Forecasting Power output of PV Grid Connected System in Thailand without using Solar Radiation Measurement

C. Chupong and B. Plangklang

Abstract - *PV systems have been increasingly installed worldwide in recent years. Because it produces clean energy, moreover the development of technology is continued therefore the reliability is increasing and the price is decreasing in opposite. To implement the PV system, however, a significant limitation of PV system is the uncertainty of power from the sun. This will affect the quality of the electrical system that connected. Therefore, this article will present the power forecasting of a PV system by calculating the solar radiation, collecting data from weather forecasting, and using Elman neural network to forecast by using data from PV system installed at roof top of Faculty Science and Technology Rajamangala University of Technology Thanyaburi.The results of study found that the tendency to apply this method any further*

Keyword **– Neural Network, PV Power Forecasting, Solar Radiation**

1. INTRODUCTION

PV systems have been increasingly installed worldwide in recent years. Because it produces clean energy, moreover the development of technology is continued therefore the reliability is increasing and the price is decreasing in opposite. To implement the PV system, however, a significant limitation of PV system is the uncertainty of power from the sun. This will affect the quality of the electrical system that connected [1].

Therefore, the forecasting power output of the PV system can help to increase the quality of the power system. There're some researches discuss about the forecasting of solar radiation [2] [3], but is not sufficient to forecast the power output of PV system because power output of PV system also depends on the temperature changes as well. And some researches discuss the forecasting power output of the PV system that need to be installed solar radiation measurement [4].

In this article will present the forecasting power output of PV Grid Connected System without using Solar Radiation Measurement. The methodology used is to calculating the hourly solar radiation for the next day and use data from weather forecasting Maximum temperature, minimum temperature and cloud conditions in the next day as input of neural network. To forecast hourly power output of PV system [5].

2. THEORETICAL BACKGROUND

2.1 Calculation of Solar Radiation on any plane

Solar radiation on any plane consist of 3 components as equation 1

$$Gt = Gb + Gd + Gr \tag{1}$$

Where

G_t is Total radiation (W/m^2)

G_b is Direct radiation (W/m^2)

G_d is Diffuse radiation (W/m^2)

G_r is Reflect radiation (W/m^2)

All 3 components can be calculated by equations 2.1 to 2.3

$$Gb = Go\cos\theta s \tag{2.1}$$

$$Gd = Go\cos\theta z \quad td\,\frac{(1+\cos\beta)}{2} \tag{2.2}$$

$$Gr = \rho Go\cos\theta z \quad tr\,\frac{(1+\cos\beta)}{2} \tag{2.3}$$

G_o is solar radiation outside the Earth atmosphere (W/m^2), which changed every day during the year due to the motion of the Earth around the Sun, calculated from equation 3.

$$Go = Gs\left[1 + 0.033\cos\left(360\,\frac{D}{365}\right)\right] \tag{3}$$

Where

G_s is Solar Constant 1367 W/m^2

D is day in year **(**1-365)

t_b, td, tr is the atmospheric transmittance for direct radiation, diffuse radiation and reflected radiation consequently calculate as equations 4 to 7 [5]

ρ is reflectance value of ground

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$$t_b = a_0 + a_1 e^{\left(-\frac{k}{\cos}\theta_z\right)} \tag{4}$$

Where

$$a_0 = r_0[0.4237 - 0.0082(6 - A)^2] \tag{5.1}$$

$$a_1 = r_1[0.5055 - 0.00595(6.5 - A)^2] \tag{5.2}$$

$$k = r_k[0.2711 + 0.01858(2.5 - A)^2] \tag{5.3}$$

$$t_d = 0.271 - 0.294 t_b \tag{6}$$

$$t_r = 0.271 + 0.706 t_b \tag{7}$$

Where

A is attitude of location in km

r_0, r_1 and r_k are correction factor for various climate type as table 1

Table 1 correction factor for various climate type

Climate type	r_0	r_1	r_k
Tropical	0.95	0.98	1.02
Midlatitude Summer	0.97	0.99	1.02
Subarctic Summer	0.99	0.99	1.01
Midlatitude Winter	1.03	1.01	1.00

From equation 2 θ_z is Zenith Angle and θ_s is Incident Angle calculate by equations 8 and 9 and β is Inclination Angle of PV surface, detail in figure 1

