PREDICTION OF PRODUCTIVITY 50 WATT SOLAR PANEL USING NEURAL NETWORK BACKPROPAGATION

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***Abstract* - This paper explain the prediction of 50 watts solar panel output using back propagation neural network based on the data of Semarang weather station climatology. Motivation of this research based on the problem that is difficult to estimate the average of solar panels power output daily.The output of solar panels influenced by the wether condition. Data of climatology used as input of artificial neural network are the intensity of solar radiation, humidity, wind speed, and temperature which are obtained from the Meteorology, Climatology and Geophysics Agency monitoring stations of Semarang. The output of neural network predicts power output of 50 watt solar panel. The neural network is trained by measurement data during nine months started from June 2012 until February 2013.Artificial neural network architectures are built using backpropagation method with four (4) inputs, one (1) unit hidden layer and one output. The inputs include the intensity of solar radiation, humidity, temperature and wind speed, and the output is the predicted energy output of 50 watt solar panels implemented in Semarang Indonesia. The amount of data used in this research was 273 days thatwere separated into two groups; 200 for training and 73 for testing. The results shows that the best configuration backpropagation neural network model with one hidden layer with eight (8) neurons, learning rate 0,01 and iteration 10000. This configuration carried out the coefficient of determination 98.5%,standard error 8,2 watt-minute, MSE 0,00369 and could predict 1026,4 watt-minute from 1071,6 watt-minute targets output 50 watt solar panel in Semarang.**

Keywords: Artificial neural network backpropagation, Solar panels, Predictions.

I. PRELIMINARY

Solar energy is an echo friendly energy source, but the ability of people to access this energy is still low, because the price of thisdevices is expensive, solar panel efficiency is still low, the technology of solar energy has not been understoodwell. Indonesia as a tropical country has the potential of solar energy by 4.8 kwh/m^2/day (Ministry of Research and Technology of the Republic of Indonesia, 2006). Several studies have been conducted in the field of solar energy, among others, study the effect of temperature on the power produced solar panels for a variety of climatological conditions (Skoplaki, et al., 2008). Research to determine the size of solar panels in solar power systems (stand-alone PV, grid-connected PV systems, PV-wind hybrid systems) using artificial intelligence techniques (Mellit, et al., 2009).Research to increase the amount of solar radiation on the surface of the solar panel to put 2 pieces of flat mirrors as reflectors so that the acquisition of power in solar module efficiency is increased and is expected to increase as well (Muchammad, et al., 2011).Feasibility of the use of ANN has also been carried out to estimate the maximum power of solar panel modules. In that study used radial basis function neural network (RBF), adaptive neuro fuzzy inference system (ANFIS) and three-layered feed-forward neural network (TFFN). Artificial neural network model developed trained with measurement data of solar panel technology is a double junction amorphous Si (a-Si 2j), solar panel triple junction amorphous Si technology (3j a-Si) solar panel technology Cadmium Indium diselenide (CIS) and solar panels thin film technology Cadmium Telluride (CdTe). This can result in the use of the selection of the most appropriate type of ANN is determined by three factors, namely: 1) the flexibility of the training process, 2) the structure of neural network model, and 3) the accuracy of validation errors (Syafaruddin, et al., 2009). Artificial neural networks have also been used to predict the output power of the solar panel to the climatological conditions. Previous research has been done the application of neural networks to predict the voltage and current output of solar panels array with input climatological conditions such as the intensity of solar radiation and ambient temperature. The solar panels used are arraytype with 6 m^2 surface area which produces a maximum voltage of 40 volts and a maximum current of 20 ampere. Data for training and testing in the form of solar radiation intensity, temperature, voltage and current solar panels by 5 x 364 days. Amount of training data for as many as 4 x 364 days, and testing the data as much as 364 days. Artificial neural network back propagation models were developed is a two neuron input layer, two hidden layer (first hidden layer with seven neurons and the second hidden layer with nine neurons), one output layer with two neurons (the first neurons prediction output voltage of of solar panels and the second neuron prediction output current solar panels). The result is a prediction of the voltage and current output of solar panels are being developed by artificial neural network conformity with the results of measurements with a coefficient of determination was 97% (Mekki, et al., 2007).

