MODELING OF PHOTOVOLTAIC (PV) MODULE TEMPERATURE BASED ON AMBIENT FACTOR IN MALAYSIA USING ANFIS

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ABSTRACT

This paper introduces a model build using Adaptive Neuro-Fuzzy Inference System (ANFIS) for evaluation of temperature for PV modules. The input of this model were taken from meteorological data which are ambient temperature,Ta, solar irradiation,GT, wind speed,Vw and humidity,RH. These parameters were evaluated from outdoor exposure data measured at Malaysia Green Technology Corporation (MGTC), Bandar Baru Bangi, Malaysia. The model was validated based on low training error and accepted validation error.

Keywords— PV Module Operating Temperature, Meteorological data, ANFIS.

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ABSTRAK

Penulisan ini memperkenalkan pembinaan model menggunakan ‘Adaptive Neuro-Fuzzy Inference System (ANFIS) model untuk menilai suhu pada panel fotovoltaik(PV). Data masukan diambil dari data meteorologi yang mana antaranya ialah suhu persekitaran, Ta, pancaran cahaya matahari, GT, kelajuan angin, Vw, dan kelembapan, RH. Parameter yang terlibat telah dinilai dari pendedahanluar yang diukur pada PV panel yang telah dipasang di bumbung Mlaysia Gree Technology Corporation (MGTC), Bandar Baru Bangi, Malaysia. Model ini dinilai berdasarkan kerendahan kesalahan ketika latihan dan nilai kesalahan yang boleh diterima ketikan penyemakkan.

Keywords— PV Module Operating Temperature, Meteorological data, ANFIS.

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LIST OF ABBREVIATIONS

PV	-	Photovoltaic
BIPV	-	Building Integrated Photovoltaic
T_c	-	Operating Temperature
T_a	-	Ambient Temperature
G_T	-	In-plane Irradiation
RH	-	Relative Humidity
V_w	-	Wind Speed
T_d	-	Dew Point Temperature
FIS	-	Fuzzy Inference System
ANFIS	-	Artificial Neuro Fuzzy Inference System
kWh	-	kilo Watt hour
PHANTASM		Photovoltaic Analysis and Transient Simulation method
MECM		Ministry of Energy Communication and Multimedia
Voc		Open Circuit Voltage

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CHAPTER I

INTRODUCTION

1.1 Introduction

Method for generating an electric power by converting solar radiation into direct current electricity using solar cell are called photovoltaic (PV). Solar cell can produce direct current electricity from sun light which can be used to power equipment. Previously, PV was used to power orbiting satellites and other spacecraft, but today PV is used for grid connected power generation. The electricity is produced silently with no pollution, no maintenance and no depletion of natural resources. PV is compassionate and exceedingly versatile [1] [2].

A PV system, either a stand-alone or a grid-connected, is classified as a building integrated photovoltaic (BIPV) system whenever the PV is aesthetically integrated into the building architecture and envelope. Most of the BIPV applied in urban areas are grid-connected systems. A stand-alone PV only produces electricity for the intended use, meanwhile BIPV system will not only produce electricity, but will also be an integral part of the building envelope, with a specific function either as a window shading device, roof or decorative building facade [2].

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Due to location of Malaysia which is located just north of the Equator, there is a high annual irradiation and simulation calculations lead to an expected AC energy output for ideally orientated grid-connected PV systems of around 1200 to 1300 kWh/kWp. Therefore grid connected PV represents one proper option to contribute to the mix of future energy sources in Malaysia [2] [3] [4].

This paper basically focused on building a model to evaluate module temperature based on ambient factor of PV in Malaysia In designing any power generation system that incorporates photovoltaic, there is a basic requirement to accurately estimate the output from the proposed PV array under operating conditions. It is well known that temperature is one of main role in the PV conversion process because it can affect the quantities of voltage and current of the PV generator. The operating temperature, Tc, of a PV device, represents a fundamental variable which directly affects the electrical power output of the device and its efficiency. The proposed correlations in the literature normally express Tc as a function of the pertinent weather variables, namely ambient temperature, Ta, and local wind speed, Vw, as well as of the solar radiation flux (or irradiance) incident on the plane of the array, GT. Generally speaking, Tc is extremely sensitive to wind speed, less so to wind direction, and practically insensitive to the atmospheric temperature [5] [6] [7].

