among all the available solar cell model. The model made of regulated current source photogenerated IPH, to represent single source Shockley equation – a diode, series of power loss modeling RS and a shunt resistance.

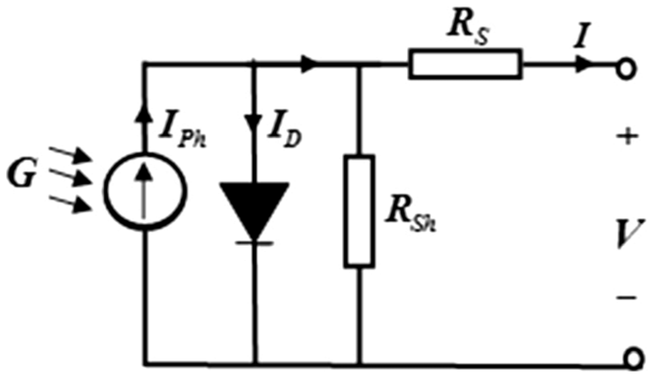

Figure-2.3: Equivalent circuit of five-parameter model of a solar cell [11].

I-V Characteristics

After that, to represent graphically the operation of a PV cell, connection in between of current and voltage I-V characteristic is a must. The provided information from the curve is essential to construct a system for operating in its best electrical outlet.

$$I = I_0[e(qVnKT) - 1] - IL \qquad 2.1$$

Here,
Io = dark saturation current
q = charge
V = applied voltage
n = ideality factor
k = Boltzman’s constant
T = temperature
IL = light generated current

Graphical representation of I-V characteristics curve is given below:

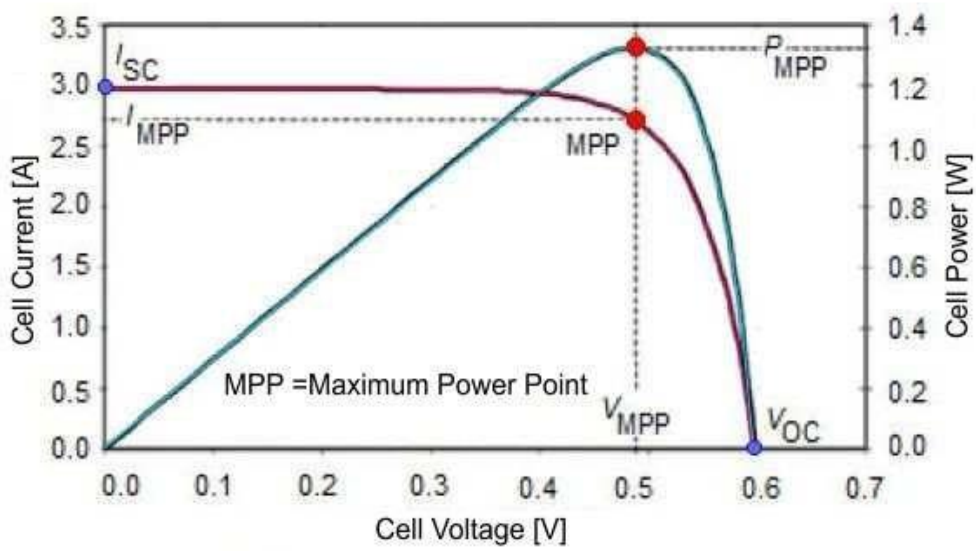

Figure-2.4: IV Characteristics curve of the Solar panel [12]

The rating of the solar cell depends on cell parameters like:

a. **Open Circuit Voltage:** It refers to the maximum output voltage that the array provides when terminals are open, means not connected to any source. Open circuit voltage represented by $V_{OC.}$ Generally, this value depends on the number of PV panel connected in series. [3]

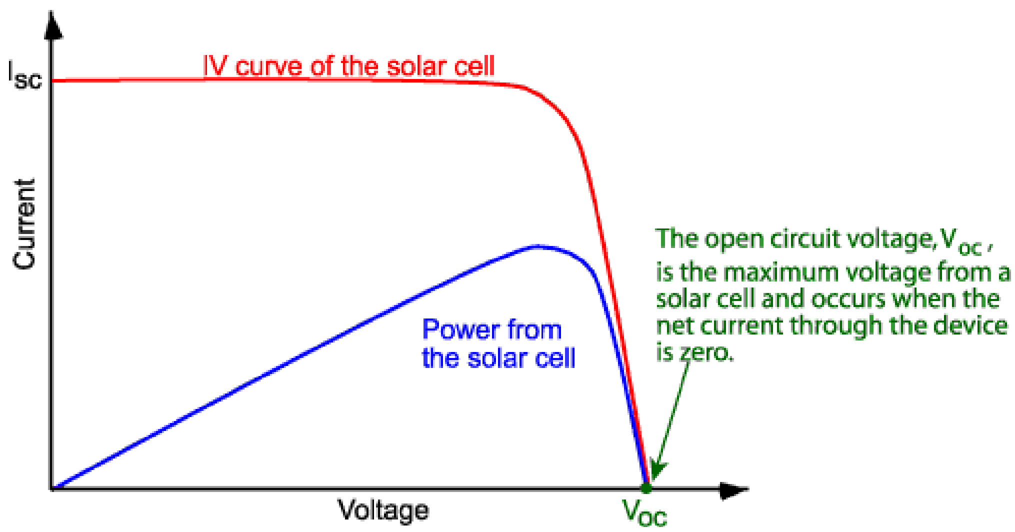

Figure 2.5: IV curve of a solar module showing the open-circuit voltage [26]

$$\text{Voc} = \frac{n*k*T*Ns}{q}\ln\left(\frac{Isc}{Io2}\right) \quad (2.2)$$

Here,

q = charge

k = Boltzmann’s constant

n = ideality factor

Ns = number of cells connected in series in the panel

T = temperature in kelvin

b. **Short Circuit Current:** This is the value of maximum current provided by the solar panel while the output connectors are shorted (short circuit condition) or when the voltage across the solar cell is zero Short circuit current represented by I_{SC}. The value is generally higher than normal operating current. [3]

c. **Fill Factor (FF):** Fill factor stands for the relationship in between the maximum power that the array can provide under normal operating condition and the product of open circuit voltage multiplied by short circuit current ($V_{OC} \times I_{SC}$). This is the basic idea of the quality of the array. Typical value of fill factor is 0.7-0.8. [3]

$$\text{FF} = \frac{Pmp}{(Voc*Ioc)} \quad (2.3)$$

$$Pmp = Vmp * Imp \quad (2.4)$$

Here ,

V_{mp} = maximum voltage and

Imp = maximum current

Voc= open circuit voltage

Ioc – open circuit current

d. **Maximum Power Point:** This refers to the point at which the array's power delivered to the load reaches its maximum value. It is noted by MPP, where

$$MPP = V_{MP} \times I_{MP}. \quad (2.5)$$

e. **Ideality Factor:** Ideality factor is denoted by n and it is one of the diodes I-V characteristics parameters. Therefore, the ideality factor 15 of a diode is a measure of how closely the diode follows the ideal diode equation. For ideal case ideality factor n=1 but in nonideal case, it is more than 1. The equation of the ideality factor is given below

$$n = \frac{(Voc1 - Voc2) * q}{k * T * Ns * \ln\left(\frac{Isc1}{Isc2}\right)} \quad (2.6)$$

Here;

q = charge

k = Boltzmann's constant

Ns = number of cells

V_{oc1} & V_{oc2} = open-circuit voltage

I_{sc1} & I_{sc2} = short circuit current

f. Reverse Saturation Current: It is a measure of the leakage of carriers across the p-n junction . The reverse saturation current denoted as Io. Equation of the reverse saturation current is given below;

$$I_0 = \frac{Isc}{e^\wedge(Voc * \frac{q}{n * k * T * Ns})} \quad (2.7)$$

Here;

q = charge

k = Boltzmann's constant

n = ideality factor

Ns = number of cells

T = temperature in kelvin

I_{sc} = short circuit current

Voc = open circuit voltage

2.2 Weather parameters effects on the performance of PV solar module:

The carbon emission due to produce electricity is increasing unconventionally. It seems the solar energy is the cleaner and reliable energy source for future to reduce the global warming. As the sunlight is the main source of solar energy, the solar panel output is also affected by its surrounding weather. There are many weather-related conditions that can affect the output of a solar cell. Effect of temperature, wind speed, humidity, air pressure affect the solar panel output. We took the data of humidity, air pressure, wind speed, temperature in our forecasting model. In this section, we are giving a short sight about those weather effect.

2.2.1 Effect of Temperature

Irradiance stands for the power density measurement of sunlight which is received at a location at earth. It measured it watt per meter square. In another word, this term irradiance is the measure of energy density from sunlight. Change in solar irradiance and temperature can make a change in the solar panel output. The solar cell efficiency and its corresponding fill factor also gets affected by solar irradiance. Whenever solar isolations get changing throughout the day, the I-V and P-V characteristics also affected by it. With the decreasing solar irradiance, both the open circuit voltage and short circuit current decreases [4]. However, we need to count on some features like azimuth angle, latitude, solar altitude, declination angle to get a the amount of irradiance from the direct sunlight observing by the solar panel as it is important to calculate solar energy.

2.2.2 Solar Altitude

This term refers to the angle between the sun's ray and a horizontal plane. It is measured in degrees. Solar altitude is related to the solar zenith angle. Zenith angle means the angle in between the sun's ray and vertical. The value of solar altitude gets affected by the moment of the day, passing time of the year, altitude on earth. The regions close to equator has greater solar altitude than the regions near earth's pole [5]. Solar altitude can be calculated by the equation below,

$$\alpha = sin-1(sin\delta * sin\varphi + cos\delta * cos\varphi * cos\omega) \qquad (2.8)$$

Here,

Hour of the angle = ω

Declination angle = δ

Latitude angle = φ

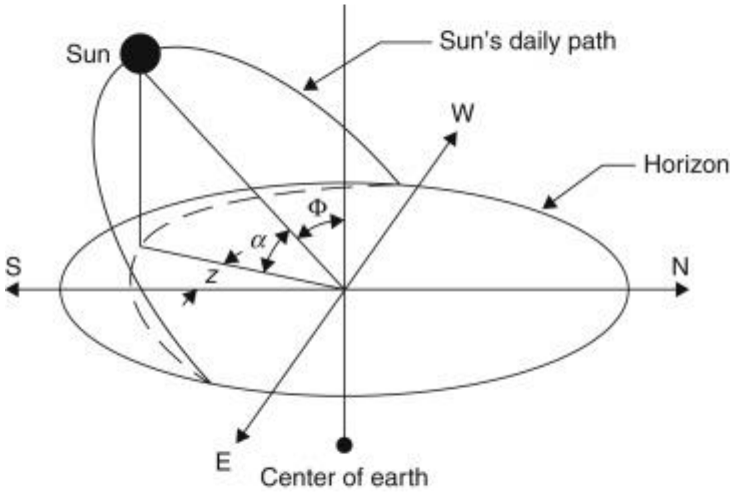

Figure-2.6: Solar Altitude Angle [14].