This research is the prediction of 50 watt solar panel output by using artificial neural network backpropagation based climatological data in the form of the intensity of solar radiation, humidity, temperature and wind speed of Semarang using visual basic 2008.

II. BASIC THEORY

Artificial neural networks (ANN) are systems that is made imitating the human brain, which can provide outputasa response to the given input. With the training and learning process through the artificial neural network is able toforecast or predict the future events based on data or pattern of previous events to put it (Siang, 2009).

In this research selected artificial neural network backpropagation architecture, with a neural network multi layer, which consists of input layer, hidden layer and output layer. Backpropagation neural network architecture is shown in Figure 1.

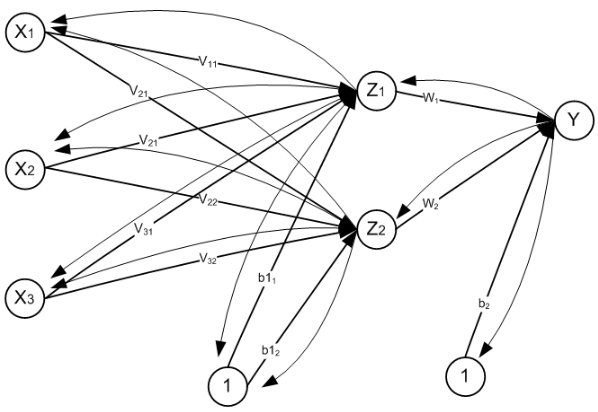

Figure 1. Artificial neural network backpropagation architecture (Kusumadewi, 2004)

Backpropagation neural network models require many learning over and over again, training aims to get the weight connecting the layers to produce the best predictions.

2.1.Backpropagation ANN training

Calculate output all hidden unit Zj (j = 1, 2, ..., p) by summing all of the input layer hidden by equation (1) as follows (Jones, 2005).

$$\mathrm{Zj} = b1j + \sum_{i=1}^{n} Xi\,Vji \quad (1)$$

To be eligible binary sigmoid activation function, the value Zj is converted to normalize value to a binary sigmoid function Zjn with equation (2) (Jones, 2005).

$$Zjn = f(Zj) = \frac{1}{1+e^{-Zj}} \quad (2)$$

Calculating the value of the output unit with equation (3).

$$Y = b2 + \sum_{i=1}^{n} Zi\,Wi \quad (3)$$

To be eligible binary sigmoid activation function of the value of Y is converted to normalized values to a binary sigmoid function Yn with equation (4) (Jones, 2005).

$$Yn = f(Y) = \frac{1}{1+e^{-Y}} \quad (4)$$

The next step is a backward. This step is starting from a unit of output, the hidden units to input units, with a counting error in each unit with equation (5) (Jones, 2005).

$$\delta o = (Ci - Yn)Yn(1 - Yn) \quad (5)$$

Error in hidden unit are given with equation (6):

$$\delta i = (\sum_{i=1}^{n} \mathrm{Wi}\,\delta o)Zi(1 - Zi) \quad (6)$$

Last is the adjustment of the weights (weight update) on each connection. Weights connecting the output unit to the hidden layer unit by equation (7).

$$Wi = (Wi) + (\rho \times \delta o \times Yn) \quad (7)$$

Weights connecting the input units to the hidden layer unit with equation (8).

$$V_{ji} = V_{ji} + \rho \delta o Zi \quad (8)$$

ρ islearning ratecan be selected with a value between0 to 1, in many cases selected 0,1 or 0,01.