For Malaysia, country which is lying between one to seven degrees north of equator line that experiences high relative humidity (RH). Referring to the meteorology data for Subang, the highest RH of 84.8 % to 91.0 % occurred during daytime from 7 am to 8 pm. The average wind speed (V_w) is 1.67 m/s with the V_w of greater than 4.0 m/s occurred about 8.4 % in five years' time [8]. The relative humidity (RH) and the dew point temperature (T_d) are two widely used indicators of the amount of moisture in air. There is a very simple rule of thumb which is to be quite useful for approximating the conversion for moist air (RH > 50%), T_d decreases by about 1°C for every 5% decrease in RH [9].

Therefore, this study will be focusing on investigating the effects of G_T, T_a, T_d and V_w towards PV operating temperature.

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1.2 Problem Statement

Photovoltaic system is a system which uses one or more solar panel to convert sunlight into electricity. Solar panel is a package connected assembly of solar cell which known as solar cells as shown in Figure 1. Solar panels require light energy from the sun in order to generate electricity through photovoltaic effect.

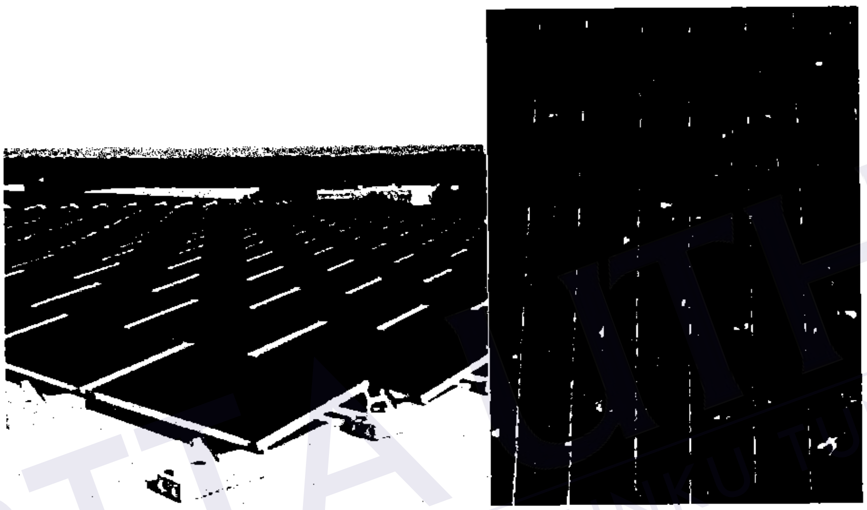

Figure 1.1: Solar panels that contain solar cells.

The photovoltaic effect differs in that electrons are transferred between different bands within the material, resulting in the buildup of voltage between two electrodes. As well established that temperatures play a central role in PV conversion since it affects basic electrical quantities which is voltage and current generate by PV [6]. Temperature affects the electricity flows through an electrical circuit by changing the speed of electrons travel. This is due to an increasing of resistance of the circuit those results from an increasing temperature. It shows that resistance is directly proportional with temperature [10].

Due to this relationship, the operating temperature, T_c, can directly affects the electrical power output of the device and its efficiency [6]. There are many correlations expressing T_c, the PV cell temperature, as a function of weather variables such as the ambient temperature, Ta, and the local wind speed, V_w, as well as the solar radiation flux/irradiance, G_T, with material and system-dependent properties as parameters [5] [6] [7].

As mention earlier, Malaysia experiences high relative humidity and annual irradiance [4] [8]. Fundamentally humidity and moisture helps to reduce temperature of PV. The dew point temperature (T_d) is significantly used to indicate the moisture content in air rather than RH. T_d can be derived through a simple thumb rule by substituting RH for RH more than 50% as shown in equation (1.1) [9].

$$T_d = T_a - \left(\frac{100-RH}{5}\right) \tag{1.1}$$

By knowing all parameter involves, correlation between G_T, T_a, T_d and V_w towards PV Tc being investigate.

1.3 Objectives

The objectives of this research are:-

a) To build a model that can evaluate the PV module temperature (Tm) based on its ambient factor in Malaysia.

b) To train the model using four input which are ambient temperature (T_a), in plane irradiance (G_T), dew point temperature (Td) and wind speed (V_w) to gain one output which is module temperature(Tm) of PV.

c) To achieve lowest validation error and training error during training.

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1.3 Project Scope

This project is primarily concerned with the implementation of Fuzzy Logic using MATLAB. The scopes of this project are:

a) Study the previous work – this study consist the research of the project related that have been done before

b) Study on PV relationship between T_m, T_a, G_T, T_D and V_w.

c) Design a model by using Adaptive Neuro Fuzzy Inference System (ANFIS) in MATLAB.