2.2.3 Zenith Angle

The solar zenith angle is the angle between the sun and it is vertical with the earth. It has similarity with the elevation angle or solar altitude angle. The difference in between them is one is measured vertical perspective and another one horizontal perspective. The equation is given below,

$$\Theta = 900 - \alpha \qquad (2.9)$$

Here,

Solar altitude angle = α

2.2.4 Latitude Angle

It is a geographic coordinate that indicates a specific point whether it is on the north or south of earth's surface. Latitude is the angle ranged from 0^0-90^0, where 0^0 at the equator, 90^0 at the poles [8].

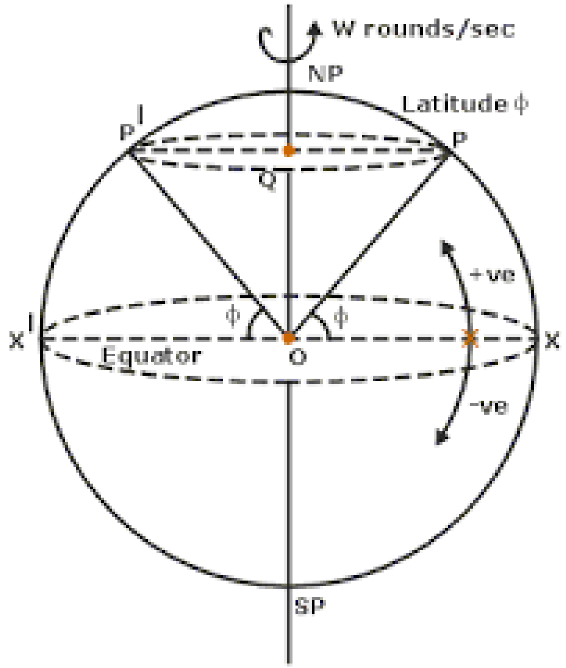

Figure-2.7: Latitude Angle, φ

The hardware setup of this experiment was installed at Gabtoli, Dhaka, Bangladesh. The respective latitude angle is φ =23.777176°.

2.2.5 Sunrise Angle

The sunrise angle is the angle at which the top limb of the sun appears on the horizon in the morning. It is denoted by ω_s, measured in degree. Equation of sunrise angle is,

$$\omega = cos - 1(-tan\varphi \times tan\delta) \quad (3.1)$$

Here,

Declination angle = δ

Latitude angle = φ

2.2.6 Hour Angle

It means a point on earth's surface, it is the expression of time which is expressed in angular measurement from solar noon. The hour angle is 0.000 degree at the solar noon, before the solar noon it is represented by negative degrees and after the solar noon is positive degree with the local time. The expression for hour angle is,

$$\omega = \omega s - 15(t - tsr)$$

Here,

Local apparent time = t

Sunrise time = t_{sr}

So, at 10:30 local apparent time the hour angle is -22.5^{0}.

2.2.7 Sunrise and Sunset time

Sunrise and sunset time can be easily determined by subtract the sunrise time from sunset time, and we get available hours for the sunlight. We can measure the total hour of sunlight available by calculating the sunrise and sunset time. The equations needed to do so is as follows,

$$Sr \ = \ 12 - (\frac{1}{15}) * (cos - 1(-tan\delta * tan\varphi))$$

$$Ss \ = \ 12 + (\frac{1}{15}) * (cos - 1(-tan\delta * tan\varphi))$$

$$t \ = \ Ss - \ Sr$$

Here,

Declination angle = δ

Latitude angle = φ

2.2.8 Air Mass

A vast volume of air in the atmosphere that is largely uniform in temperature and moisture is referred to as an air mass. Air masses may travel thousands of kilometers in any direction and can reach as far as the stratosphere, which is 16 kilometers (10 miles) above the earth's surface. In short, it is a measurement of how much atmosphere the sun's rays must pass through on their route to the earth's surface. The amount of solar energy is less than expected just because the atmosphere absorbs the particle [6]. The equation of the air mass is,

$$AM \ = \ \frac{1}{cos \ \Theta z} \ = \ csc\alpha \ = \ sec\Theta z$$

2.2.9 Solar irradiance calculation

Our experiment is based on two solar modules two fixed position solar panel. Here, firstly we calculated dual-axis solar irradiance. The output result is used to calculate the fixed axis solar module's solar irradiance. The followed equations are given below:

a. For Dual Axis:

$$I = I_0 * (0.7) AM \wedge^{(0.078)}$$

Here,

I_0 = Solar irradiance in the space outside the atmosphere = 1276W/m^2

AM = Air mass

b. For Fixed Axis

$$G = I * \cos\delta * \cos * \Theta z$$

Here,

I = Dual axis solar irradiance

δ = Declination angle

Θ_z = Zenith angle

2.3 Chapter Summary

"Theoretical Background" in this chapter discussed the basic fundamentals of a solar module. Initially, it started with a glimpse of the construction of a solar module and working principle. The weather parameters and their effects are discussed in this chapter. Moreover, some basic angles are defined for the theoretical calculation of the incident solar irradiance (W/m^2) on the solar module used in this experiment. The results are further integrated to measure the cumulative light energy (Wh/m^2).

Chapter 3

Methodology

3.1 Predictive Analysis with Machine Learning (Approach-1)

In this chapter, the application of the machine learning algorithm on the collected data and the predicted output result will be discussed. The machine learning algorithm used is a TensorFlow Regression application of the "Artificial Neural Networks Model." Data has been effectively collected from the seven sensors installed across the two Photovoltaic Modules in the outdoor hardware setup from November 2019 to February 2020. The collected data must be preprocessed so that the algorithm will serve as a core foundation block in predicting the short circuit current, Isc(mA), of both the Clean Module and the Dusty Module, can be trained. Data preprocessing mainly removes outliers in data due to system error because they would introduce bias into the predicted output. The main focus is to predict the data the of different days and calculate the accuracy of the proposed model also we have found different errors and average percentage

3.1.1 Artificial Neural Network Model (Part 1)

The machine learning model is used to predict the probable output short circuit current, I_{sc}(mA) for three days of a week. In the following algorithm, in the initial state, all the required libraries are called. Training on a similar dataset to understand the behavior of the parameters and the targeted output parameter is required in the machine learning model. So, we load the training dataset in the algorithm. The dataset is divided into two parameters in the algorithm, called X_train and y_train. Here, y_train is the target parameter - the short circuit current, Isc(mA) from current sensors connected to the Clean Module and Dusty Module. In the following algorithm, in the initial state, all the required libraries are called. Traning on a similar dataset to understand the behavior of the parameters and the targeted output parameter is required in the machine learning model. So, we load the training dataset in the algorithm. The dataset is divided into two parameters in the algorithm, called X_train and y_train. Here, y_train is the target parameter - the short circuit current, Isc(mA) from current sensors connected to the Clean Module and Dusty Module. 4 layers with 201neurons and 0.2 dropout with each layer are used in the following machine learning algorithm. The dropout is used to avoid the overflow of the data. The layers inclusively with the neurons decrease the training loss of the algorithm. The parameter epoch is 1000, which means the algorithm passes over the training data 1000 times, and since the whole training dataset is different from the testing dataset, the parameter batch size is doubled to the epoch set in the machine learning algorithm. In addition to these parameters, the optimizer used is "ADAM" and it is necessary for the fair boost in the choice of hyperparameters if the learning rate sometimes needs to be changed from the default in the algorithm. Using the root mean square method compared with the actual data from the current sensor of that specific day whose Isc(mA) is predicted, the prediction error is calculated.

Using the machine learning algorithm, the whole procedure of predicting the short circuit current, Isc(mA), is explained using the flowchart below

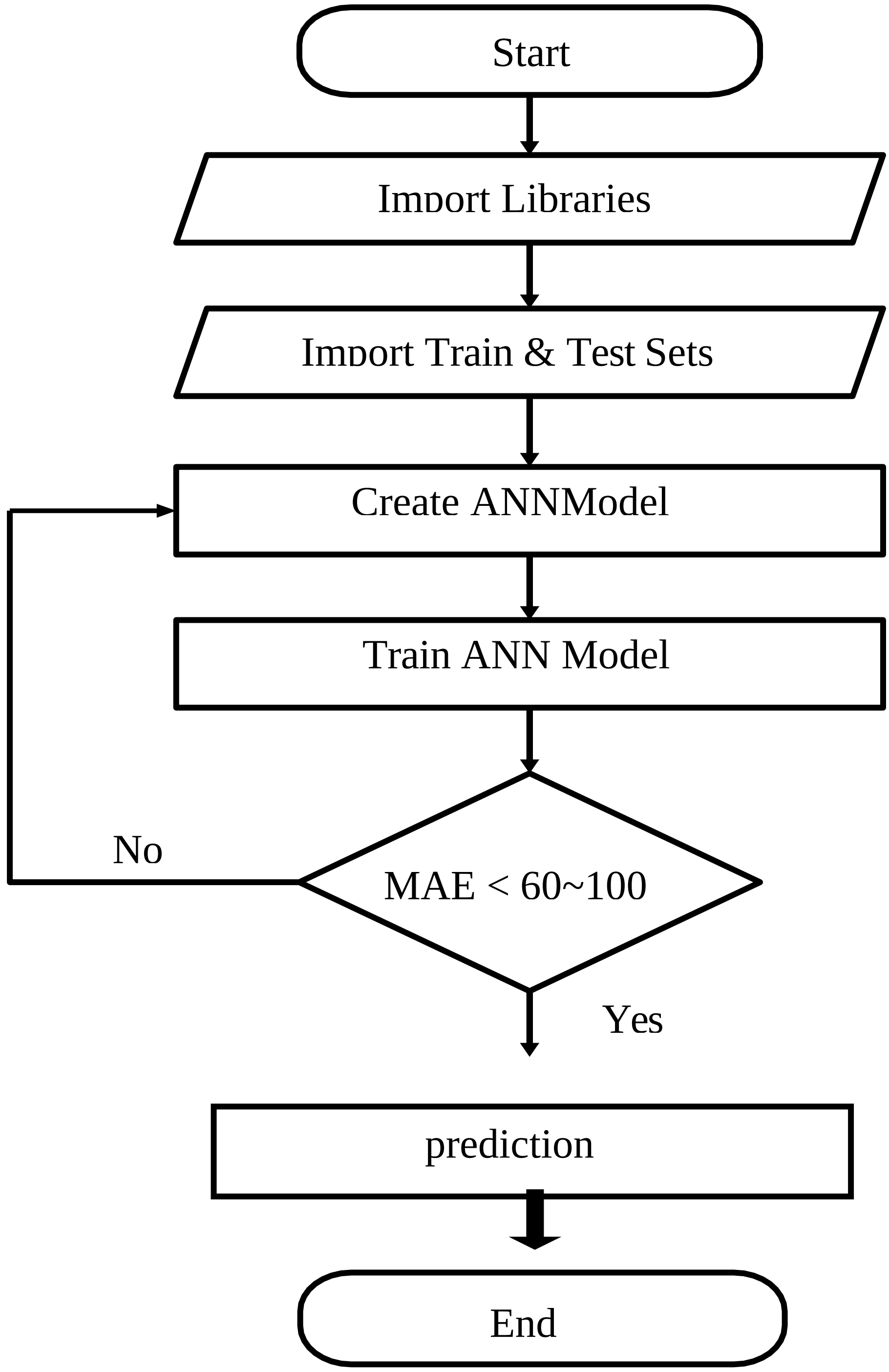

Fig3.1 : Flowchart of the working procedure of ANN model

3.1.2 Training Set and Testing Set

Based on the training dataset, the machine learning model needs to be trained, and the learning expertise of the model is tested based on the testing dataset. When it is trained on a dataset of a long period, there is a usual phenomenon of the learning algorithm to predict more accurately.

