Prediction of Heat Transfer Coefficient of PV/T-SAHP Heat Pump System

Xingcao Zhou\(^1,^2,^*\), Zezhong Wu\(^1,^2,^a\) and Jigang Wang\(^1,^2,^b\)

\(^1\)College of Electrical Engineering, Guangxi University, Nanning 530004, China
\(^2\)Guangxi Key Laboratory of Power System Optimization and Energy Technology, Guangxi University, Nanning 530004, China

*Corresponding author e-mail: 1319011590@qq.com, ^a^1666497004@qq.com, ^b^197465868@qq.com

Abstract. In order to facilitate performance research and control strategy formulation, Elman neural network is used to predict heat transfer coefficient of heat pump, which is convenient for dynamic modeling of PV/t-sahp system. The accuracy of the prediction model was verified by selecting typical sunny and cloudy days. The experimental results show that the maximum relative errors of the predicted values in sunny and cloudy weather are 5.4% and 7.2% respectively. The mean relative errors were 2.57% and 2.69%, respectively. The results show that the prediction model of Elman neural network proposed in this paper is more accurate and can better simulate the actual operation, which can provide technical support for the follow-up research.

1. Introduction
Solar energy is a kind of renewable energy, which is abundant and covers a wide range. In recent years, the gradual expansion of the scale of solar energy use has accelerated the technological upgrading of related industries, and the application of solar energy in the field of building energy in China also shows great potential for popularization [1]. But subject to the material physical properties limited, including monocrystalline silicon, polycrystalline silicon photovoltaic (PV) components for solar energy conversion rate is still less than 20%, the temperature rise of the sun brings further reduce its power generation efficiency [2], so the collection of photovoltaic power generation and heat storage function integration of field coupled heat pump (PV/T-SAHP) system by the people more and more attention [3-4].

PV/T-SAHP system mainly includes PV/T components, heat collecting tank, heat pump, heat storage tank, etc. The operation of the whole system is directly affected by the change of weather conditions. The modeling of PV/T-SAHP system is not only convenient for performance research, but also can be used to design the thermoelectric decoupling control strategy to realize the efficient utilization of solar energy. At present, the modeling methods of PV/T-SAHP system are divided into two categories: first, the simulation is carried out with the help of various simulation software. JohnClau [5] used building performance software (BPS) to study the impact of the complexity of heat pump modeling on key performance indicators such as energy efficiency and heat pump operation. FrancescoReda and SatuPaiho [6] compared the energy-saving heating performance of two PV/T-SAHP systems, solar assisted absorption heat pump and photovoltaic driven air source heat heat-2-
pump, in the software of TRNSYS. Due to the different types of PV/T-SAHP systems, it is difficult for the simulation software to achieve high applicability, and the accuracy also needs to be improved. Second, the thermodynamic analysis, the establishment of complex mathematical model. The PV/T-SAHP system model proposed by pei gang and ji jie [7] includes two parts: PV/T model and heat pump thermodynamic cycle model. This model can simulate the dynamic change of PV/T-SAHP system performance parameters in the all-day process, and can be used to analyze the influence of PV/T module parameters such as area, inclination Angle and pipe spacing on system performance, so as to facilitate the optimal configuration of the system. Zhang zheng [8] established a mathematical model for the photovoltaic solar heat pump/ring heat pipe (PVSA–HP/LHP) composite hot water system, and compared and simulated the performance of the system under the independent operation of the heat pump (HP) mode and the compound operation of the ring heat pipe – heat pump (LHP–HP). In the above two literatures, the heat pump model construction is the most complex. The heat pump is generally composed of evaporator, compressor, condenser, capillary tube, etc., among which the refrigerant has three states: liquid phase, gas-liquid two-phase and gas-phase during the system operation, and the micro-element method is adopted in the model construction. As a result, the model solution requires continuous iteration and timely change of the set refrigerant evaporation temperature, which takes too long and the model is too complex.

