The Development of Photovoltaic System in Indonesia

EECE 492: Distributed Energy System Management

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ABSTRACT

"The Development of Photovoltaic System in Indonesia"

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Indonesia is a tropical country that has abundant renewable energy such as geothermal, tidal, wind, solar, and biomass energy because it is located at equator. However, most power plants in Indonesia are still dependent on fossil fuels to generate electricity. Today, Indonesia has made a treaty with other countries to use renewable energy not only to decrease the pollution but also to increase the demand electricity on remote islands. This allows inhabitants to use the electricity anytime they want. This report presents the investigation of the development of photovoltaic system in Indonesia by discussing the general operation of photovoltaic system, the solar projects installed in Indonesia, and the impacts of photovoltaic system. At the end, photovoltaic system can bring benefits to Indonesia in terms of social and environment aspects. The schedule of installation of the system is entirely dependent on the budget of the Indonesian government.

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1.0 INTRODUCTION

Every year each nation leaders always meet at annual summit meeting to discuss the renewable energy policy because they are concerned with the fossil fuels which are the primary energy sources for thermal power plants. Because the fossil fuels are non-renewable energy, the governments have decided to find alternative energy to tackle this problem before the fuels are ran out. Moreover, renewable energy will also decrease the number of CO_2 emissions. Indonesia, along with other industrialized and developed countries, has started to reduce the number of thermal power plants by building renewable power plants such as geothermal power plants. However, the common problem that other countries have is that the growth of the electricity demands increases significantly that it exceeds that the capacity of power plants. If this still keeps going on, it will damage the plants. This report presents the investigation of the development of photovoltaic system in Indonesia to determine if the system is suitable to be built in Indonesia.

The following first section covers the principle operation of photovoltaic system. The second section explains the potential of solar systems to be developed in Indonesia. The final section focuses on the impacts of photovoltaic in Indonesia.

2.0 PHOTOVOLTAIC SYSTEM

Photovoltaic system is a power system that converts solar energy into electrical energy using solar cells. This section explains the operation of photovoltaic system.

2.1 Photovoltaic System

Photovoltaic system can be divided into three main parts: solar cells, controller system and the energy storage as shown in Fig. 1.

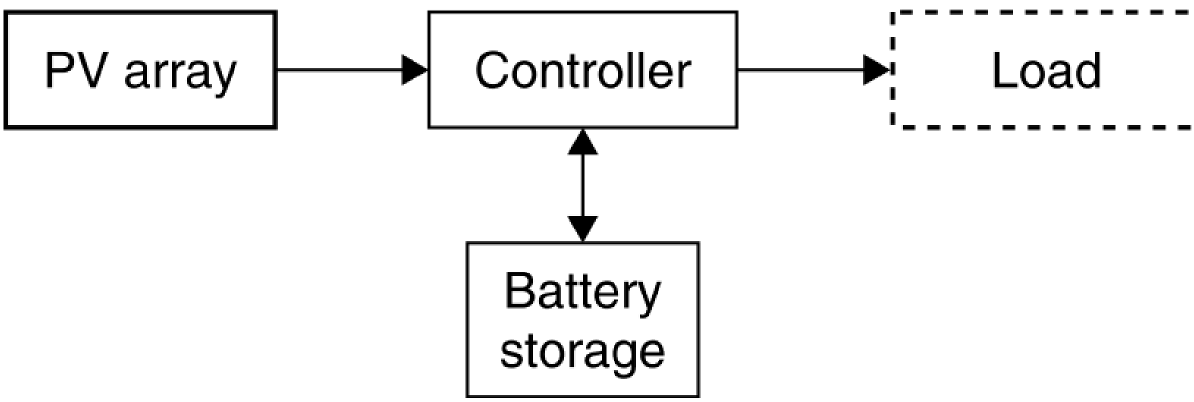

Figure 1: Basic photovoltaic system [4]

The main principle of the system is that after the PV array, which is consists of solar modules, generates electricity to the load, the electricity will also charge the energy storage such as battery shown in Fig. 2 at the same time [8]. The battery storage controlled by the controller will supply power to the load in case the solar cells do not have enough solar energy or at night. If the load is in AC, then the DC-AC inverter is connected before the load because the current generated from solar cells is in DC. Moreover, the DC-AC inverter also is connected between the battery and the load. The next section will explain each component in more details.

2.1.1 Solar Cell

As shown in Fig. 1, a solar cell consists of two thin layers of semiconducting materials such as Silicon [9]. When the light enters the gap between the top layers, it will cause the majority holes and free electrons in the p-type side and the n-type side to diffuse each other [4]. As a result, it creates the depletion region resulting in an electric field across the region. The electric field then sends the electrons to the n-side and the holes to the p-side [4]. Since the load such as lamp is connected to both sides, the electrons will flow through it to the p-side to unite with the holes, constituting electrical current [4]. This is called photovoltaic effect. However, the electrical output from a single cell is so small that several cells are connected together to form a solar module. Photovoltaic panel (PV panel) connects solar modules either in series or parallel depending on the voltage and current as shown in Fig. 2[15]. The unit power of solar cell is W_p.