2.2.Backpropagation ANN testing

Based on the final weight of each link on the smallest error condition obtained in the process of learning, further testing by using a new set of input data. To evaluate the results of prediction errors is to use MSE calculation with equation (9).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Yai - Yti)^2 \quad (9)$$

Explanation : *MSE= Mean Square Error*

Yti = target data

Yai = the actual (prediction result)

n = number of data

2.3. Panel Surya

Solar panels are devices that convert solar radiation energy (photons) into electrical energy. Solar panels assembled from multiple solar cells (photovoltaic), this is done to get the current and voltage is greater than a single solar cell.Block diagram of the solar cell is shown in Figure 2. Solar cell junction formed by p-type semiconductor and n-type. Semiconductors are formed by the arrangement is similar to a diode with a p-type silicon produces the positivepole is called the anode and n-type silicon produces negative pole is called the cathode.At the time of the solar cells do not receive sunlight (photons), then the solar cells do not produce voltage and current. As well as a diode, the current Io flowing when the voltage between the cathode-anode is greater than the knee voltage (0.6 volts).

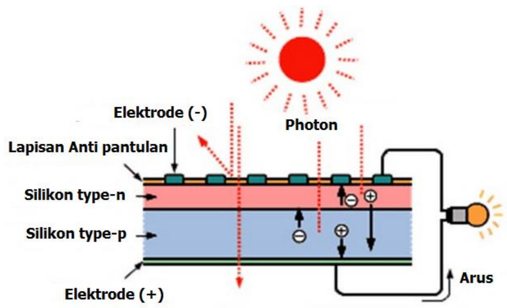

Figure 2. Diagram of solar cells (Christiana dan Stuart, 2013)

At the moment there are photons that irradiate the solar cell, causing a voltage between the anode-cathode pole. In this condition the voltage-current curve and the equivalent circuit of the solar cell is shown in Figure 3.

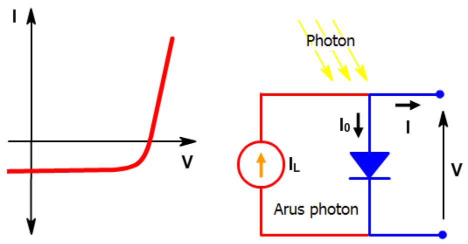

Figure 3. Equivalent circuit and the I-V curves of solar cells (Christiana dan Stuart, 2013)

The resulting value of current solar cells when there are photon is on the surface of the solar cell is written by equation (10)

$$I = I_L - I_0\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \quad (10)$$

Explanation : V = 25.7mV at 25°C

k = 1.380658x10-23J/K (const Boltzmann)

T = 273.15K = 0°C

q = 1.60217733 x 10-19 c (electron charge)

IL = resultant photon current

At the time of the solar cell is not connected to the load, the voltage that exists between the anode-cathode pole is called the open circuit voltage which is the maximum voltage on a solar cell and given a notation Voc. Since there is no load, the load current is zero. This voltage is the forward bias voltage of the anode-cathode junction solar cells when there are light on the solar cell surface. The magnitude of the voltage Voc written in equation (11) (Lindholm, dkk., 1979).

$$V_{OC} = \frac{nkT}{q}\ln\left(\frac{I_L}{I_0} + 1\right) \quad (11)$$

V_{OC} values on the saturation current without photons (Io) = $1e^{-10}$ A, the current generated photons (IL) = 0.5 A, n = 1 and temperature (T) = 300^o K, the value of the voltage Voc = 0.578 volts. There are two parameters which determine the performance of solar cells that I_{SC} is the short circuit current, and V_{OC}. For the solar cells ideal, the short circuit current is identical to that produced by the sun. Therefore, the short circuit current is the largest current generated by solar cells. In an ideal solar cell, the magnitude of the short circuit current can be written by equation (12) (Lindholm, dkk., 1979).

$$J_{SC} = qG(L_n + L_p) \quad (12)$$

Explanation : q = electron charge

G = the generation rate

Ln,Lp = the electron and hole diffusion lengths respectively

2.4. Efficiency of Solar Cells

Efficiency is defined as the ratio of the energy output of solar cells with energy from the sun through solar cells. Efficiency value is written in equation (13) (Green, 1982).