- Training dataset – November 2019 to February 2020

  (We are using same training Data set for three different days)

- Testing Data 01 : 4^{th} March 2020
- Testing Data 02 :8^{th} March 2020
- Testing Data 03 : 10^{th} March 2020

3.1.3 Prediction Analysis with different training dataset

The same training dataset is used to predict the short circuit current of 3 different days, 4th March, 8th March, and 10th March hence our testing data was 4^{th} , 8^{th} , and 10^{th} march accordingly .The prediction of the short circuit current, Isc(mA) for Clean Module and Dusty Module is predicted separately and plotted against time in x-axis and Isc(mA) in y-axis.

The output for the Clean Module is plotted as follows

Here, in figure 3.2 we can see the difference between predicted value and real value of short circuit current of clean module changing with time. By observing the graph, it can be determined that it was a cloudy day. For the cloud, module did not get proper sunlight and as a result there are many ups and down visible in the graph. Between 10 am to 12 pm, the cloud was more, and due to lack of proper sunlight we can see the output of solar panel decreases there. The maximum output short circuit current of the panel on March 4 was around 12.30 pm.

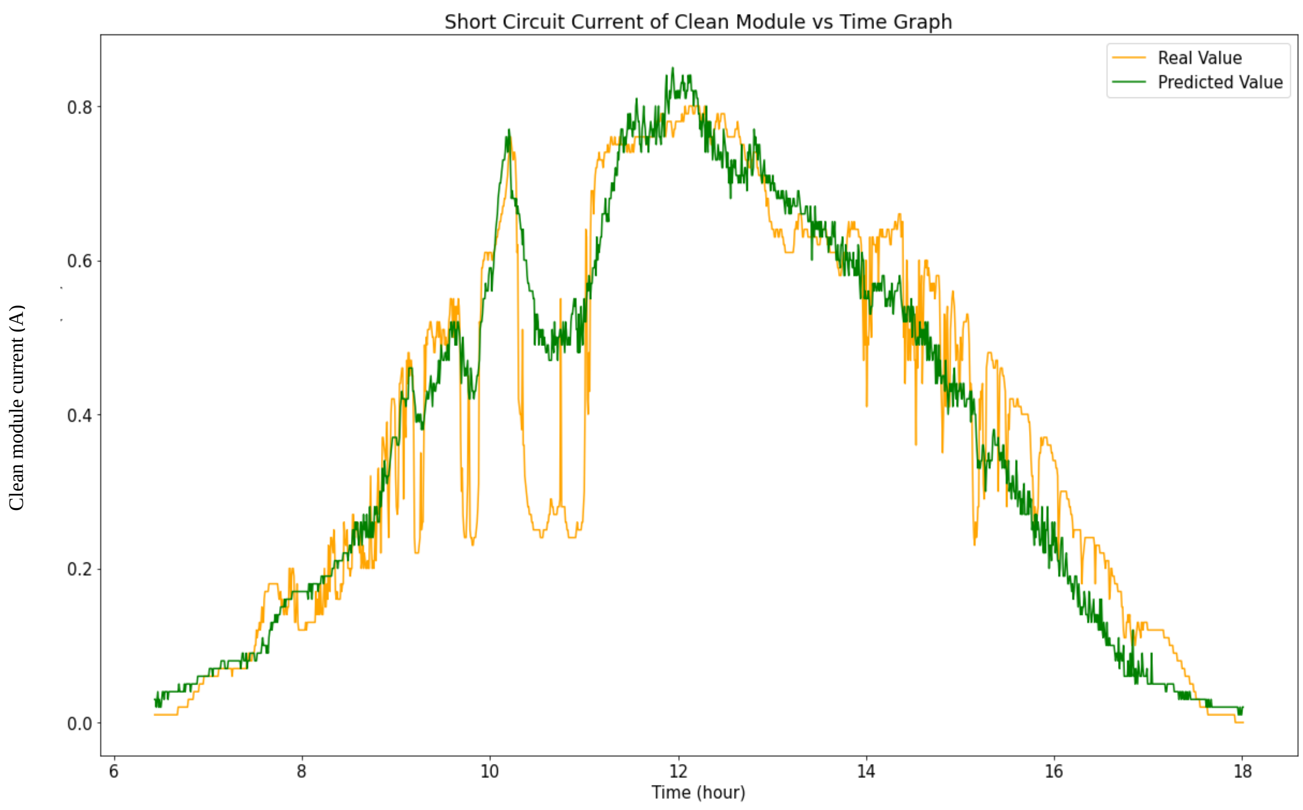

Figure3.2 :Plots of experimental and predicted short circuit current of clean module, using testing Data set 4th March

In figure 3.3 we can see the difference between predicted value and real value of short circuit current of clean module on 8th March. It was a cloudy day. For the cloud, module did not get proper sunlight and as a result there are many ups and down visible in the graph. Apart from ups and down in the output short circuit current, from 12 PM to 12.30 PM the current reading was recorded almost 1000mA and it is the maximum current for 8th March.

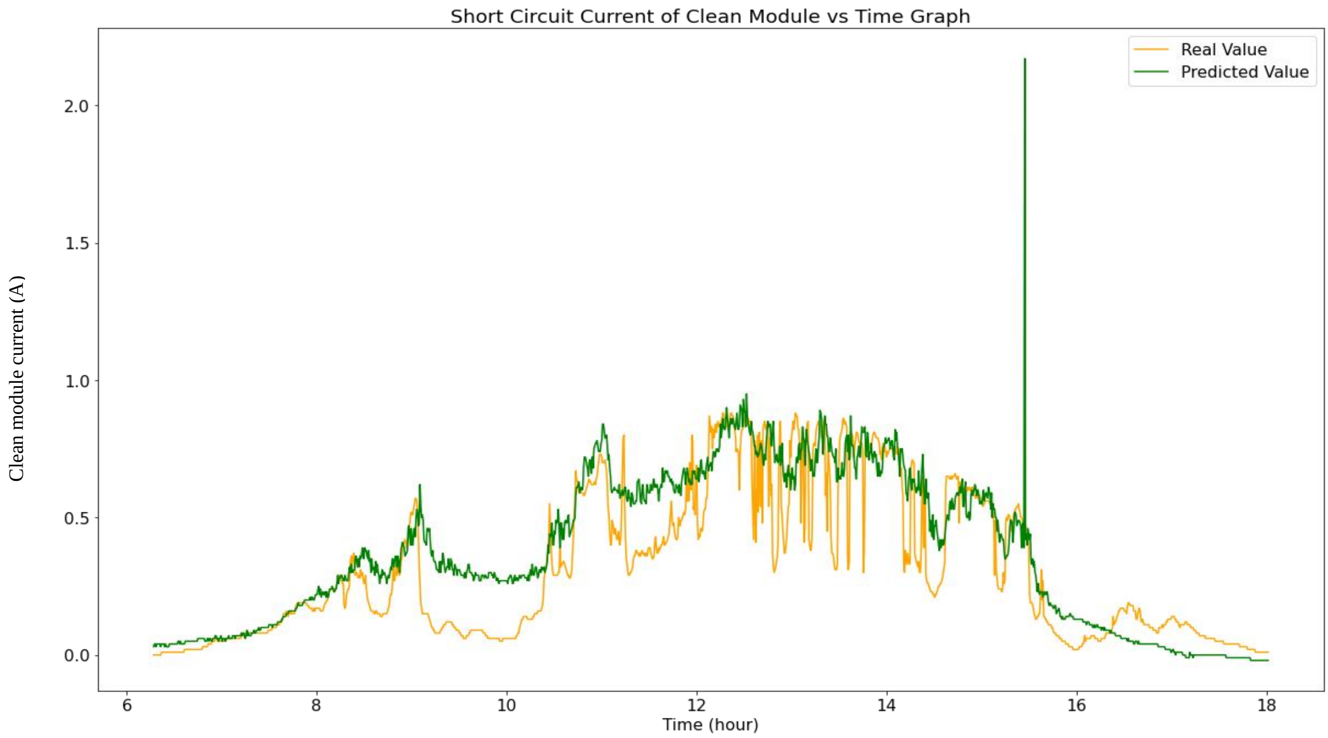

Figure3.3 :Plots of experimental and predicted short circuit current of clean module, using testing Data set 8th March

From figure 3.4, it can be said that it is a typical sunny day. The short circuit current increased gradually over time. At noon, around 1 pm, it is giving the maximum output.