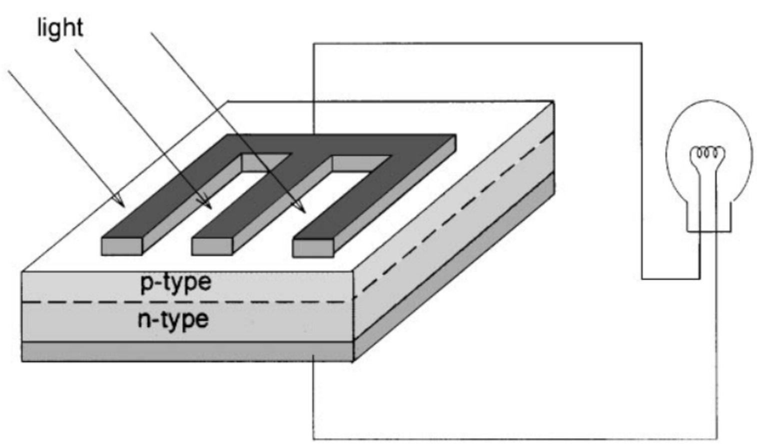

Figure 2: Schematic of a Solar Cell under Illumination [9]

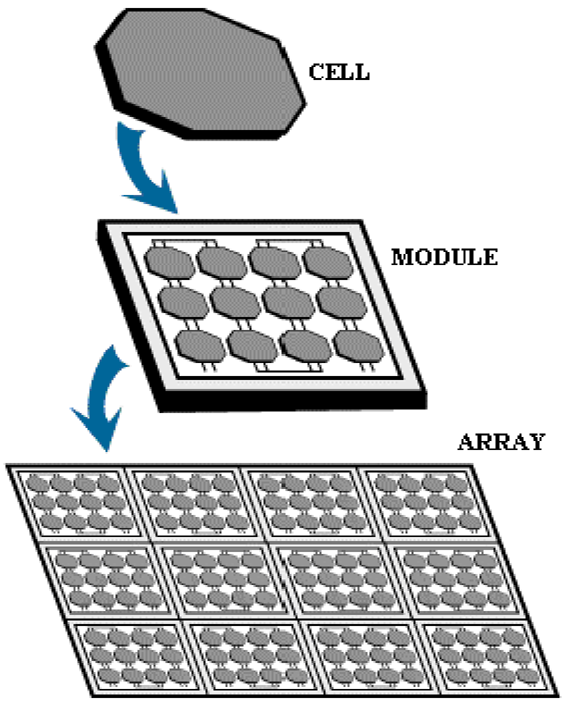

Figure 3: Solar Cell. Solar Module and Solar Array [5]

2.1.2 Control System

The controller system is consists of a DC-DC converter controlled by a control circuit for photovoltaic system as shown in Fig 4. Boost converter is used to step up the voltage into kV [15]. It can reduce the switching power losses and increasing the power conversion efficiency [18]. The duty cycle of the converter and the inverter will be determined by Maximum Power Point Tracker in the circuit system to track the maximum power of solar array to meet the load demand. This is done because the array has non-linear relationship based on solar depending on environmental factors such as solar irradiation and temperature [19]. The characteristic of solar array can be seen in Fig.5. Moreover, the control circuit is also used to monitor the condition of the battery.

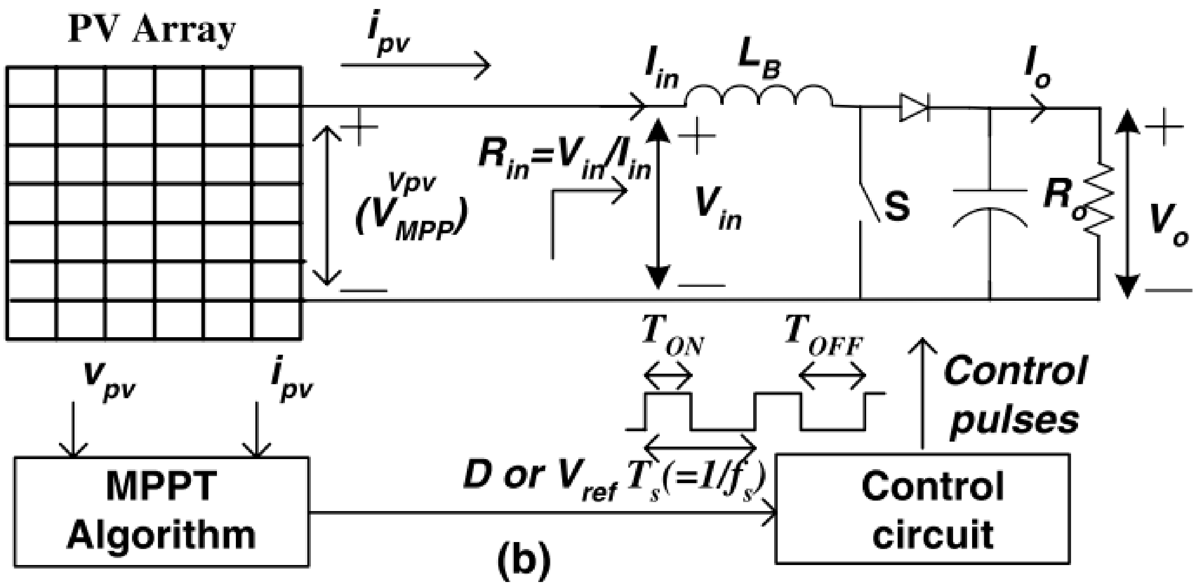

Figure 4: Control System Consisting of Boost Converter and Control Circuit [15]