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} \tag{13}$$

Explanation : V_{OC}= open circuit voltage

I_{SC} = short circuit current

FF = fill factor

P_{in} = energy from the sun through solar cells

The intensity of solar radiation reaches the earth's surface has a value varies according to each wavelength, but it is also influenced by the air mass (AM = Air Mass) and air temperature. In the ideal air conditions, sunlight received by the Earth's surface area of 1 m^2 has a value equivalent to approximately 1.353kW/m^2. At zero air mass (AM 0) and the air mass 1.5 (AM 1.5), the energy received by the Earth's surface will vary according to each wavelength of sunlight. At air mass 1.5, at a temperature of 25 ° C and 1.5 μm obtained power spectrum of solar radiation as the energy input to the solar cell around 1 kW/m^2 or 100 mW/cm^2. When the solar cell has a size of 100 × 100 mm^2 obtained input power of 10 W (Wenbo, 2011).

Output performance of solar cells is influenced by the intensity of solar radiation and temperature of the solar cell surface. In general, the power output of solar cells written in equation (14) (Jie, dkk., 2007).

$$P = G_T \tau_{pv} \eta_{T_{ref}} A[1 - 0.0045(T_c - 25)] \tag{14}$$

Explanation :

P=power output solar cell (watt); GT=sun radiation (kw/m^2); τpv= surface solar cell transmitance (0,2 – 0,46); ηTref=efficiency solar cell at temperature reference (0,108 at 45°C; 0,118 at 28°C (Hendrie, 1979); A=surface area solar cell (m^2); Tc=temperaturesolar cell (°K)

III. METHODOLOGY

This research is started with the identification of problems, the next stage of analyzing the data and determining the appropriate method of evaluation, and data collection.

At the stage of data collection is done by measuring the voltage and current 50 watt solar panels every day from 06.00 am until 17.00 pm from June 2012 to February 2013. The frequency of data recording is done per minute, which recorded includes voltage and current output of solar panels are loaded with batteries 12 volt, 45 AH. To keep the batteries do not have excess charging, installed a 1000watt inverter connected to the lamp 10 watt, 220 volt. Location data collection of solar panels made atKelapa Kopyor XI/B1-03 street in Bukit Bukit Kencana Jaya Semarang Housing. Solar panels placed at a height of 8 meters above the ground. Data generated as many as 660 data/day and then calculated the average power generated per day of solar panels. Climatological data in the form of solar radiation, wind speed, humidity and temperatureobtained from the Meteorology, Climatology and Geophysics Agency of Semarang City, for measurement in June 2012 until February 2013. Furthermore, the data of solar panels electrical measurements and climatological data for 9 months (273 days) is mounted on the same month and day to be used as training data and testing of data, sampling data is shown in Table 1.

Table 1. Solar panel paired with climatological data

Days	Solar Radiation (Cal/cm^2)	*Output* Solar Panel (watt mnt)	Temperature (kelvin)	Humidity (%)	Wind Speed (m/mnt)
1	557,0	684,0	301,6	71,5	108,3
2	752,0	714,0	301,0	73,8	80,0
3	878,0	1.008,0	301,1	72,5	100,0
4	878,0	1.032,0	301,3	56,3	86,7
5	871,0	852,0	300,7	71,0	111,7
6	882,0	1.422,0	302,3	74,3	103,3
7	861,0	1.206,6	302,2	76,3	123,3
8	693,0	1.147,2	302,4	75,8	115,0
...	....	....	....	....	....
...	....	....	....	....	....
267	735,0	1134,4	300,3	85,0	171,7
268	378,0	664,2	298,9	92,3	245,0
269	525,0	806,0	300,3	85,3	135,0
270	878,0	1253,8	300,8	83,5	120,0
271	672,0	1141,8	300,9	86,3	153,3
272	798,0	1186,6	300,5	88,0	135,0
273	873,0	1444,2	301,1	84,8	135,0

The amount of data used in this research was 273 days, taken 200 is used for training and 73 are used for testing ANN backpropagation.