1.4 Thesis Outline

This thesis consists of five chapters. The current chapter mainly presents the objective and the background and scope of this study. It also provides the general idea of this project.

Chapter 2 consists of previous studies and research that are relevance in defining the relation of PV module temperature, T_m from ambient factor of PV which is T_a, T_d, G_T, V_w.

Chapter 3 discussed the methodology that is used for this study. It details the process and explains the command related during the process of building the ANFIS model.

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Chapter 4 details the analysis and the result of the study. The data collected from the site then being trained to create a model. From the model, users are allowed to insert the input parameter and the model will do the evaluation and result to module temperature of PV solar cell. All the result also discussed in this chapter.

Chapter 5 discusses and concludes the findings of this thesis, and review the parameter and suggestion for the future development.

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CHAPTER II

LITERATURE RIVIEW

2.1 Introduction

This chapter discusses about the literature reviews of previous research work and the method of how others people construct their project. Around the world, there are many researches about the concept and implementation of this system which that use in suitable applications

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2.2 Technology Developments

2.2.1 Modeling Of The Nominal Operating Cell Temperature Based On Outdoor Weather

This research was done by Michael Koehl. Markus Heck,StefanWiesmeier and Jochen Wirth from Fraunhofer ISE, Freiburg,Germany[11]. In this paper,an investigating simple analytical and statistical models for the evaluation of the temperature of PV-modules from climatic data such as, ambient temperature, global solar irradiation and wind speed was carried out.

Moreover, the effect of cell technology and module design which was evaluated from outdoor exposure data at different climatic region will be described as the parameter. The models were then verified by comparison of the simulated module temperatures with measured module temperature at different test sites.

In this paper, the impact of radiation cooling and natural convection for wind speeds 2m/s and above was neglected. The effect of radiation cooling was found only during night time which is not relevant for the solar energy gain. So, the effect of wind blow and fast temperature changes are excluded.

The models are useful to simulate the transient temperature loads on modules at locations and periods for which the needed weather data are only available. These simulation data can be used for estimation of the energy gain of different module types or for estimation of the thermal stress on the materials.

2.2.2 Assessment of PV Cell Performance under Actual Malaysia Operating Condition.

The research is made by Hasimah A. R., Khalid M. n and Mohammad Yusri H. from Centre of Electrical Energy System, Faculty of Engineering, University Technology Malaysia[12]. This paper presents a comparative analysis on PV cells performance for four different PV technologies under actual Malaysia operating conditions.

Comparison has been done to four type of PV technologies which are Shell Ultra 85-P, BP Solar-380X, Bp Solar-Millenia MST 50MV and BP Solar-BP Apollo 980. The comparison is based on the conversion efficiency for different PV technologies under actual operating condition. During predicting the output of PV component of an energy system, two basic input sets are used which are meteorological data and specification PV modules. The required inputs are the weather data such as solar radiation and ambient temperature and PV module specification for each four type.

Two simulation tools which are RETScreen and PVSYST are used to predict the total PV array area, number of modules, and annual energy in kWh per m^2, initial cost investment and energy cost per kWh. Both simulation tools used an average monthly solar radiation and the mean ambient temperature data as the input.

The result indicates that higher module efficiency needs less collector area of the PV modules and hence less support structure to be built for the system. Shell Ultra 85-P and BP Solar-380X give higher returns of annual energy yields but required high investment cost. Meanwhile, BP Solar-Millenia MST 50MV and BP Solar-BP Apollo 980 give less annual yields with lower investment cost and low rate of energy production cost per kWh.

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2.2.3 Operating temperature of photovoltaic modules: A survey of pertinent correlations.

Research made by E. Skoplaki and J.A Palyvos from Solar Engineering Unit, School of School Chemical Engineering, and National Technical University of Athens[5][6][7]. This paper is a survey of correlation on operating temperature of photovoltaic.

From the survey that have been done, most literature produce dozens of correlations expressing T_c, the PV cell temperature, as a function of the pertinent weather variables, such as ambient temperature, T_a, local wind speed, V_w, and solar radiation flux G_T. besides weather variable, these correlations also includes material and system-dependent properties such as glazing-cover transmittance, τ and plate absorptance, α as parameter.