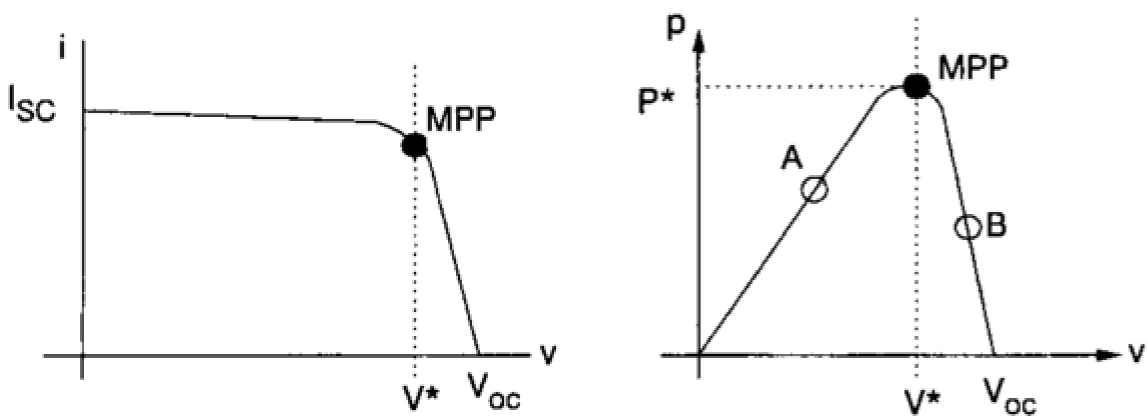

Figure 5: The nonlinear relationship; (left) between current and voltage; (right) between power and voltage [18]

2.1.3 Battery Energy Storage System

Battery Energy Storage System (BESS) is a storage that is used to store electrical energy in chemical energy. The most common type of battery is lead acid based on the factor price and availability [14]. The battery will be controlled by control circuit in order to prevent reducing its lifetime. In other words, the control circuit will control the charge of battery and protect the battery from overcharging [2].The lifetime of batteries is affected as follows:

- the high state of charge where the charge current must be limited to avoid overheating the batteries (overcharge protection) [2]
- every single cells within a battery must be homogenised by an equalisation charge [2]
- The lowest limitation of lowest state of charge for lead acid batteries is between 20% and 50 % [2].

The MPPT will determine if the battery is allowed to discharge to deliver power to the load depending on the battery condition. If the battery condition is not allowed to supply, then it must be supplied with external source such as AC source or solar array to prevent it from damaging the battery. If it does not have external source, then it must be disconnected completely from the line.

3.0 THE DEVELOPMENT OF PHOTOVOLTAIC IN INDONESIA

Indonesia is one of tropical countries that are considered to develop photovoltaic (PV) system due to its geographic location. Because of its location, the country has a lot of abundant solar energy. This section covers solar irradiation in Indonesia and the solar projects developed in Indonesia.

3.1 Solar Irradiation

Solar irradiation is the amount of available solar energy on the ground surface over a specified time, expressed as kWh/m^2 or MJ/m^2. The sum of direct and diffuse solar irradiation is called global irradiation. Solar irradiation is important factor for design and operation of solar energy system because it can estimate the cost of building photovoltaic system, especially solar cells which are sold based on the area.

Although Indonesia has potential to utilize solar energy systems, the solar irradiation data is not existed because some meteorological stations do not have reliable pyranometers to measure the solar irradiation [12]. Due to limited solar irradiation data, it is not possible to estimate the cost of building photovoltaic system. Therefore, based on the study by author [12], the estimated monthly global solar irradiation for entire country can be done by using artificial neural network (ANN) method.

ANN is a mathematical method that is used to predict the output by considering several inputs. To get best estimated global irradiation, average temperature, relative humidity, sunshine duration, precipation, wind speed, longitude, latitude, altitude, and months are used for the inputs of the ANN methods as shown below.