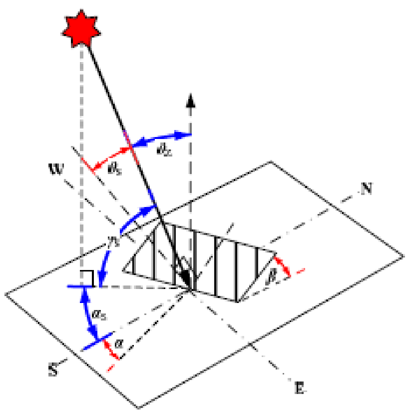

Fig 1 Zenith Angle, Incident Angle and Inclination Angle

$$\cos\theta z = \cos\delta\cos\phi\cos\omega + \sin\delta\sin\phi \tag{8}$$

$$\cos\theta s = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\alpha$$

$$+\cos\delta\cos\phi\cos\beta\cos$$

$$+\cos\delta\sin\phi\sin\beta\cos\alpha\cos\omega$$

$$+\cos\delta\sin\alpha\sin\omega\sin\beta \tag{9}$$

Where

δ is Declination Angle

ϕ is Latitude of Location

ω is Hour Angle of the sun equal 0 in noon, +90° when sunrise -90° when sunset change 15° every 1 hour [6]

α is Azimuth Angle

$$\delta = 23.45\sin\left[360\frac{(D+284)}{365}\right] \tag{10}$$

$$\omega = 15(12 - ST) \tag{11}$$

Where

$$ST = LST + 4(Ls - Lloc) + Et \tag{12}$$

ST is Sun Time (Hour, Minute)

LST is Local Standard Time (Hour, Minute)

Ls is Reference Longitude (for define time zone, i.e. 105° for Thailand)

Lloc is Longitude for Site Location

Et is Equation of Time (Minute)

$$Et = 229.1831(0.000075 + 0.001868\cos\theta - 0.032077\sin\theta - 0.014615\cos 2\theta - 0.040849\sin 2\theta) \tag{13}$$

Where $$\theta = 360\frac{(D-1)}{365} \tag{14}$$

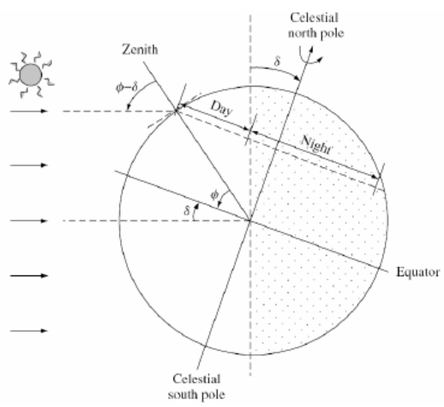

Fig 2 Declination Angle and Zenith Angle

We can use equations 1 -14 to calculate solar radiation on any surface in anytime of year in clear sky without cloud only [5]

In forecasting PV power output application we must consider other weather condition as temperature and cloudy too.

2.2 Recurrent Artificial Neural Network

The Elman network commonly is a two-layer network with feedback from the first-layer output to the first-layer input. This recurrent connection allows the Elman network to both detect and generate time-varying patterns. A two-layerElman network is shown in figure3.

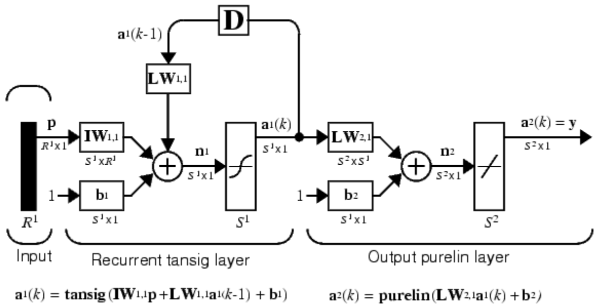

Fig 3 Elman Network

3. PROPOSED FORECASTING METHOD

Proposed forecasting method presented in this article is to use Elman neural networks which the Inputs for network has 14 inputs includes the solar radiation from 7:00 to 17:00 for next day, which was calculated in section 2.1 (11 inputs) and other 3 inputs are data from weather forecast highest temperature for next day, lowest temperature for next day and cloudy condition for next day that use cloudy index as table 2

Table 2 cloudy index

Cloudy condition	Cloudy index
Clear, Partly-Cloudy	0.9
Cloudy	0.6
Rain,Fog	0.3

And Outputs from network are forecast hourly power output (kW) from PV from 7:00 to 17:00