PV cell temperature rise over the ambient one is extremely sensitive to wind speed, less so to wind direction and it is practically insensitive to the atmospheric temperature. PV cell temperature depends strongly on the impinging irradiance namely, solar radiation flux on the cell or module.

Correlation for PV operating temperature can be either explicit in form where Tc is given directly or implicit which involve variable that depends on T_c. PVFORM hourly simulation package used to predicts the cell temperature of photovoltaic array. PVFORM photovoltaic performance model used in PVWATTS to do estimates monthly and annual electrical energy production and cost savings for grid-connected via hour-by-hour calculation. Photovoltaic analysis and transient simulation method (PHANTASM) used to predict the output energy of a BIPV installation which requires less parameter compare PVFORM.

2.3 Project Review

2.3.1 Photovoltaic System in Malaysia

Photovoltaic (PV) system or solar electricity is the name of a system that converts the sunlight into electricity. A basic solar PV panel consists of connected PV cells, which contain a semiconductor material covered by protective glass connected to a load. When light energy strikes the cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current or electricity. This electricity can be used to power a load, such as a light or a tool. This form of energy conversion is safe, require no moving parts, consuming no conventional fuels, creating no pollution, and lasting for decades with little maintenance [13] [14].

With increasing population, the cost energy consumption also has increased day by day. Every decade witnessed a doubling of energy consumption. Due to increasing the consumption, the price of traditional fuel such as oil and coal has also increased. Sun is the original source of most energy, which is used on the earth like wind energy, water and waves which are in fact from solar energy. Trees and all plants can be alive by using sunlight from sun. Therefore, the energy released during burning of these materials is from sun. So, almost all traditional resources of energy are indirectly from sun [14]. Malaysia is located just north of the Equator, experience high annual irradiation and the average of daily solar irradiation at Malaysia is more than many countries hence it is suitable region for using this free source of energy [3][14]. The amount of power generated is depending on the ambient factors such as

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irradiation, ambient temperature, wind speed and dew point temperature [4][5][6][7][9][13][12] and[14].

Malaysia is between latitudes 1° and 8°N and between longitudes 99° and 120°E. According to the Ministry of Energy Communications and Multimedia (MECM),Malaysia is in the equatorial region with an average daily solar radiation of 4,500 kWh/m2 and sunshine duration of about 10 hours. Ambient temperature stays high during the year between 27°C to 33°C with the average humidity of 80% – 88%, in the highland areas arise to nearly 90%, and never falling below 60%. An installation of PV in Kuala Lumpur receives 1.3 times higher global solar irradiance in compare to Germany. The differences between a standard condition and the maximum solar radiation is usually between 800 W/m2 to 1000 W/m2 but the ambient temperature could be as high as 40°C at noon, resulting in a 60°C PV cell temperature. Therefore, an 80 Wp PV would only produce a maximum of 65Wd.c at times [9][12] and[14].

In order to identify the performance of PV modules, the effects of environmental factors such as meteorological parameter as humidity, ambient temperature, and wind speed should be taken into account. Variable character of all these factors, however, it is common for outdoor operating conditions and to more or less extent they all together must affect every module's behavior[5][6][7][12] and [15].

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2.3.1.1 Operating Temperature

It is well known that system output power, or efficiency, decreases with the increasing temperature of the cell incorporated within the system mainly due to a decrease in open-circuit voltage (Voc) as a function of increasing temperature.

Lowering the normal operating temperature of the system increases the power output for both applications. It is commonly believed that concentrator systems are fundamentally inferior, compared to one-sun designs, by having higher operating cell temperatures when they are installed and operated at similar sites under similar ambient conditions for wind and temperature[5][6][7][14] and [15].

2.3.1.2 Ambient Temperature

Ambient temperature or temperature in a room is the air temperature of any environment where computers and related equipment are kept. Ambient temperatures play a major role to keep the functionality of many types of machines and equipment, and various methods can be used to control ambient temperature.

The PV system must carefully size depends on different ambient temperature to ensure that the output voltage is not too high, which could damage the equipment. This is because PV panels are more efficient at lower temperatures. Cooling the PV panels allows them to function at a higher efficiency and produce more power[5][6][7][10] and [15].

Temperature affects how electricity flows through an electrical circuit by changing the speed at which the electrons travel. This is due to an increase in resistance of the circuit that results from an increase in temperature. Likewise, resistance is decreased with decreasing temperatures[5][6][7][8] and [15].