3.1.ANN Backpropagation models were developed

Development of neural networks backpropagation in this research were made with some models. In general, neural network model consists of 4 pieces of input climatological data (solar radiation, wind speed, humidity and temperature), one hidden layer and one output layer. To get the best ANN backpropagation models is done by adjusting the number of neurons in the hidden layer neurons begin 8, 16 neurons, 32 neurons and 64 neurons. Block diagram of the ANN models to predict the productivity of a 50-watt solar panel is shown in Figure 4.

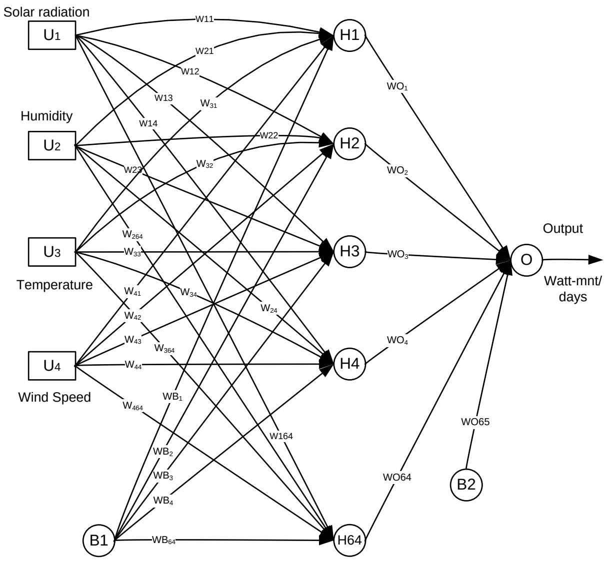

Figure 4. Architectural ANN backpropagation predicted output 50 watt solar panel.

ANN Backpropagation model Figure 4 further written program code similarities feed forward, backward and update weight using visual basic 2008 program package, and produce the desired output includes MSE, MSE charts, a data file containing predictions and targets as well as data files weight training results. Weights were obtained at the training will be used for testing, the results of testing in the form of charts and predictions of the target, and the target data file and prediction.

IV. RESULTS AND DISCUSSION

4.1.Results of Data Collection

To see the relationship between solar radiation, humidity, wind speed and temperature of the solar panel output, the data were analyzed using linear regression correlation method. The data processing and analysis in the form of correlation between: 1) the pattern of solar radiation with solar panel power output, 2) the pattern of humidity with the power output of solar panels; 3) the pattern of the wind speed with a power output of solar panels and 4) temperature pattern with a power output of solar panels. The pattern of solar radiation with solar panel power outputis shown in Table 2.

Table 2. Solar radiation and output solar panel

Month	Solar Radiation (Cal/cm^2)	Output Solar Panel (watt minute)
Jun	788,0	1195,4
Jul	789,0	1228,6
Agt	836,0	1232,6
Sept	875,0	1269,0
Oct	844,0	1271,6
Nov	781,0	1143,9
Dec	583,8	903,0
Jan	614,0	887,4
Feb	634,0	1045,7

Chart patterns of solar radiation and chart patterns 50 watt solar panel output is presented graphically in Figure 5.

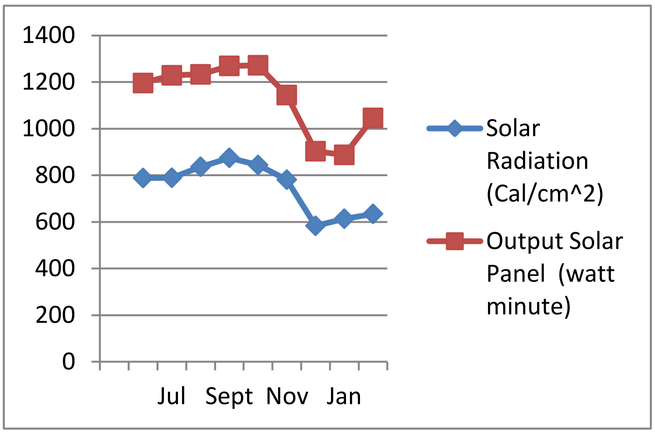

Figure 5. Graph of solar radiation intensity and the energy output of solar panels

Relationship with the intensity of solar radiation output of solar panels, based on the calculation of correlation values (r) = 0.963951134, this shows that the relationship between the intensity of solar radiation at the output of solar panels have **high linear positive correlation**.