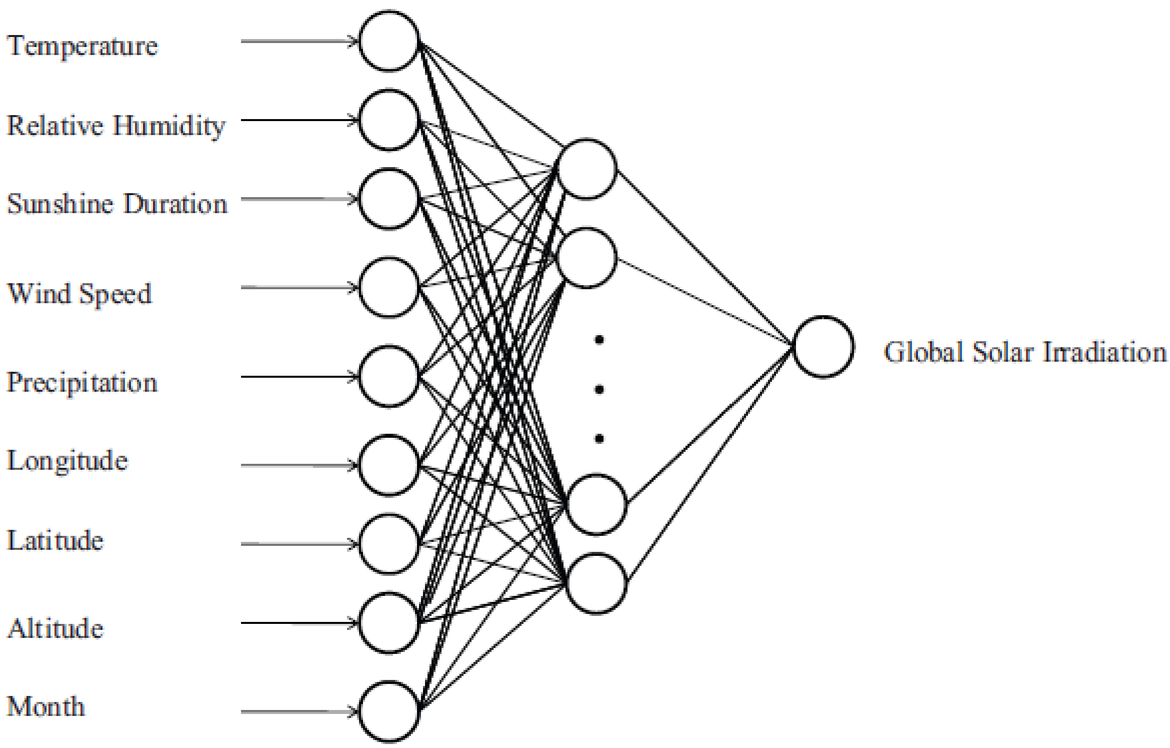

Figure 6: The Best Approximation Inputs of ANN [11]

Please refer to Appendix to understand ANN method in details.

The estimated data using ANN method can be compared to measured data in Fig 7.

According to the author [12], the ANN model for Manado estimates the data with the accuracy of 93% and the error of 7.6%. This shows the ANN model is reliable to be used to predict the global solar irradiation in Indonesia.

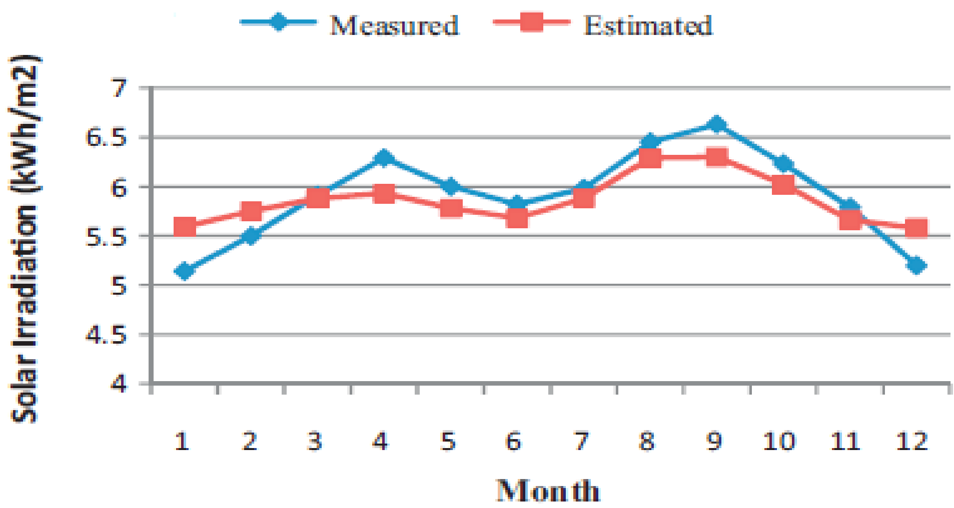

Figure 7: The Solar Irradiation in Manado City [12]

After obtaining the best estimated solar irradiation, Geological Information System (GIS) uses the estimated data and put the data in the map to produce solar irradiation map [12].

The following figure shows solar irradiation map in Indonesia.