2.3.1.3 In-plane Irradiation

Solar irradiance reaching Earth is plentiful and can be harnessed to provide electricity through solar PV panels. Radiation, the transfer of energy through electromagnetic waves, is the energy transfers medium from sun to Earth. Conduction, the transfer of energy through solid material by electron movement, occurs on the PV cells themselves.

There is a difference between direct and diffuse radiation. When it comes directly from the sun it is known as direct radiation. When the radiation is scattered by the atmosphere back to Earth it is called diffuse radiation.On an annual basis, about half of the radiation is direct and the other half is diffuse.

Because solar PV panels interact with their environment and their efficiency reference is so low, they passively absorb about 80% of the incoming solar irradiance as heat.

2.3.1.4 Wind speed

The maximum power generation depends on the environmental factors, mainly the irradiation and the cell temperature. The other environmental factors which involve are such as the humidity, the temperature, and the wind velocity [6] [12]. PV cell temperature rise over the ambient which is extremely sensitive to wind speed, less so to wind direction, and practically insensitive to the atmospheric temperature [5].

Convection, the transfer of energy by a moving fluid, occurs when wind blows on the solar panels.Usually more than one of these mechanisms is involved in real-world heat transfer problems, such as PV panels. Heat transfer is one of particular importance because of the inverse relationship its efficiency and temperature speed is less than 0.5 meters per second or less than one knot[13].

The cell temperature mainly depends on the temperature and the wind velocity. The wind has the cooling effect for the PV module[12].

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2.3.1.5 Dew-point Temperature, T_d

Dew point is the temperature at or below which dew or liquid water will drop out of the air because the cooling temperature means the air can hold less water and the relative humidity has reached or exceeded 100% for that temperature and air mass.

Generally relative humidity (RH) is a percentage measure of moisture in the air compared to what the air actually is capable of holding at a particular temperature. The higher the humidity, the closer the dew point to the air temperature. When the humidity is 100 percent, the dew point and the air temperature are the same .The dew point can never be higher than the temperature of the air at any given time.

For PV, current increases when relative humidity drops which means low water vapor in the atmosphere, resulting to high flux which enhances high current production. Meanwhile, increasing in voltage leads to decrease in relative humidity. This shows that efficiency is high during low relative humidity.

Hence an increase in solar flux combined with low relative humidity leads to increase in output current and efficiency of the PV panel, the electrical efficiency drops with increase in operating temperature.

2.4 Conclusion

As a conclusion, all the findings from the previous method will be accumulatively used to gain more knowledge about PV module and parameter involve. By revisiting the previous research, can be summarize that beside type of PV used, meteorological parameter also can give high impact on module temperature, T_m and at the same time affect the power produce by PV.

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CHAPTER III

METHODOLOGY

3.1 Introduction

This chapter will discuss the overall methods involved in this thesis.This project begins with gathering information regarding the technique or format required to train and evaluate the data. The flowchart of the overall project is shown in Figure 3.1. Flowchart shows the guidelines on how to execute the project practically to ensure overall project implementation will be run smoothly and succeed. The flowchart also describes the phases of project achievement from beginning until the end of this project.