The pattern of humidity with solar panel power outputis shown in Table 3.

Table 3. Humidity and output solar panel

Month	Humidity (%)	Output Solar Panel (watt minute)
Juni	72,0	1195,4
Juli	67,0	1228,6
Agt	66,0	1232,6

Sept	67,0	1269,0
Okt	69,0	1271,6
Nov	77,0	1143,9
Des	80,0	903,0
Jan	82,0	887,4
Feb	84,0	1045,7

Humidity measurement results and output 50 watt solar panels are graphically shown in Figure 6.

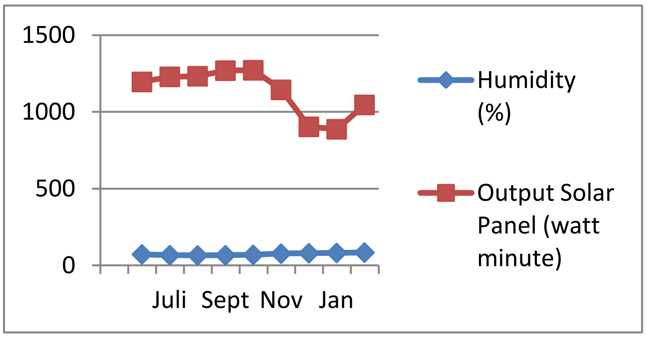

Figure 6. Chart patterns of moisture and energy output of solar panels

The relationship between humidity with solar panel output, based on the calculation of correlation values obtained (r) = -0.861102046, this suggests that the relationship between the moisture output of solar panels have **high linear negative correlation.**

Wind speed and solar panel 50 watt output as measured from June 2012 to the month of February 2013 are shown in Table 4 in the graph shown in Figure 7.

Table 4. Wind speed and output solar panel

Month	Wind Speed (m/minute)	Output Solar Panel (watt minute)
Jun	101,1	1195,4
Jul	92,3	1228,6
Agt	102,2	1232,6
Sept	116,0	1269,0
Oct	108,2	1271,6
Nov	93,8	1143,9
Dec	79,9	903,0
Jan	123,2	887,4
Feb	115,4	1045,7

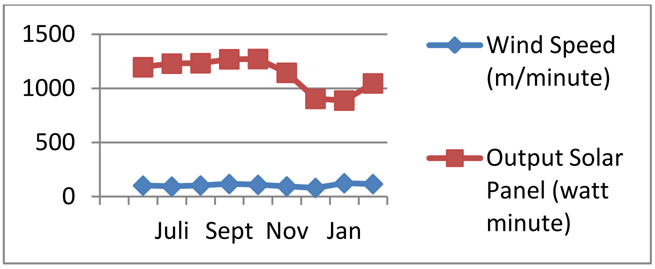

Figure 7. Chart the average wind speed and energy output of solar panels

Measurementresults of the average environmental temperature and output 50 watt solar panelshown in Table 5, the graph in Figure 8.