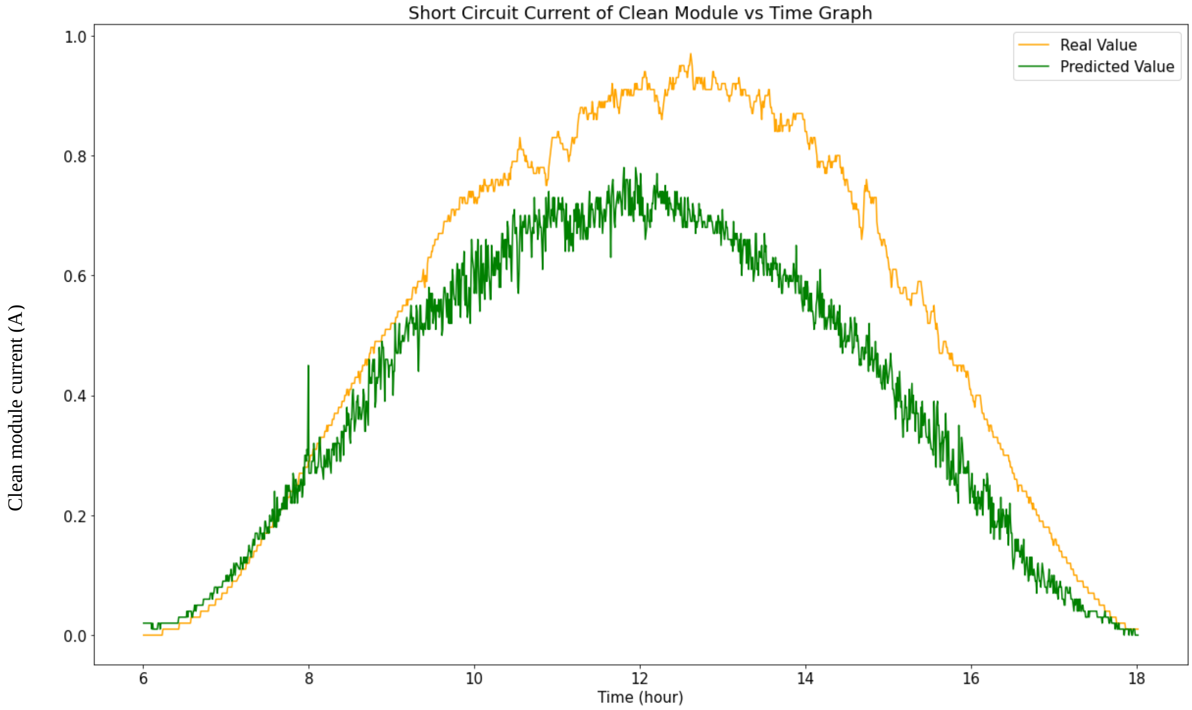

Figure3.4 :Plots of experimental and predicted short circuit current of clean module, using testing Data set 10th March

The output for the Dusty Module is plotted as follow

Here, figure 3.5 shows the difference between predicted value and real value of short circuit current of dusty module changing with time. As it is mentioned before, 4th March was a cloudy day, module did not get proper sunlight and as a result there are many ups and down visible in the graph. Between 10 am to 12 pm, the cloud was more, and due to lack of proper sunlight we can see the output of solar panel decreases there. The maximum output short circuit current on dusty panel was 700 mA on March 4 was around 1 pm.

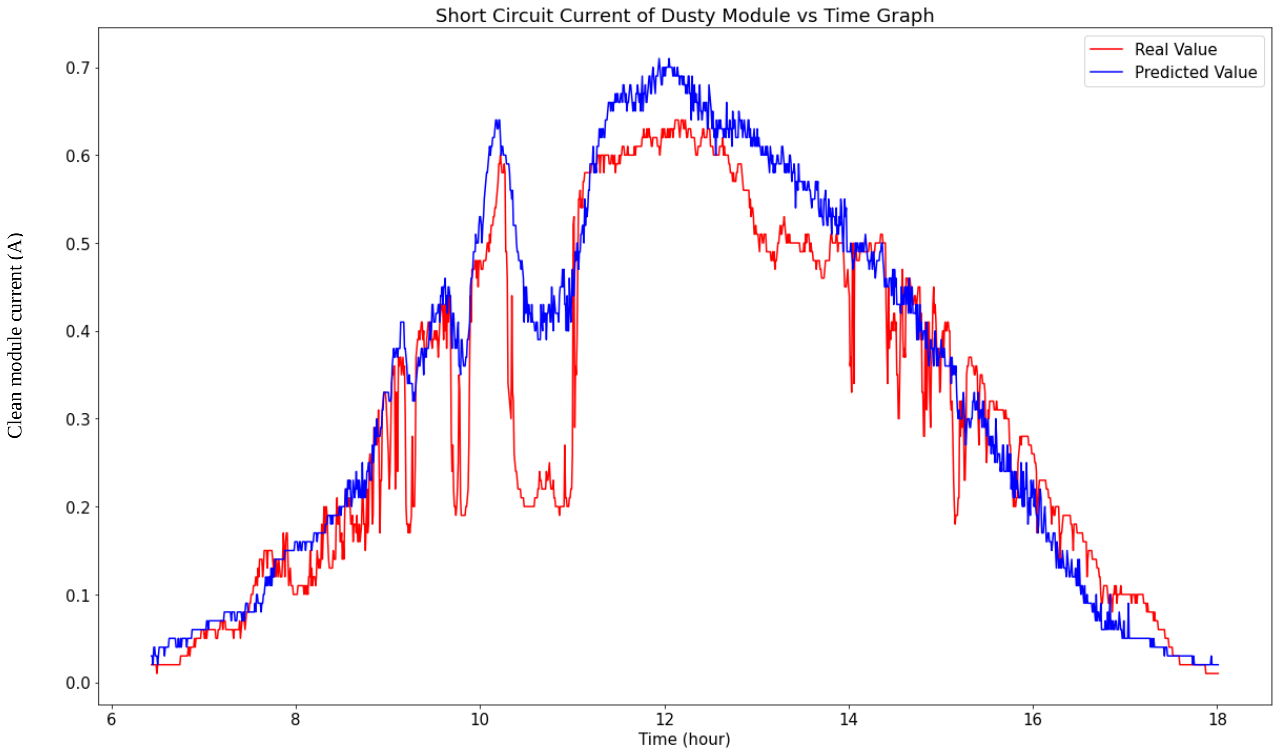

Figure3.5 :Plots of experimental and predicted short circuit current of Dusty module, using testing Data set 4th March.

In figure 3.6 we can see the difference between predicted value and real value of short circuit current of dusty module on 8th March. It was a typical cloudy day. For the cloud, module did not get proper sunlight and as a result there are many ups and down visible in the graph. From 12 PM to 12.30 PM the current reading was recorded almost 1000mA and it is the maximum current for 8th March.

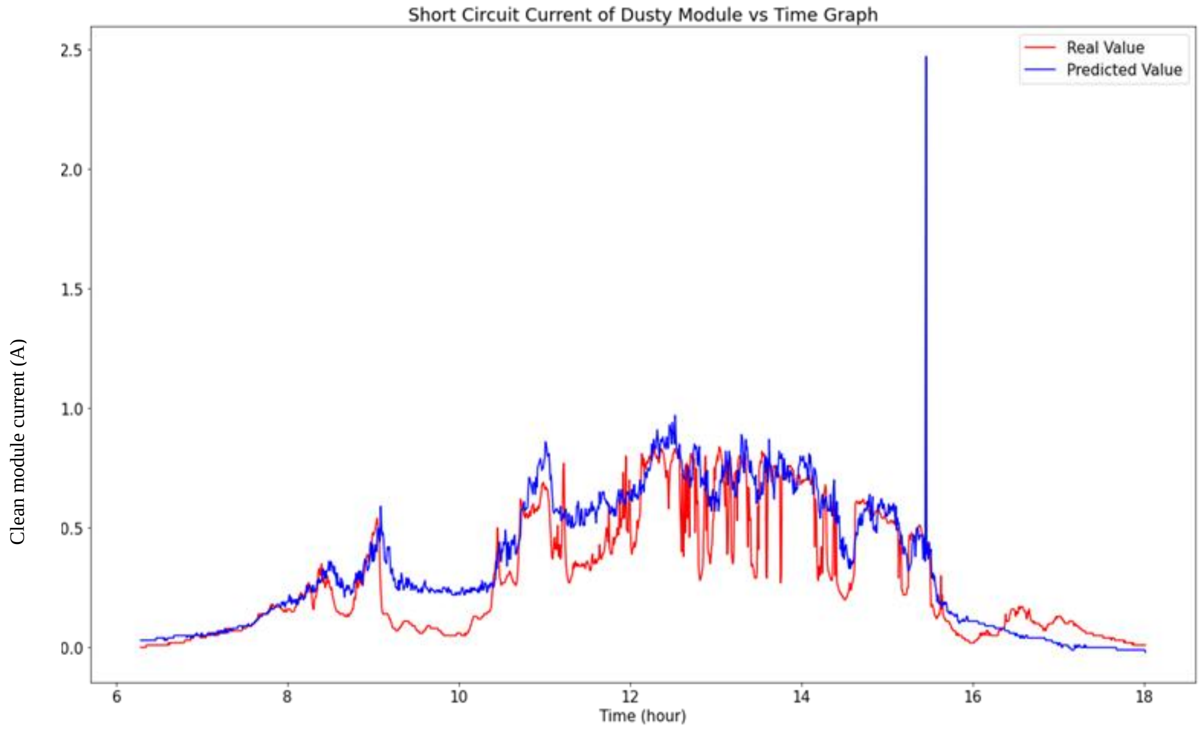

Figure : 3.6 Plots of experimental and predicted short circuit current of Dusty module, using testing Data set 8th March

As mentioned before, 10th March was a sunny day. We can observe the dusty panel output in figure 3.7. The output short circuit gradually increased till noon and it reached maximum 800 mA current output.

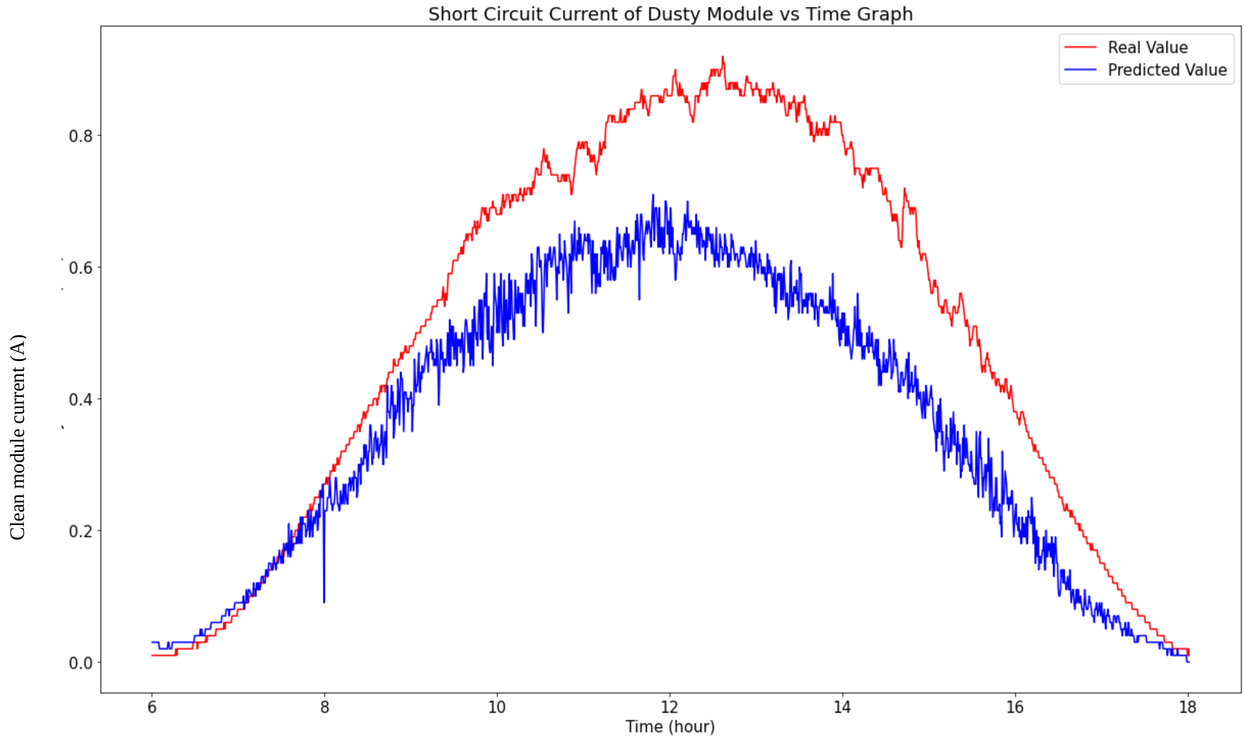

Figure : 3.7 Plots of experimental and predicted short circuit current of Dusty module, using testing Data set 10th March

The solar irradiance (W/m^2) is calculated from the experimental output short circuit current, Isc(mA) of the Clean Module using empirical method; considering the solar irradiance is same for both Clean Module and Dusty Module. The cumulative light energy (Wh/m^2) is calculated for both the experimental data and predicted data and compared to observe the difference.