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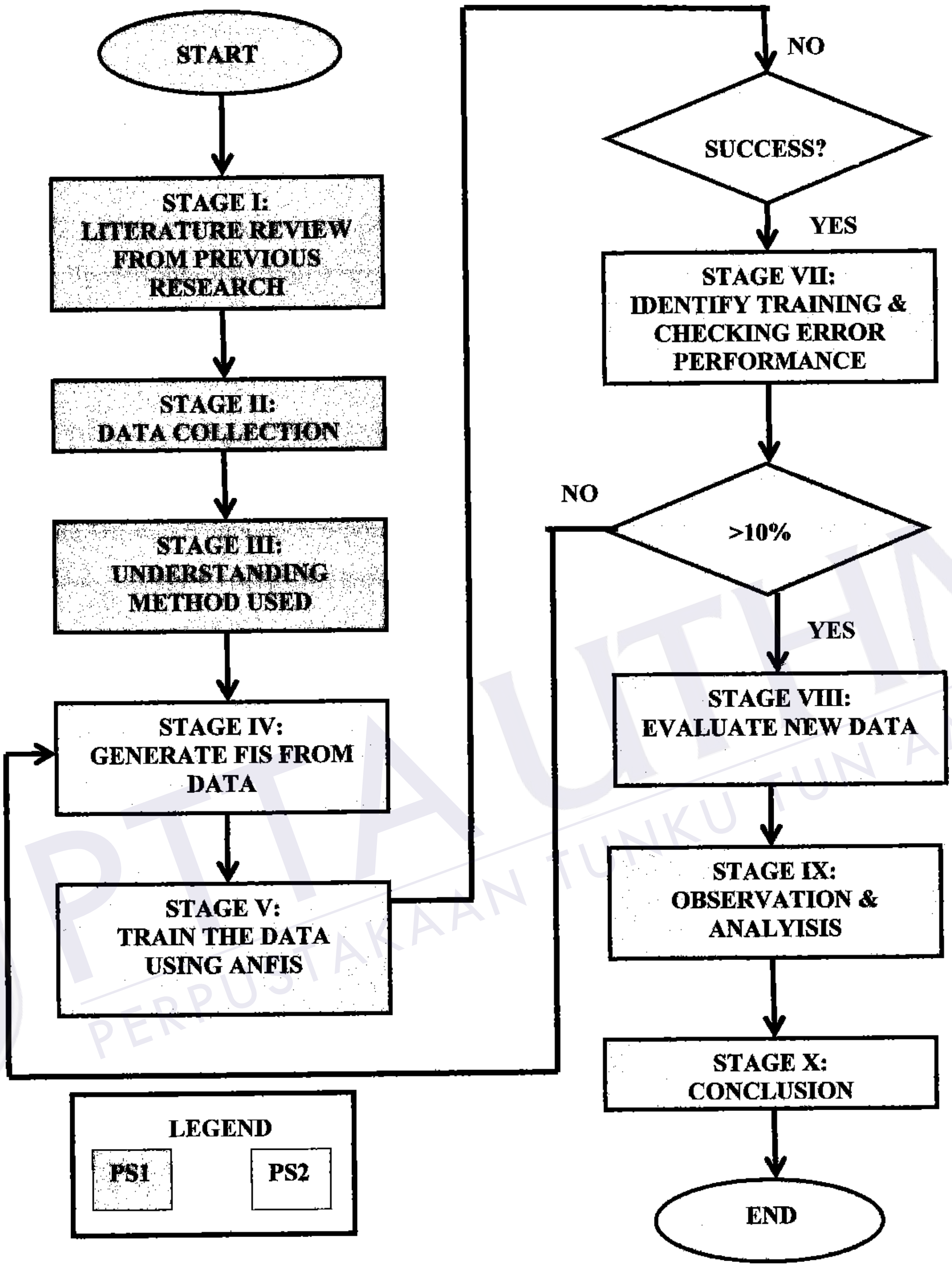

Figure 3.1: Flow chart for overall process

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3.2 Project Review

Figure 3.1 shows the overall processes involved in executing this project. The process will be divided into nine stages accordingly. In the first stage, studies are done on literature review from previous researches to gain the knowledge and information required of PV meteorological parameter and PV cells.

The second stage is data collection. The data used in this project are obtained from PV reading where the testing was conducted at a BIPV system located at Malaysia Green Technology Corporation, Bandar BaruBangi, Malaysia as shown in Figure 3.2. The system specification and site description are shown in Table 3.1[16].

Figure 3.2: Location of the investigated PV (refer arrow)

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TABLE3.1: System Specifications and Site Descriptions

Subjects	Descriptions
Site	Pack A, MGTC, Bandar BaruBangi, Malaysia
Longitude & Latitude	2.96^0N & 101.75^0E
Type of system	Grid-Connected
Nominal Power	$45.36kW_p$
PV module type	Polycrystalline
PV module tilt angle & orientation	7^0& facing west
Mounting type	BIPV(PV array acts as a roof. Refer Fig 3.2)

There are four type of data had been collected during the testing. First is the module temperature, T_m where the sensor was located at backside of the module. Second is array irradiance, G_T using pyranometer. Irradiance not only being converts into direct current at the PV array, but it also will increase the module temperature of the PV array. For ambient temperature, relative humidity and wind temperature, three sets of sensor were installing above the roof. The data taken from the site are collected and used to represent the behaviour of input data as shown in Figure 3.3. The target is the data of module temperature T_m[16].