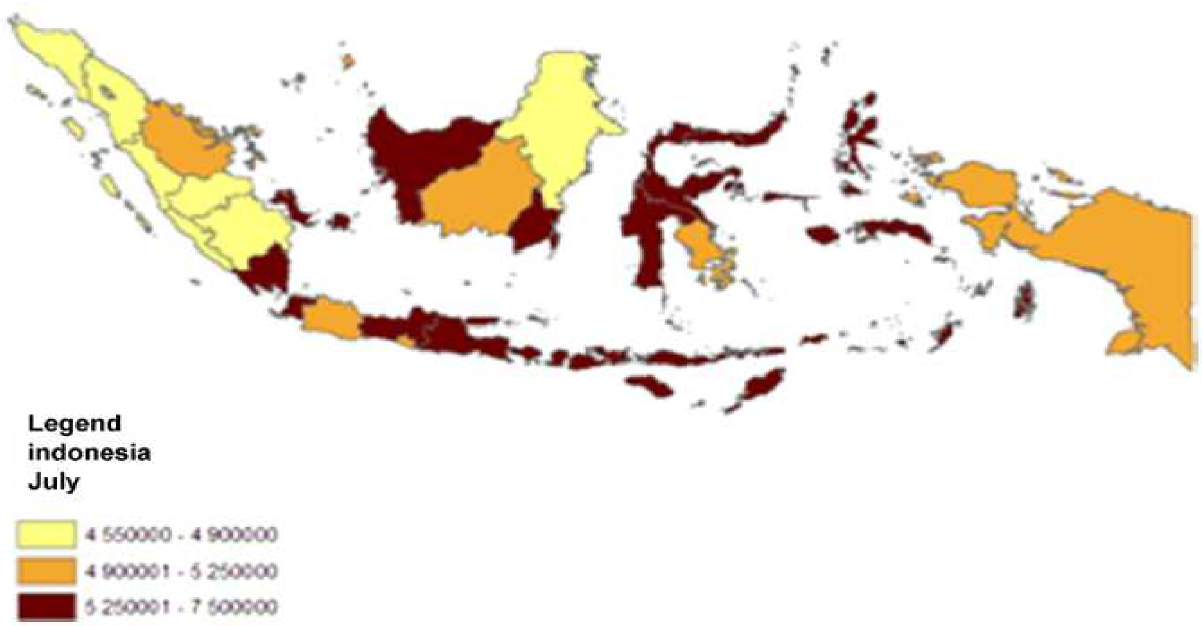

Figure 8: The Solar Irradiation Map in Indonesia [12]

After mapping solar irradiation in Indonesia in Fig. 8 using ANN method, the solar irradiation values are divided into three classifications: yellow (below 4.9 kWh/m^2), orange (4.9-5.25 kWh/m^2), and dark brown (above 5.25 kWh/m^2) [12].

As shown in Fig.6, not all cities receive equal distribution of solar energy due to continuously high humidity [6].However, it is clear that most islands in Indonesia have high potential of global solar irradiation ranging between 4.6 kWh/m^2 and 7.2 kWh/m^2 [12].

The solar irradiation map indicates that Indonesia is suitable place to generate electricity using photovoltaic system.

3.2 Solar Projects

Solar projects have been implemented in Indonesia since 1979, but only two solar projects that are still being promoted by the government today: solar home system (SHS) and street lightning system (SLS). The projects have been implemented in Sukatani village, which is the first village to use PV system to generate electricity. This section will focus on PV system and PV hybrid system in Indonesia.

3.2.1 PV System

The state electricity company has built 88 SHS and 15 SLS in Sukatani village in West Java since 1988 because of three reasons:

1. The Sukatani villagers did not have access to get electricity from electricity grid [7]
2. The climate in the village was a perfect place to test solar system [7]

3. The operation of SHS allowed the villager to maintain the system by themselves based on their lifestyle and education [7].

The Sukatani's SHS consist of three components: two PV modules of 38 W_p (a PV array of 80 W_p), a BAS (Battery Autoguard Safety), and a 100 Ah battery. The modules are mounted at the outdoor of the house and the other two components are installed inside the house as shown in Fig 9[7]. SLS consists of two PV modules of 38 W_p, a TCU (Time Control Unit), and two 100Ah batteries [17]. The TCU controls the light of the street lamps at desired time and monitor the condition of the batteries [7]. Meanwhile, the BAS also controls the charging and discharging of the battery [7]. According to the author [1], the average global irradiation in Sukatani village is around 4 kWh/m^2 day which meets the estimated data in Fig.8.

After nine years later, the performance of SHS is still reliable although the batteries are replaced with 70 Ah batteries due to low electric consumption [1]. The new batteries are required to be replaced with a new one every 3.5 years [1]. Because there is an increase in electrical consumption, the authors [1] analyse that a PV module in the range of 35-130 W_p and a battery with the capacity of 35-130 Ah can meet different demand of electrical consumption.

Figure 9: Sukatani Village [11]

3.2.2 PV Hybrid System

As the electrical consumption starts to increase as year goes by, PV hybrid system is considered to tackle the weakness of PV system, which is the output power of PV module depending on the solar irradiation.