Table 5. Temperature and output solar panel

Month	Temperature (^{o}Kelvin)	Output Solar Panel (watt minute)
Jun	300,9	1195,4
Jul	299,5	1228,6
Agt	299,4	1232,6
Sept	301,4	1269,0
Oct	301,3	1271,6
Nov	301,9	1143,9
Dec	299,7	903,0
Jan	299,3	887,4
Feb	300,4	1045,7

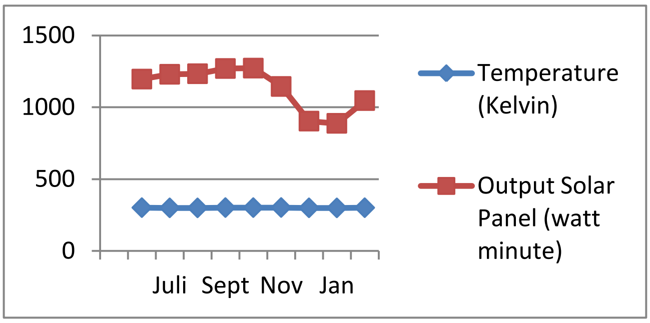

Figure 8. Graph average temperature versus energy output of solar panels

The relationship between wind speed with solar panel output, based on the calculation of correlation values obtained (r) = 0.027008761, this indicates that the relationship between wind speed with output of solar panels have **a low positive linear correlation**.

The relationship between the temperature of the solar panel output, based on the calculation of correlation values (r) = 0.455877055, this indicates that the relationship between the temperature of the solar panel output has **a low positive linear correlation.**

4.2. Results Software ANN Backpropagation

The software prediction of productivity 50 watt solar panel using back propagation neural network based on climatological data, built using visual basic 2008 program package produces the main page is shown in Figure 10.

The main page of the user interface Figure 10 consists of four parts areas including **Training**, **Report area**, **area Main Square-Error**, **Result Charts** and **Chart area**.

Training and testing using 273 pair of measurement result data for 9 months. From these data is taken200 data sets used for training ANN backpropagation. Training is done to get back propagation neural network models by adjusting the learning rate parameter, iterations and the number of neurons in the hidden layer are listed in Table 6. sequentially.

Table 6. Backpropagation ANN training parameters.

No	The number of hidden layer	Learning Rate	Iteration
1	8	0,1	5000
2	16	0,1	5000
3	32	0,1	5000
4	48	0,1	5000
5	64	0,1	5000
6	8	0,01	5000
7	16	0,01	5000
8	32	0,01	5000
9	48	0,01	5000
10	64	0,01	5000
11	8	0,01	7500
12	16	0,01	7500
13	32	0,01	7500
14	48	0,01	7500
15	64	0,01	7500
16	8	0,01	10000
17	16	0,01	10000
18	32	0,01	10000
19	48	0,01	10000
20	64	0,01	10000

Each training generate data and graphs MSE, learning rate, the number of training data and others shown in the Figure 9.

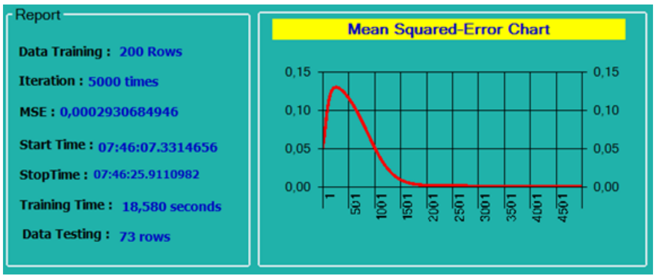

Figure9. The result of training

The graph shown in the Figure 9, is MSE during the training process, so it ends on a given number of iterations. The data training process includes the amount of time training, the amount of training data. For each model ANN backpropagation training was followed by testing. Results of testing produces data and graphs that show the target and predicted results on the result chart in Figure 10.