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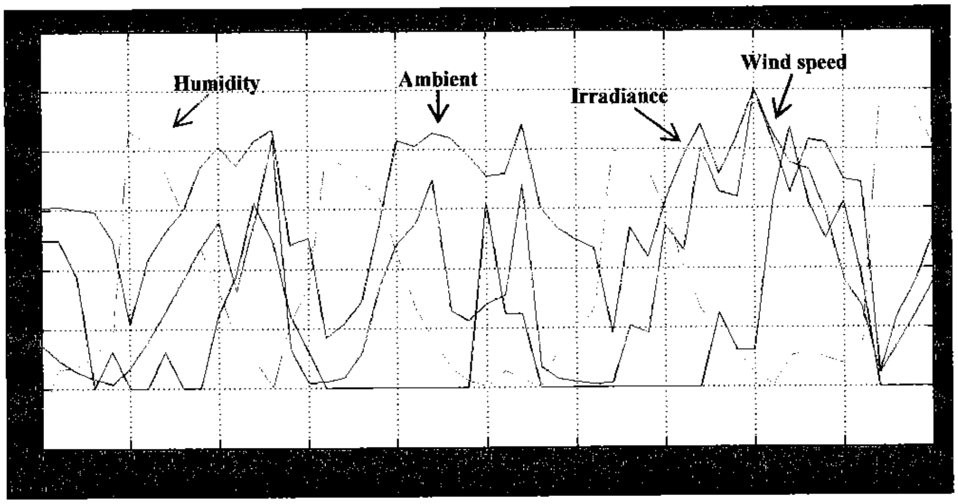

Figure 3.3: Input data need to be train

The final stage in this master project 1, which is the third stage, refer to the training data using Adaptive Neuro-Fuzzy Inference System (ANFIS) method. The result and analysis of the data training will be explained on stage seven, thus giving a model that can evaluated T_m based on four input parameter T_a, G_T, V_w and RH. The result and analysis of the model will be explained in stage nine. Finally, the conclusion for the whole process involved in this project will be explained in stage ten.

3.3 Artificial Neuro-Fuzzy Inference System (ANFIS)

Artificial Neuro-Fuzzy Inference Systems (ANFIS) approach learns the rules and membership function from data. ANFIS is Adaptive networks that consist of network of nodes and directional link. Learning rule is associated with network. These networks are learning a relationship between inputs and output. It can only be representing in Sugeno e Tsukamoto fuzzy models. A first-order Sugeno fuzzy has rule as the following [17] [18]:

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Rule 1:

If x is A1 and y is B1, then $f1=p_1x+q_1y+r_1$

Rule2:

If x is A2 and y is B2, then $f2=p_2x+q_2y+r_2$

And the model will be as shown in figure 3.4.

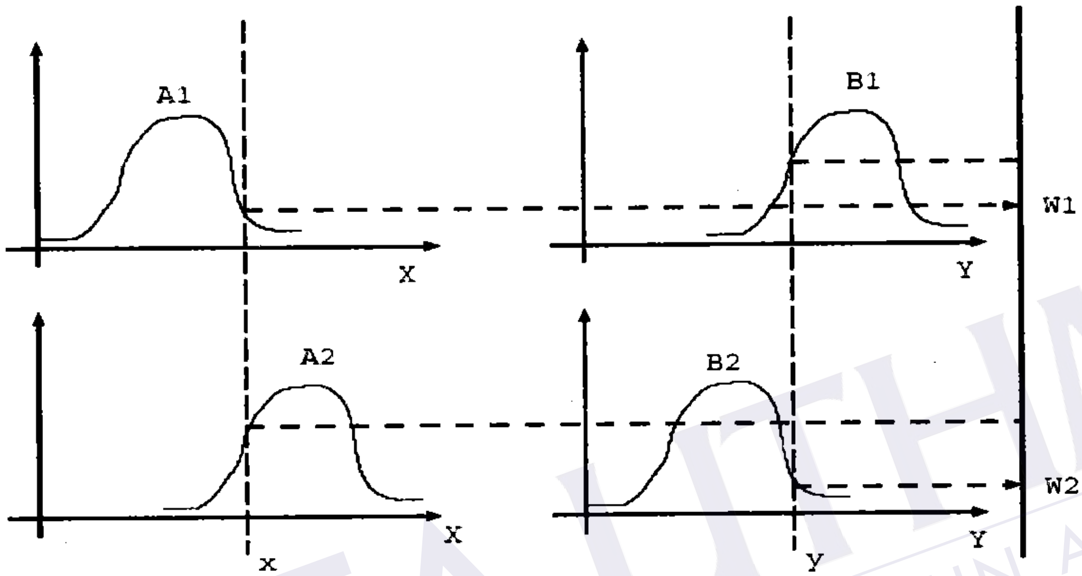

Figure 3.4: Rule view of two rule Sugeno system

ANFIS uses a hybrid learning algorithm. The ANFIS architecture is shown in figure 3.5. The circular nodes represent nodes that are fixed whereas square nodes are nodes that have parameters to learn [19].