Another pilot solar project, PV-micro-hydro hybrid system, has been installed in Taratak village in Lombok Island since 1989. Besides solar energy, the system uses hydropower as a back up because many small rivers in every island that can be used to generate electricity. The system is comprised of a 48 kW_p PV array, system control (control circuit), a 480 kWh battery, and micro-hydro generator, rectifier, and inverter as shown in Fig.10 [14].

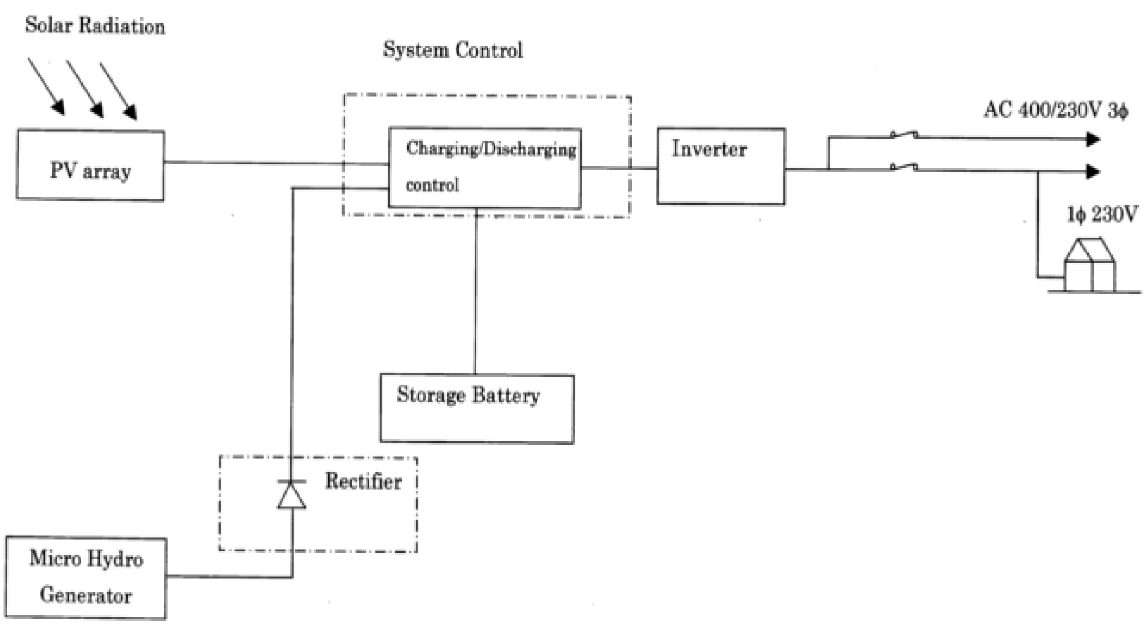

Figure 10: The PV-Micro-Hydro Hybrid System in Taratak Village [14]

The rectifier in Fig.10 is used to convert from AC to DC waveform. The operation of the system is micro hydro generator will supplement power from the PV array system in case the output of PV array cannot meet the demand load during the peak time [14]. Moreover, the generator will reduce the functionality capacity required for battery [14]. However, the micro hydro generator cannot be used as primary generator due to the low potential of hydropower at the site [14]. As a result of the low potential of hydro energy, the generator can only generate 6.3 kWh with discharge rate of 2401/s [14]. The hydro generator is only operated at night for 12 hours because the water is used for irrigation during daytime [14]. When the system control detect that the charging level of battery is lower than 80%, then hydro generator is usually operated at 6 pm by opening the intake gate [14]. The authors [14] analyze the performance of PV-micro-hydro hybrid system is still dependable, but the local people require to replace the batteries to keep the best performance of the system [14].

4.0 THE IMPACTS OF PHOTOVOLTAIC SYSTEM

Since Indonesia has implemented photovoltaic system in some areas, the impacts of the system are needed to be considered if it is needed to be installed further in other areas. This section explains the impacts of photovoltaic system in Indonesia in terms of social, environment, and economical aspects.

4.1 Social Analysis

Since the installation of SHS in Sukatani village and PV Hybrid system in Taratak village, the government of Indonesia has started to deploy solar project known as “The Presidential Aid Project” in some remote areas [13]. The government believes that the SHS and PV Hybrid system are the solutions to remote village electrifications [13]. Through this project, the government has built 3,300 SHS in 15 provinces in the year 1990 [13]. This movement helps inhabitant to use electricity for 24 hours as long as they have been instructions how to use and maintain the system properly.

4.2 Environmental Analysis

The deployment of photovoltaic system in remote area reduces gas emissions because most inhabitants living remote are use fossil fuels as primary energy for diesel generator to generate electricity. The installation of the system will save approximately 2.2 millions of tons of CO_2 [11]. However, the system might pose a threat to environment if it is not handled carefully.