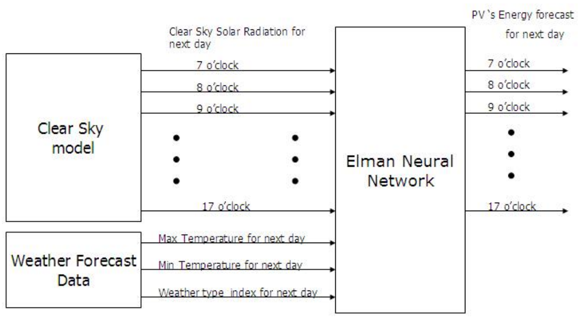

Fig 4 Diagram of propose forecasting method

4. EXPERIMENT AND RESULT

4.1 Training the network

In this experiment using MATLAB software to create network and training, data used to train the network come from the calculation in section 2.1, weather forecast website www.wunderground.com and hourly data of output PV 1 kWp Grid Connected System at roof-top of Building Faculty of Science and Technology, Rajamangala University of Technology Thanyaburi. In this training use these data from 17th Jan 2011 to 23rd Jan 2011

Fig 5 PV Grid Connected System used in this article

These data are taken through a pre-processing by Linear model in MATLAB to normalize all data in range [-1 1] that make more efficiency in training process.

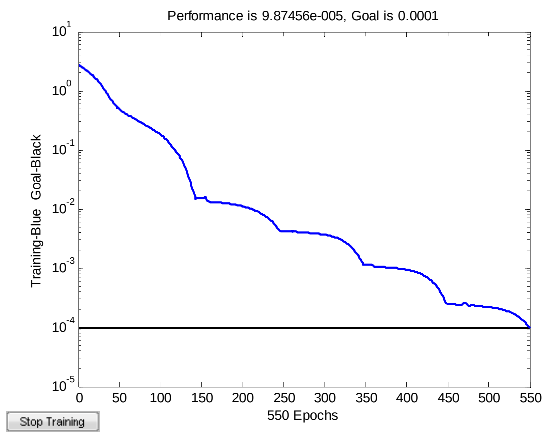

Fig 6 Training of Elman Neural Network

4.2 Experiment Results

After training the network, we have another set of data to test the network. These data are come from calculation of the solar radiation and weather forecast during 31 January to 3 February 2011 we normalize these data by Pre-processing process and then input to network. Now network give output in range [-1 1] then input these data to Post-processing by Linear model in MATLAB we can get forecast values. These forecast values are compared with the actual values recorded at site. Then calculated as the average error Mean Absolute Percentage Error (MAPE) by equation 15, which in this experiment, the MAPE is equal to 16.83%.

$$MAPE = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|P_f^i - P_a^i\right|}{P_a^i}\% \qquad (15)$$

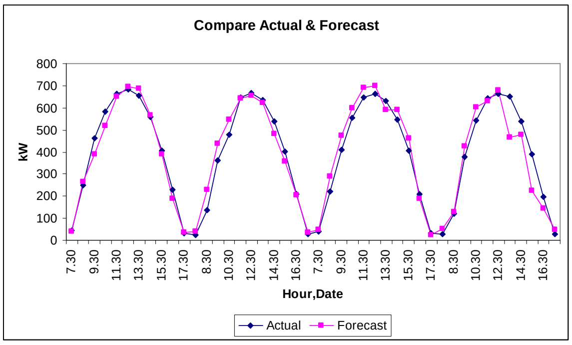

Fig 7 Compare Forecast value and Actual value

To validate this result we compare this MAPE 16.83% with application of Recurrent Neural Network and measured data of solar radiation to forecast PV power output [4] that have MAPE about 12% -17% vary in each month. The MAPE of 2 methods are too close that mean this forecasting method can acceptable.

5. CONCLUSION

Forecasting power output of PV Grid Connected System by data from calculating the solar radiation in clear sky condition and weather forecast data as Input to the Elman neural network instead of using a solar radiation measurement. In this experiment found that the forecast and actual values go in the same direction. The errors were 16.83% the data used in this study were also few and still have to collect more data to study in further.

6. ACKNOWLEDGEMENT

Authors would like to Thank you Dr.Morakot Puttakarn for kindly support the data of Power Output of PV Grid Connected System for this experiment.

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