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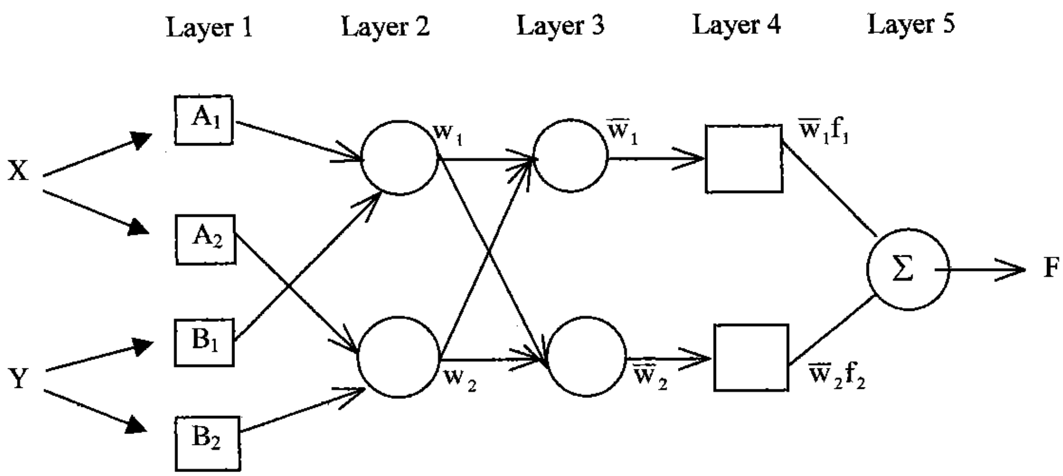

Figure 3.5: An ANFIS architecture for a two rule Sugeno system

3.3.1 Layer 1

The output of the *i*th node of the layer *l* is $O_{l,i}$. every node *i* in this layer is an adaptive node with a node function as shown in equation (3.1).

$O_{1,i}=\mu A_i(x)$ for $i = 1,2$, or $O_{1,i}=\mu B_{i-2}(x)$ for $i=3,4$ (3.1)

x or y is the input node *i* and A*i* or B*i-2* is a linguistic label associated with the node. Therefore O1 is the membership grade of the fuzzy set (A1,A2,B1,B2). The membership function is shown in equation (3.2)

$$\mu A(x) = \frac{1}{1 + \left|\frac{x-c_i}{a_i}\right|^{2b_i}}$$

Where a,b,andc are parameters to be learnt. These are the premise parameters

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3.3.2 Layer 2

Every node in this layer is a fixed node labeled with Prod. The output of this layer is the product of all incoming signals as shown in equation (3.3).

$$O_{2,i} = w_i = \mu_{Bi}(B), \quad i = 1,2 \tag{3.3}$$

Each node represents the fire strength of the rule. This is where the t-norm is used to 'AND' the membership grades.

3.3.3 Layer 3

Every node in this layer is a fixed node labeled with Norm.The ith nodes calculate the ratio of the firing strength of the rule to the sum of all firing strengths as shown in equation (3.4). The outputs of this layer are called normalized firing strengths.

$$O_{3,i} = \bar{W}_i = \frac{W_i}{W_1 + W_2}, \quad i = 1,2 \tag{3.4}$$

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3.3.4 Layer 4

Every node i in this layer is an adaptive node and perform the sequent of the rules with a node function as shown in equation (3.5).

$$O_{4,i} = \overline{W}_i f_i = \overline{W}_i (p_i x + q_i y + r_i) \tag{3.5}$$

Where $\overline{W}_i$ is the normalized firing strength from layer 3. The parameter set of the node is (p_i, q_i, r_i) are determined and referred to as the consequent parameter.

3.3.5 Layer 5

The single node in this layer is a fixed node labeled SUM, which computes the overall output as the summation of all incoming signals as shown in equation (3.6).

$$O_{5,i} = \sum_i \overline{W}_i f_i = \frac{\sum_i W_i f_i}{\sum_i w_i} \tag{3.6}$$

This is how the input vector is fed through the network layer by layer.

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