4.3 Economical Analysis

As the cost of fossil fuel increases, the cost of solar energy will be cheaper in the long run as shown below [10]. However, although the break-even point for solar energy will be happened in 10-15 years in Fig. 11, the cost of installation of photovoltaic system is four times the budget of the government of Indonesia. As a result, the schedule of the installation of the photovoltaic system is delayed. The solution to this problem is the Indonesian government invites international companies or donor countries to cover the cost of photovoltaic system [13]. For example, the Australian government gave AUSAID (Australian Aid) to Indonesia to install 36,400 units of SHS in 1997 [13]. Last year, Sharp made a contract with the Indonesian government to build a 100 MW photovoltaic power plant in Bali [3].

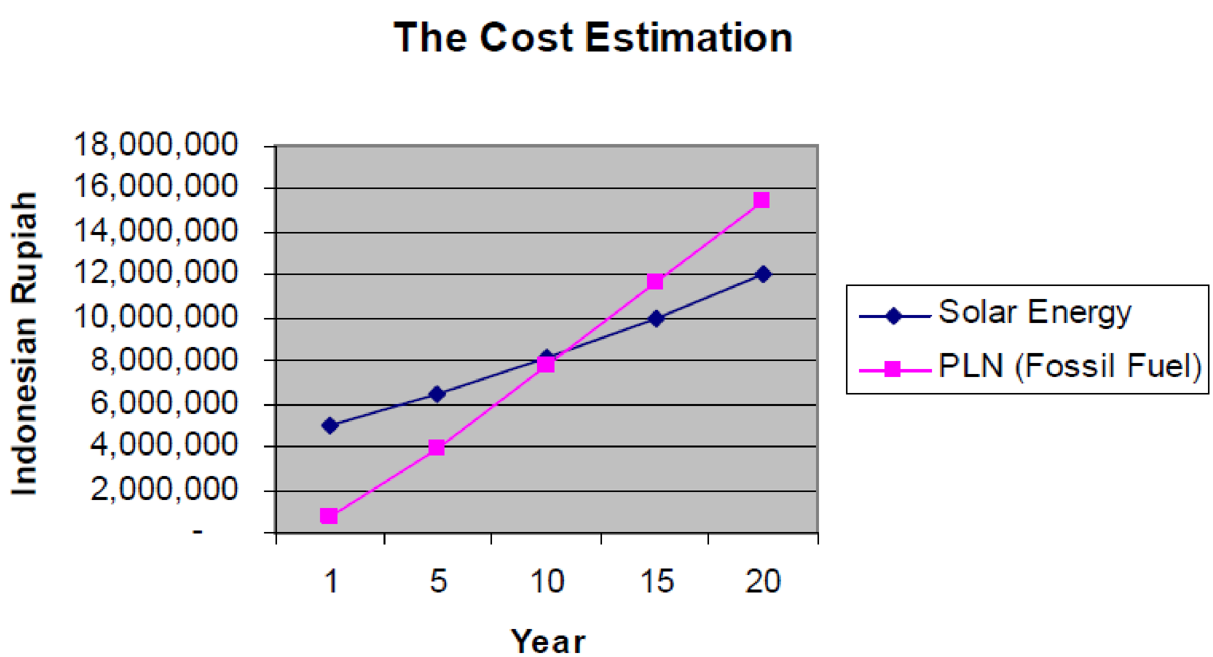

Figure 11: The Comparison price between Solar Energy and Fossil Fuel

5.0 CONCLUSION

This report investigated the development of photovoltaic system in Indonesia, which is a tropical country that has a lot of solar energy across the entire country. The photovoltaic system is consists of photovoltaic modules, control system, and battery storage. The condition of battery will be monitored by control system to protect the battery from overcharging. Because of ANN model and GIS, the global solar irradiation can be estimated for Indonesia. This will lead to development of photovoltaic system. The development of SHS in Sukatani village has led the Indonesian government to promote and install SHS in several remote areas. Although the impacts of photovoltaic system has brought benefits in terms of social, environmental, and economics aspects, the cost of installation of photovoltaic system is not possible for the government, so the government must have to find sponsors from international companies or other countries to fund the rural remote electrification.

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APPENDIX

Artificial Neuron Network is a mathematical method that is used to get the desired output by considering several inputs. This is method is very useful to predict solar irradiation

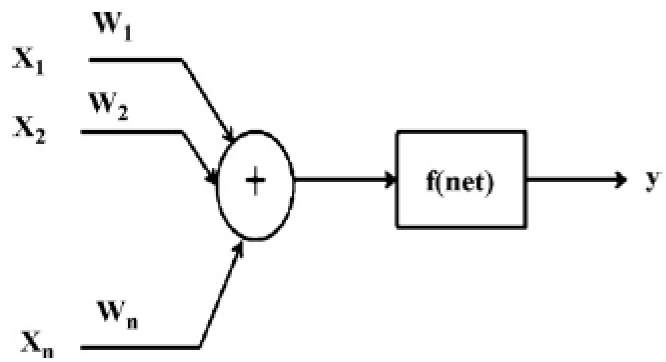

Figure 12: Typical ANN Model [12]

Every input X_n is weighted by W_n before going to the main body of artificial neuron (f(net) in Fig.12 [12]. The W_n will determine the strength of the connection between neurons as the neuron passes the value from one layer to next layer. Then the weights will be adjusted during the training process to get desired output [12].