The average percentage error rate of the predicted short circuit current, Isc(mA) is calculated using the formula:

$$average\ percentage\ error\ rate\ =\ ((ytrue - ypred)/ytrue)N *\ 100\%$$

where,

- $ytrue$ contains the value of experimental short circuit current, Isc(mA)
- $ypred$ contains the value of predicted short circuit current, Isc(mA)
- N is the total number of data in a Training dataset.

3.2 Predictive Analysis with Machine Learning (Approach-2)

3.2.1 Artificial Neural Networks Model (Part 2)

The machine learning model is used to predict the probable output short circuit current, Isc(mA) for three days of a week. In the following algorithm, in the initial state, all the required libraries are called. Training on a similar dataset to understand the behavior of the parameters and the targeted output parameter is required in the machine learning model. So, we load the training dataset in the algorithm. The dataset is divided into two parameters in the algorithm, called X_train and y_train. Here, y_train is the target parameter - the short circuit current, Isc(mA) from current sensors connected to the Clean Module and Dusty Module. In the following algorithm, in the initial state, all the required libraries are called. Traning on a similar dataset to understand the behavior of the parameters and the targeted output parameter is required in the machine learning model. So, we load the training dataset in the algorithm. The dataset is divided into two parameters in the algorithm, called X_train and y_train. Here, y_train is the target parameter - the short circuit current, Isc(mA) from current sensors connected to the Clean Module and Dusty Module. In this algorithm, as input 4 hidden layers of neurons used, in first layer there are 32 neurons , second layer 64, third layer 132 and in fourth layer 256 and as output 2 layers have been used. The layers with neurons decreases training loss . The activation function used in Rectified Linear Unit (ReLU) because of its ability to deal with non-linear equations. In addition to these parameters, the optimizer used is rms prop and it is a necessity because the optimizer is considered to be the engine of the machine learning algorithm which dominates the learning procedure of the algorithm . Moreover as loss fuction , we have used mse . The parameter epoch is set at 500, which means the algorithm passes over the training data 500times .

3.2.2 The output for the Clean Module is plotted as follows

Figure 3.8 shows the predicted and real short circuit current of clean module. Both real and predicted short circuit current increased till 1 pm. From 10 am to 12 pm the real short circuit current fell to 300 mA and predicted short circuit current fell to 600 mA due to cloudy weather. From 2 pm the output was gradually dereasing with the decreasing of solar irradiance and reached almost 0 mA at 6 pm. The maximum short circuit current was around 1200 mA at 2 pm. Most of the time the predicted values followed the real values where the predicted values were slightly higher than the real.

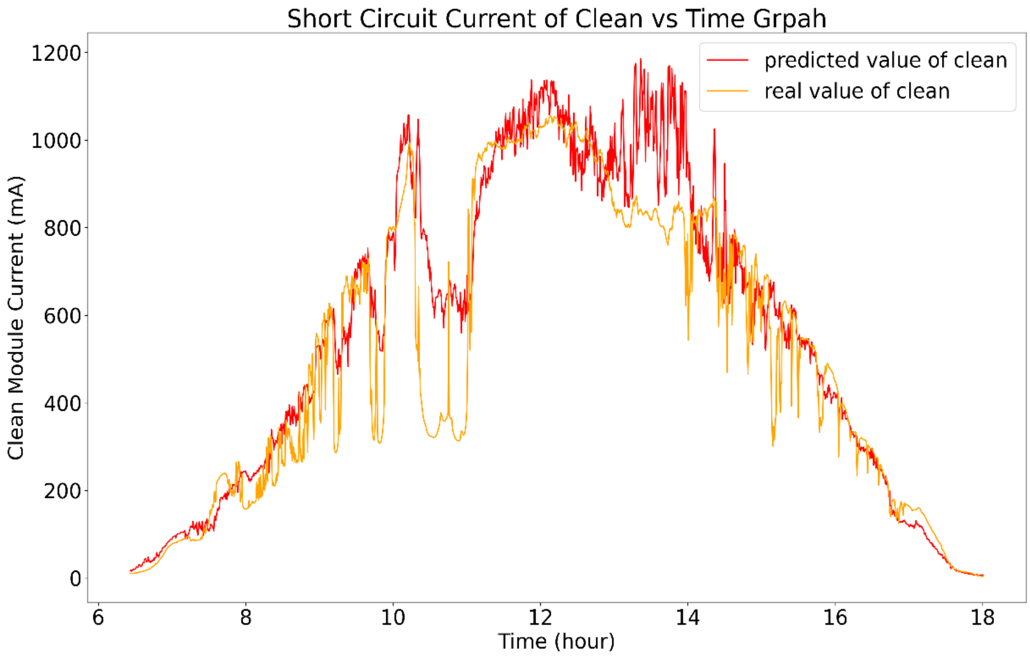

Figure 3.8 : Plots of experimental and predicted short circuit current of clean module, using testing Data set 4^{th} March

In figure 3.9, the graph indicates the predicted and real short circuit current of 8th March. It was a cloudy day and the short circuit current was not stable. After increasing from 6 am to 9 am, both short circuit current dropped below 200 mA at 10 am. Then short circuit current again increased gradually and reached around 1100 mA. Short circuit current fluctuated a lot from 11 am to 3 pm, then gradually decreased until sunset.

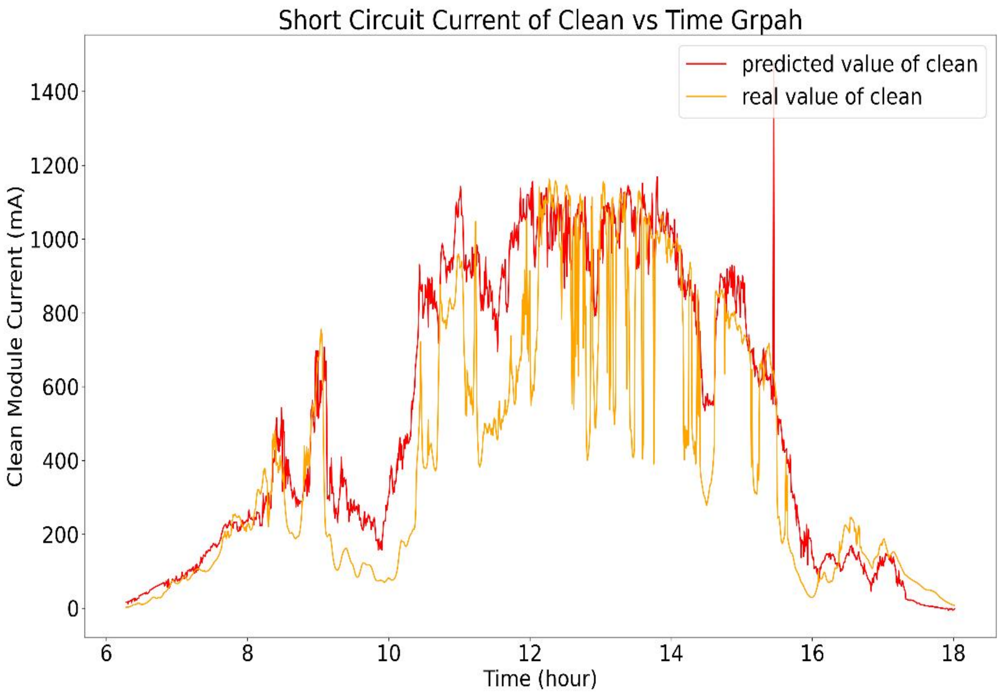

Figure 3.9: Plots of experimental and predicted short circuit current of clean module, using testing Data set 8th March.

Figure 3.10 depicts the predicted and real short circuit current of 10th March. It was a typical sunny day. The short circuit current was increasing gradually till 1 pm with slight flactuation, then started deacreasing again till sunset. The real value was significantly higher than the predicted value around noon to afternoon.

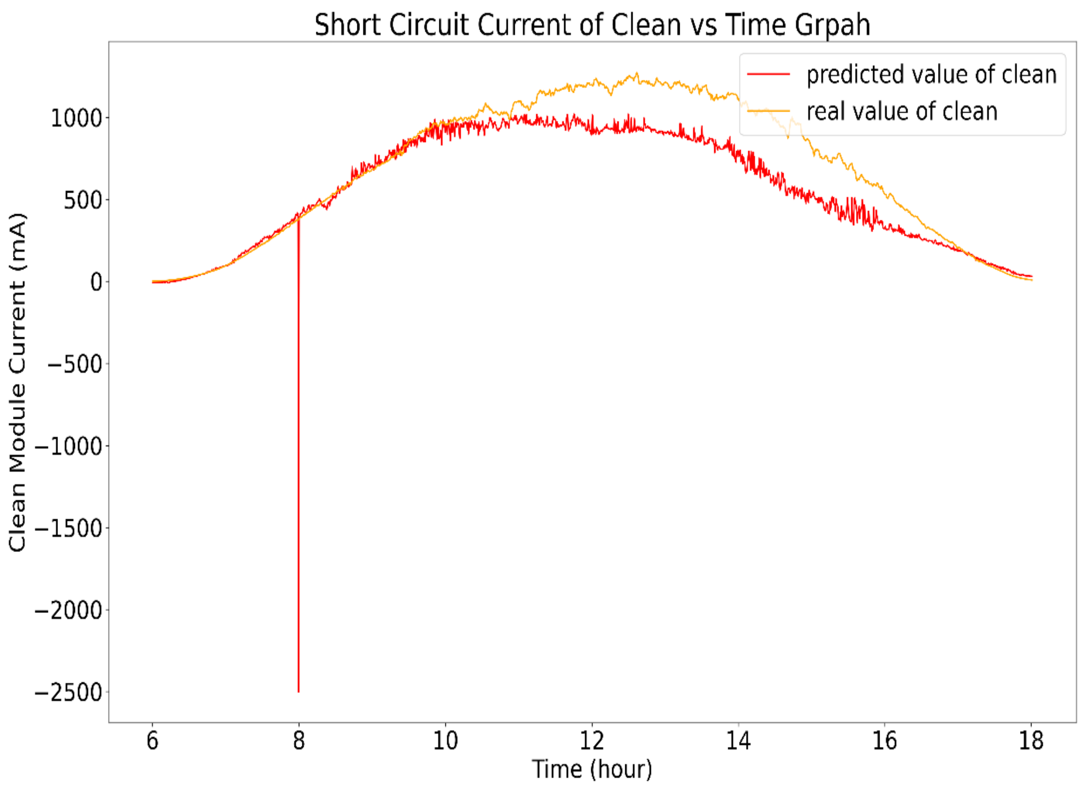

Figure 3.10: Plots of experimental and predicted short circuit current of the clean module, using testing Data set 10th March

3.2.3 The output for the Dusty Module is plotted as follow

Figure 3.11 shows the predicted and real short circuit current of clean module. As mentioned before both real and predicted short circuit current increased till 1 pm. From 10 am to 12 pm the real short circuit current fell to 300 mA and predicted short circuit current fell to 500 mA due to cloudy weather. From 2 pm the output was gradually dereasing again. The maximum short circuit current was around 1000 mA at 1.30 pm.