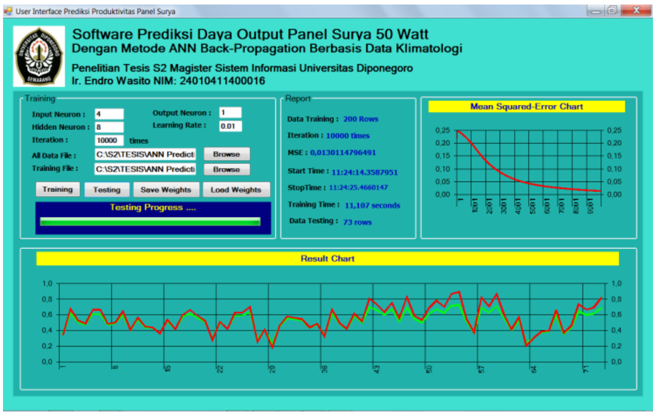

Figure 10. Training and testing results of ANN with 48 hidden neurons, 5000 iterations, learning rate 0.1

Prediction results are drawn in the graph at **Result Chart**, the red line is the target and the yellow line is the prediction.

Backpropagation ANN testing refer to table 6, have done as many as 20 times.The result of testing are summarized in Table 7 with the created order of accuracy of the predictions of the best neural network models respectively.

Tabel 7. Rangkuman hasil *training*

No	Number hidden layer	Learning Rate	Iteration	MSE	Target (watt-mn)	Prediction (watt-mn)	SE (watt-mn)	R (%)
1	8	0,1	5000	0,038309	1071,6	838,6	27,8	96,8
2	16	0,1	5000	0,033977	1071,6	852,7	26,2	97,2
3	32	0,1	5000	0,040132	1071,6	831,9	28,5	97,2
4	**48**	**0,1**	**5000**	**0,028432**	**1071,6**	**870,3**	**23,9**	97,3
5	64	0,1	5000	0,036143	1071,6	844,4	27,0	97,1
6	8	0,01	5000	0,007621	1071,6	1094,9	12,4	98,4
7	16	0,01	5000	0,008388	1071,6	1088,5	13,0	98,2
8	32	0,01	5000	0,008553	1071,6	1098,5	13,1	98,3
9	48	0,01	5000	0,006776	1071,6	1085,9	11,7	98,2
10	**64**	**0,01**	**5000**	**0,005752**	**1071,6**	**1047,1**	**10,8**	98,2
11	**8**	**0,01**	**7500**	**0,005038**	**1071,6**	**1027,9**	**10,1**	98,3
12	16	0,01	7500	0,005764	1071,6	1080,1	10,8	98,3
13	32	0,01	7500	0,005947	1071,6	1076,6	10,9	98,2
14	48	0,01	7500	0,005117	1071,6	1085,1	10,2	98,3
15	64	0,01	7500	0,005264	1071,6	1024,6	10,3	98,3
16	**8**	**0,01**	**10000**	**0,003369**	**1071,6**	**1026,4**	**8,2**	**98,5**
17	16	0,01	10000	0,006189	1071,6	982,5	11,2	98,0
18	32	0,01	10000	0,004515	1071,6	1081,2	9,5	98,2
19	48	0,01	10000	0,004577	1071,6	1038,5	9,6	98,2
20	64	0,01	10000	0,004633	1071,6	1045,7	9,7	98,2

4.3. Discussion

The more the number of hidden layer neurons and number of iterations that the training takes longer, but it does not guarantee the best MSE.

Based on Table 7, the best ANN ANN training results achieved by the number of hidden layer 8, 10000 iterations and learning rate of 0.01, achieved MSE of 0.003369, standard error of 8.2 watt-hours, the predictive value of 1026.4 watts -minutes of the target 1071.6 watt-hours with an accuracy of 98.5% based on the calculation of the prediction coefficient of determination (R).

V. CONCLUSION

From this research it can be concluded that backpropagation neural network can be used for prediction of solar panel 50 watt output with input climatological data such as intensity of solar radiation, humidity, temperature, and wind speed in the city of Semarang.

The most optimal ANN architecture in this research is achieved by the ANN with a number of input layer neuron 4 pieces, 1 unit hidden layer with 8 neurons, 1 unit of output layer with 1 neuron with predictive accuracy (a coefficient of determination=R) of 98.5%.

Backpropagation neural network architecture best results, able to predict the output of a 50 watt solar panel mounted in the city of Semarang at 1026.4 watt-minutes from the target 1071.6 watt-minutes.

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