The equation for f(net) is as follows:

$$net = \sum_{i=1}^{n} x_i w_i - \theta = w_1 x_1 + w_2 x_2 + \cdots + w_n x_n - \theta \rightarrow net$$
$$= W^T - \theta$$

Figure 13: The original signal X_iW_i as function of net [12]

This will give nonlinearity output of the function if the input signals exceed a threshold value, θ as shown in Fig.13 [12]. The main difference between ANN and other methods is that the information can be stored as weights between neurons by learning algorithm [12].The most known learning algorithm is the back propagation [12]. This algorithm allows each weights to be updated in each iteration by Fig.14.

$$w_{jij}^{new} = w_{ji}^{old} - \eta \frac{\delta E}{\delta w_{ji}}$$

Figure 14:The Back Propagation learning method [12]

Where W_{ij} represents the weight connected between neuron i^{th} and neuron j^{th} and η means the learning rate indicating how much weight will affect on each pass [12]. The value of learning rate should be between 0 and 1.

Then the equation shown below is used to calculate the error.

$$E = \sum_{k=1}^{L} \sum_{j=1}^{q} (b_{kj} - z_{kj})^2$$

Figure 15: Error Equation [12]

The estimated value with the least error is the best estimation for solar irradiation.

The summary of obtaining the best estimated data is shown in the next figure.

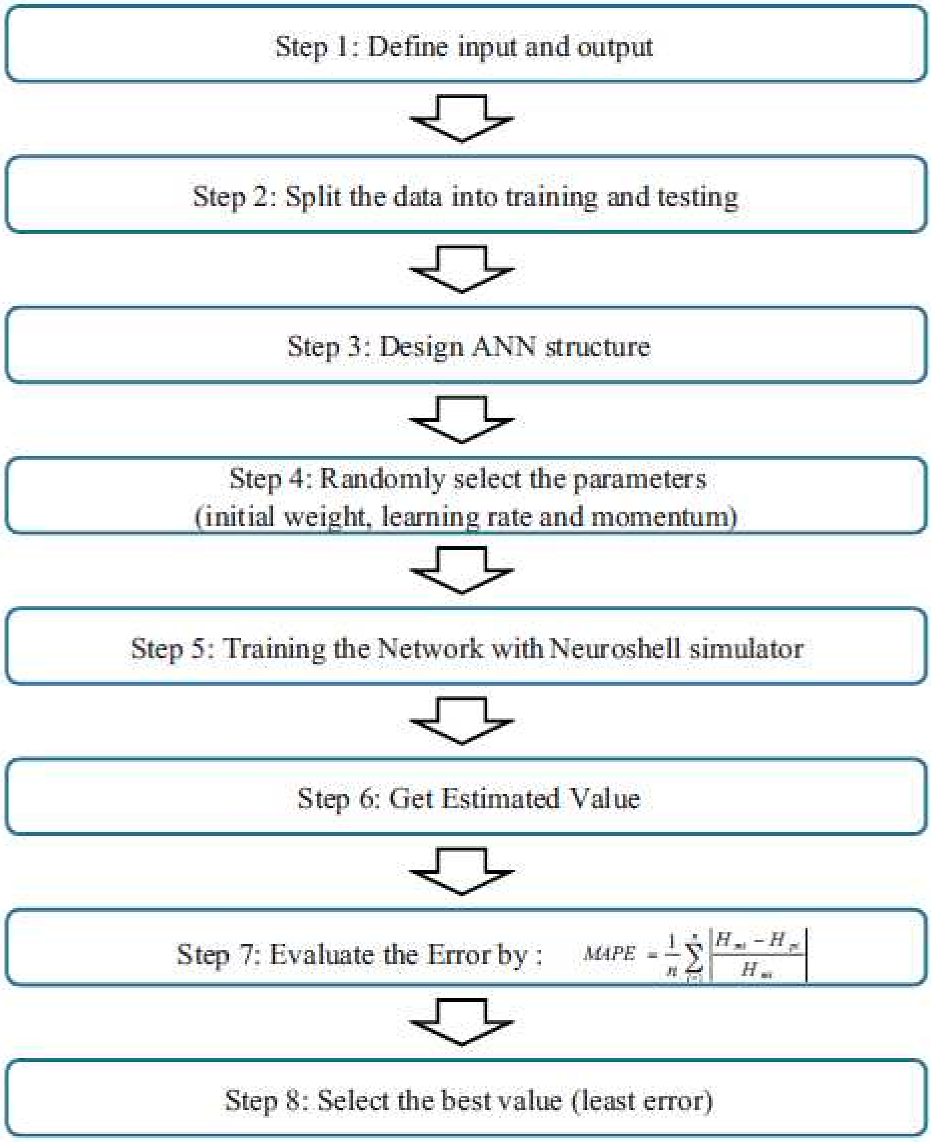

Figure 16: The steps of ANN model to predict solar irradiation [12]