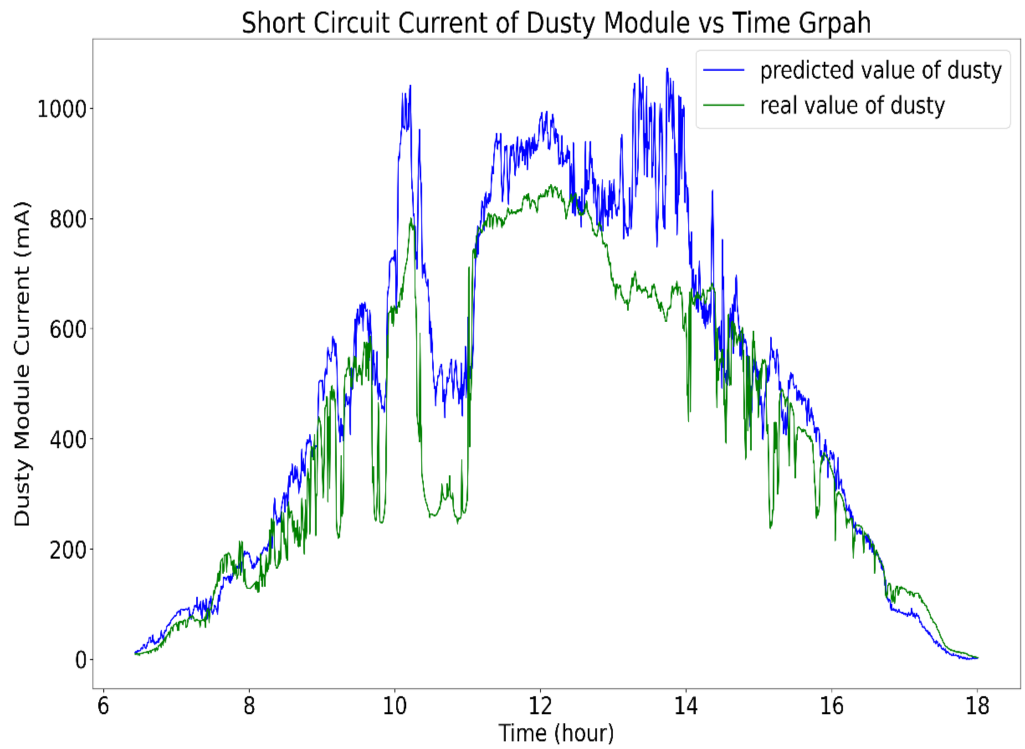

Figure 3.11: Plots of experimental and predicted short circuit current of the Dusty module, using testing Data set 4th March

The graph of figure 3.12 shows the predicted and real short circuit current of 8th March, It was a cloudy day and the short circuit current was not stable. Short circuit current was increasing from 6 am to 9 am, then both short circuit current dropped below 200 mA at 10 am. Then short circuit current again increased gradually and reached around 1100 mA. Short circuit current fluctuated a lot from 11 am to 3 pm, then gradually decreased until sunset.

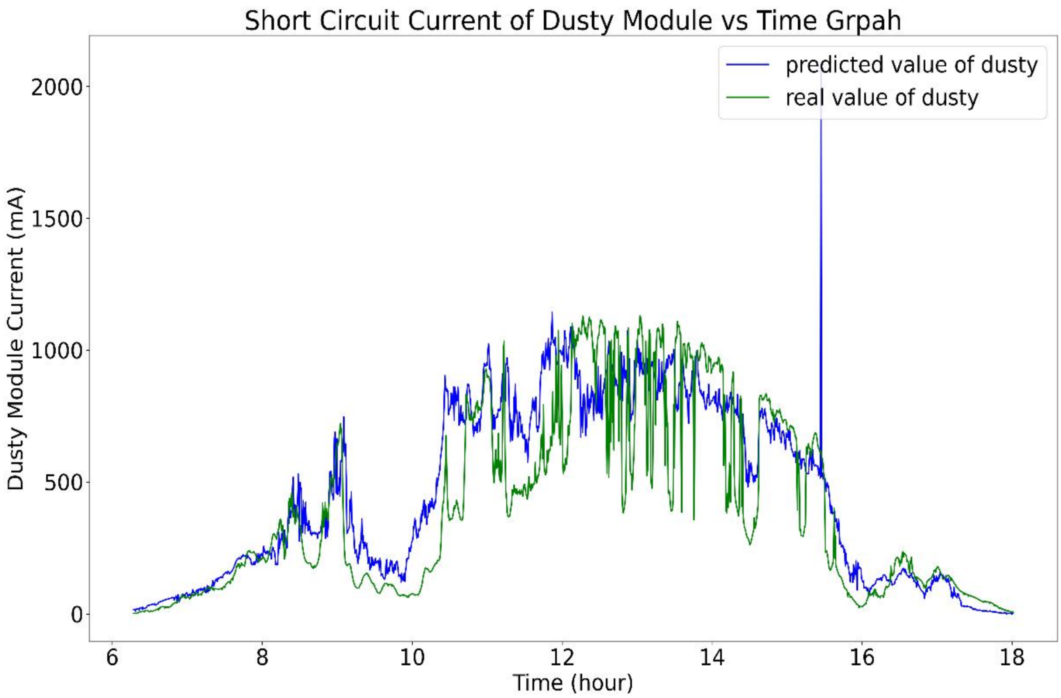

Figure 3.12: Plots of experimental and predicted short circuit current of the Dusty module, using testing Data set 8th March.

Figure 3.13 illustrates the predicted and real short circuit current of 10th March. As mentioned before, it was a typical sunny day. The short circuit current was increasing gradually till 1 pm with slight flactuation, then started deacreasing again till sunset. The real value was significantly higher than the predicted value around noon to afternoon.

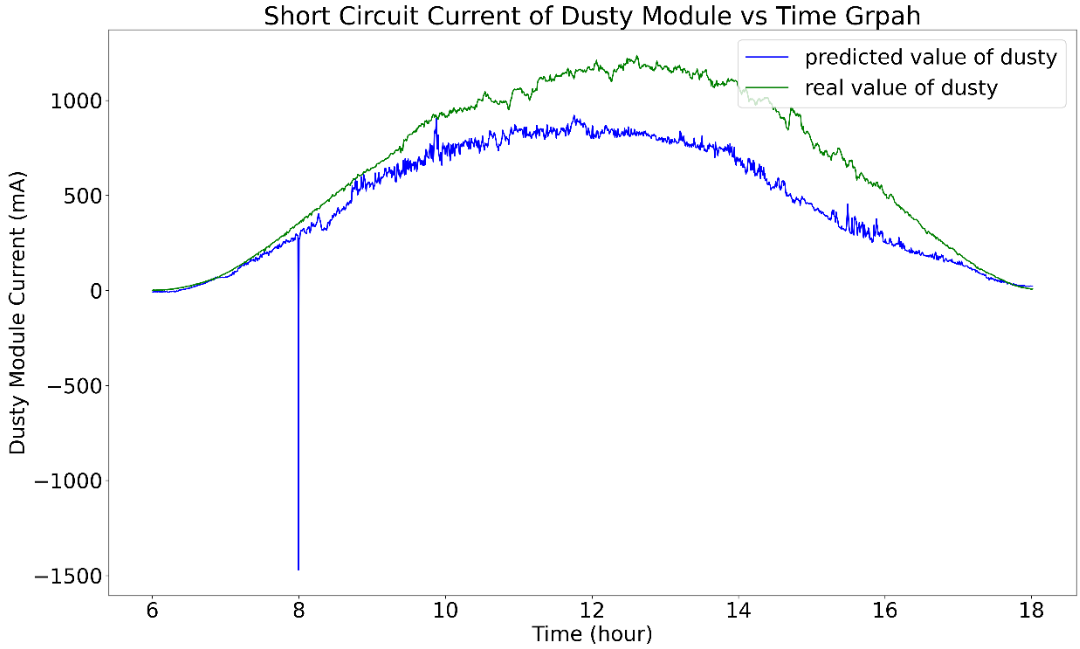

Figure 3.13: Plots of experimental and predicted short circuit current of the Dusty module, using testing Data set 10th March

The figures shows the plots of experimental and predicted short circuit current, Isc(mA) of PV Module, and predicted Three different days. All data was estimated by using Four training datasets and Three different testing datasets.

Chapter 4

Results Analysis

4.1 Effect of Weather Parameters

The sensors include humidity, air pressure, wind speed, and temperature sensors for each Clean Module and Dusty Module are somewhat weather parameters. A correlation heatmap is created to comprehend and evaluate the influence of each of these four meteorological characteristics on the output short circuit current, Isc(mA), of the Clean Module and Dusty Module. The degree of each parameter's influence on the others is quantified on a scale of 1 in the heatmap, with matching variations in color intensities.

Heatmaps are a graphical presentation where values are depicted by color intensity. The heatmap is created using the training dataset from 1st November 2019 to February 2020. Here two heatmap has been, one is for Clean Module and another is for Dusty Module. it can be used to understand the correlation between the short circuit current, Isc(mA), and the weather parameters; humidity, air pressure, wind speed, and temperature. It is evident from the value assigned to humidity and air pressure relative to the short circuit current, Isc(mA) of both modules that these parameters affect the least. The weather parameters having a specific Impact on the short circuit current, the output of the PV module

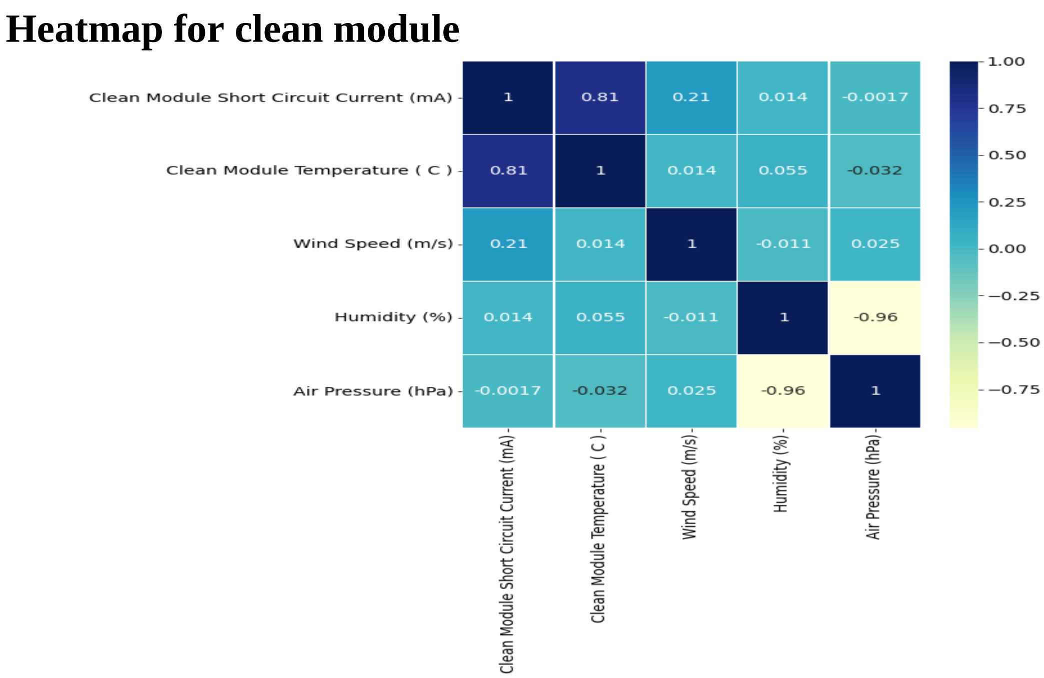

Fig 4.1.1: Correlation between each weather parameter corresponding to short circuit current, Isc (mA) of PV Module(Clean)

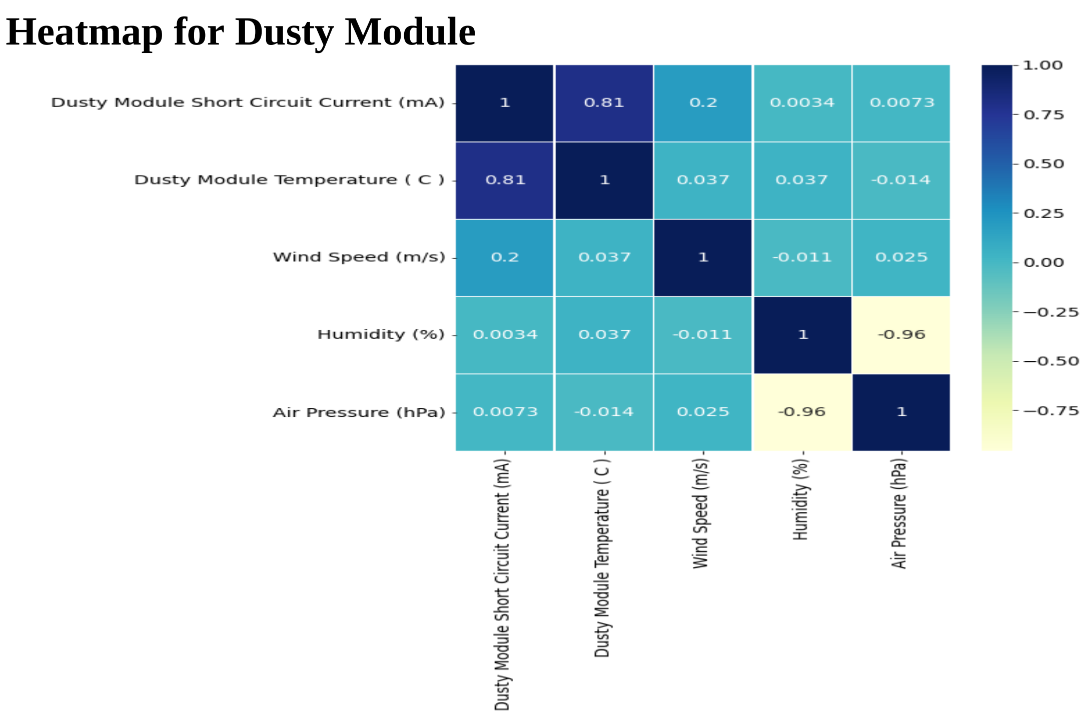

Fig 4.1.2: Correlation between each weather parameter corresponding to short circuit current, Isc(mA) of PV Module(Dusty)

4.1.1 Analysis of Heatmap

The heatmap shows the effect of the four weather parameters on both the Clean Module and Dusty Module separately. Here dark color represents strong correlation while the lighter color represents low correlation with each other It measures only the linear relationship between two variables and ranges from -1 to +1. On the side of negative, there is no correlation, and 0 to 1, the impact of correlation is good. That means if the short circuit current PV module shows 0.81 with the temperature that means Isc is highly correlated with temperature. The second most correlated parameter is wind speed which shows 0.2. Hence this heatmap shows weather parameter temperature has the strongest correlation with the Isc(ma) of the PV module.

Error and Percentage Calculation

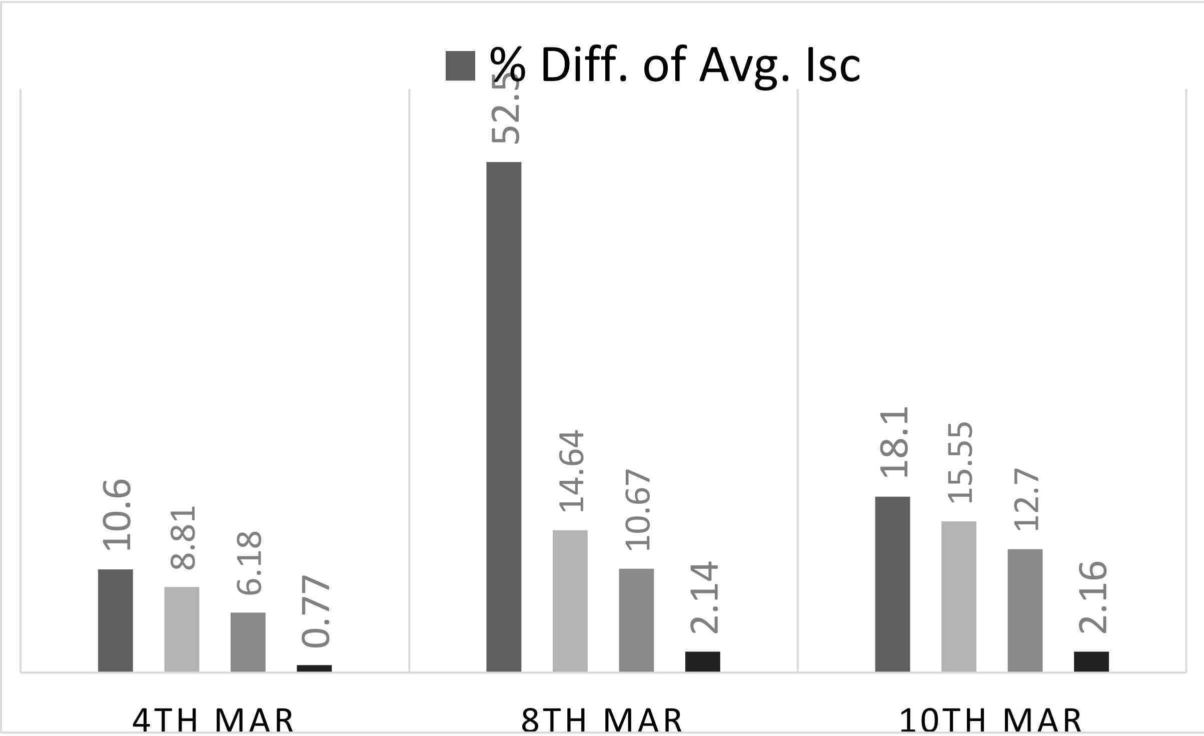

Fig. 4.1.3 Results between the Experimental and Prediction of the Short Circuit Current Isc (mA) for Clean Solar Panel.

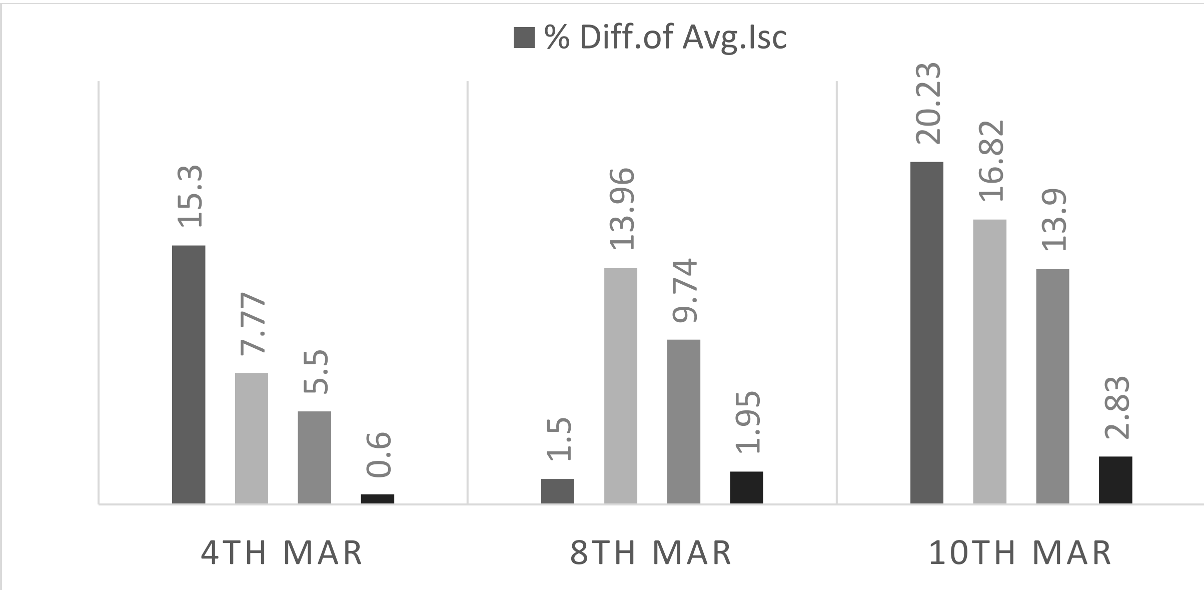

Fig: 4.1.4 Results between the Experimental and Prediction Short Circuit Current Isc(mA) for Dusty Solar Panel.

Accuracy

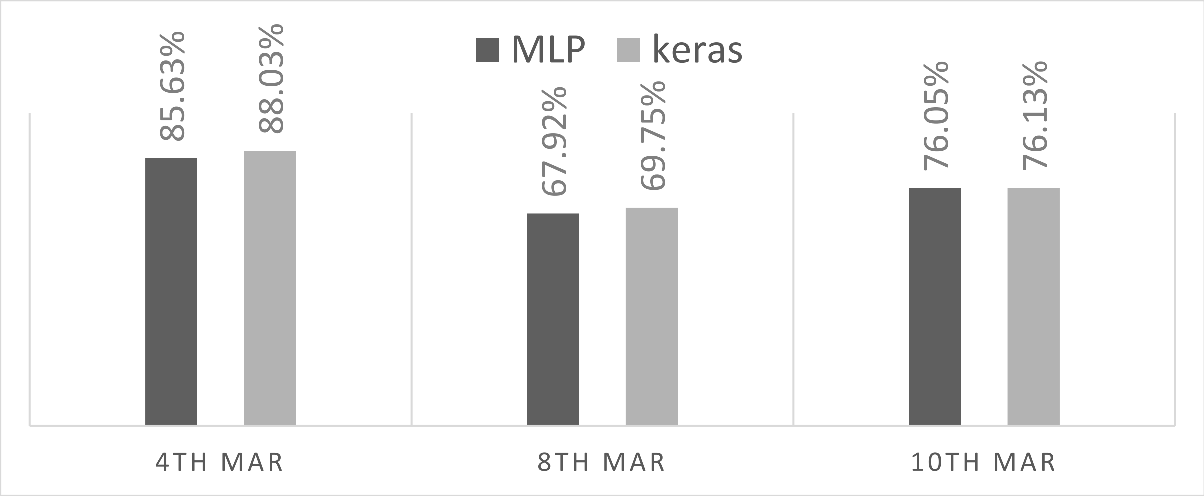

Fig. 4.2.2: The accuracy percentage of the two Models for Clean PV module.

Isc(mA) for Clean Solar Panel

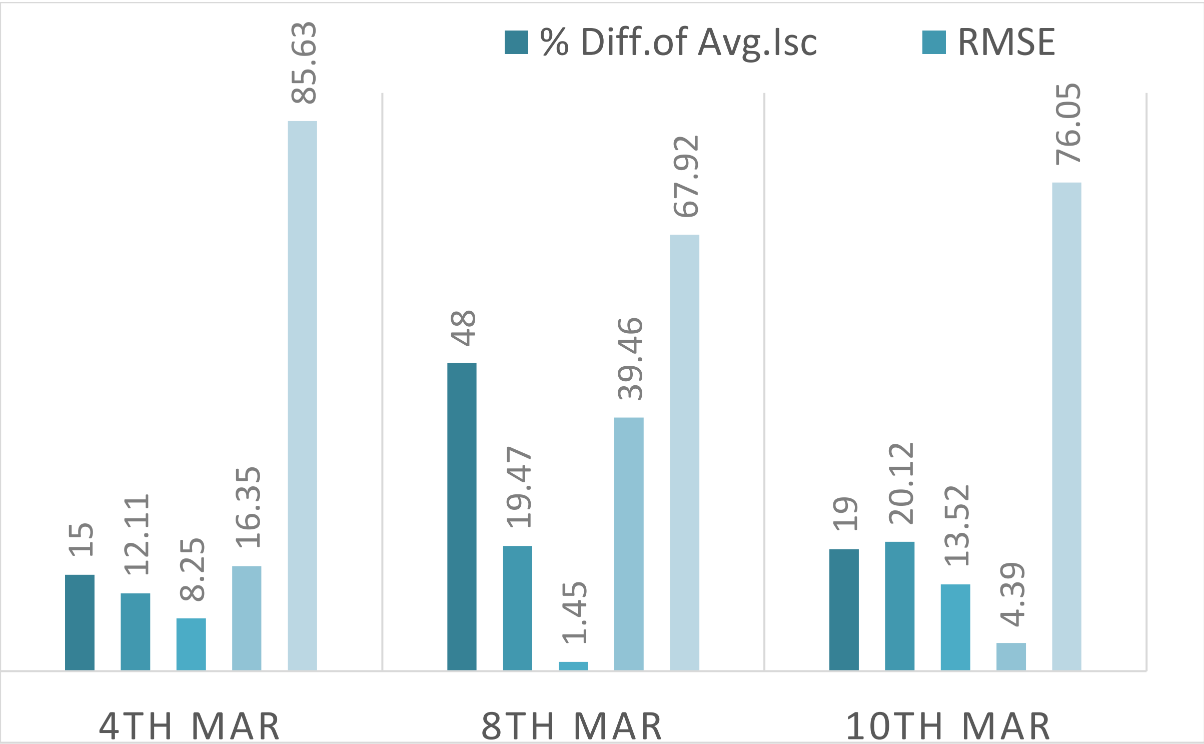

Fig. 4.1.5 Results between the Experimental and Prediction of the Short Circuit Current Isc (mA) for Clean Solar Panel.

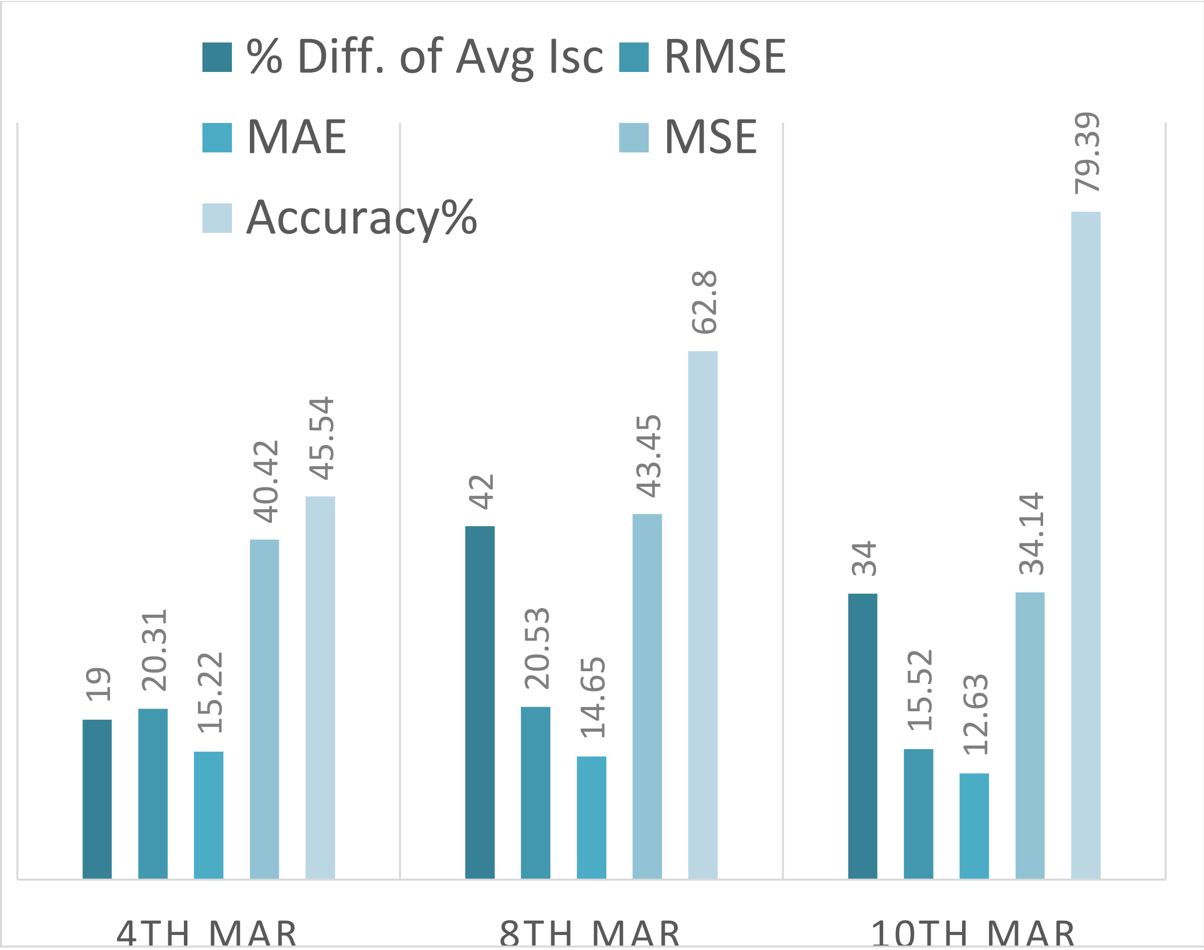

Fig. 4.3.6 Results between the Experimental and Prediction of the Short Circuit Current Isc (mA) for Dusty Solar Panel.

4.2 Chapter Summary

This chapter discusses the results and analysis of the thesis work's machine learning model implementation. The machine learning model is applied to predict the short circuit current, Isc(mA). The projected Isc(mA) findings offer a clear idea of the length of the training dataset used to train the learning system. It has been discovered that when the algorithm is trained on a dataset that spans a longer period of time, it produces superior results. As a result, the average percentage error rate was calculated compared to the experimental short circuit current, Isc(mA).

Conclusions and Future Work

This study represents Short term comparing analysis of PV modules using machine learning. This work is done based on the data collected from November 2019 to February 2020 of two PV panels and environmental parameters. Data are extracted with a combined implementation of hardware and software. The analysis works are discussed into two main parts, one is a performance analysis and the other one is prediction analysis of PV panels. Initially, this study investigates the performance analysis of both Clean and Dusty panels in environmental conditions based on the experimental and theoretical analysis in chapter 4. It concludes that weather parameters such as humidity and wind speed have an ignorable impact on PV panels output. However, the short circuit current is mostly correlated with the solar irradiance among all the weather parameters. The short circuit current and the solar irradiance are mostly proportional as with increasing sunlight more energy can be generated. Besides this dust has a very important role in the performance of the solar module, in chapter 4 dust impact on the performance of solar panels has been described in various ways which can be concluded that due to dust accumulation on the surface of the dusty panel, the performance of the dusty panel compared to the clean module is degraded. The result shows if the training data set increased, the difference between experimental data and predicted data decreased by observation.

For future work, a longer period dataset like yearly data can assist the analysis of dust on both panels over the year. MLP model needs independent variables like temperature and solar panel surface irradiance for the prediction of short circuit current on a specific day. Hence, in the future, a longer period datasets collection will be a great assist for this MLP model to predict the short circuit current and panel energy output for any day of the year with high accuracy

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