At first, this paper combined with the actual situation of the experimental platform of Chung-Feng [9] and others to build water cooled photovoltaic PV/T system component heat transfer model of lumped heat capacity method, and then using the Elman neural network to predict the heat transfer coefficient of heat pump [10], the PV/T-SAHP system as a whole, greatly simplifies the complexity of the model, also increased the universality of this model. Finally, Simulink software tool was used to establish the above simulation model and the accuracy of the PV/T-SAHP system dynamic model was verified by the PV/T-SAHP system experimental platform in Nanning, Guangxi.

2. Introduction of PV/T-sahp system

In this paper, the water-cooled PV/T heat pump coupling system is studied. As shown in Fig.1, the water pump is controlled by the controller to pump the cooling water in the collecting water tank to the PV/T component and continuously circulates, which reduces the temperature of the PV/T component while accumulating heat. When the water temperature of the collecting water tank rises to a certain value, its cooling effect decreases significantly. At this time must open the heat pump, on the one hand, the heat in the heat collection tank can be transferred to the heat storage tank to store to meet the daily hot water demand, on the other hand, also can reduce the water temperature in the heat collection tank to ensure the cooling effect. PV/T-sahp system can greatly improve the efficiency of photovoltaic panel power generation and realize the comprehensive utilization of electric energy and thermal energy.

![Figure 1. Schematic diagram of PV/T-SAHP system.](image-url)
3. Heat transfer coefficient prediction of heat pump

3.1. Heat transfer coefficient prediction of heat pump

In this article, click in Guangxi Nanning area between north latitude (108.3° east longitude 22.8°), component south toward, 22° Angle placed, through the campus weather stations collect meteorological data, including the solar irradiance \( G_i \), environmental temperature \( T_{bj} \) and environmental humidity \( H_{bj} \), wind speed \( W_s \), collected by photovoltaic solar-thermal monitoring system water pump 2 frequency \( f_{sb} \). In addition, the coefficient should also have an autocorrelation on the time sequence. Therefore, the data of the first two time series \( K_{(t-2)} \), \( K_{(t-1)} \) before the prediction time are selected in this paper to analyze the autocorrelation. The time interval is 20s. The calculation formula of correlation coefficient \( r \) is as follows:

\[
r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2}}
\]

(1)

Under sunny days, the correlation results of the above variables are shown in Table 1.

| predictor | \( T_{(t-2)} \) | \( T_{(t-1)} \) | \( f_{sb} \) | \( G_i \) | \( T_{bj} \) | \( H_{bj} \) | \( W_s \) |
|-----------|----------------|----------------|-------------|--------|--------|--------|------|
| \( r \)   | 0.75           | 0.89           | 0.92        | 0.64   | 0.59   | 0.12   | 0.13 |

Under cloudy conditions, the correlation results of the above variables are shown in Table 2.

| predictor | \( T_{(t-2)} \) | \( T_{(t-1)} \) | \( f_{sb} \) | \( G_i \) | \( T_{bj} \) | \( H_{bj} \) | \( W_s \) |
|-----------|----------------|----------------|-------------|--------|--------|--------|------|
| \( r \)   | 0.81           | 0.88           | 0.87        | 0.66   | 0.45   | -0.2   | 0.09 |

It can be seen from Table 1 and Table 2 that under sunny and cloudy conditions, the correlation coefficient of each factor is slightly different, but the overall correlation trend is the same, and the heat pump heat transfer coefficient has a strong autocorrelation, and the closer the time series temperature data is to the prediction time, the stronger the correlation is. The correlation of water pump 2 frequency, solar irradiance and ambient temperature was weakened in turn, and the correlation of environmental humidity and wind speed was the weakest, so it was not considered. Therefore, in this paper, the historical data of the first two moments of the component prediction time and the data of the pump 2 frequency, solar irradiance and ambient temperature are selected as the input parameters of the neural network model. The prediction process is shown in Fig.2.
3.2. Elman neural network model

Elman network is a typical recursive neural network. The output state of k at a certain time is not only related to the input state of k, but also related to the recursive signal before k, showing the characteristic of being good at dynamic modeling. Fig.3 is the schematic diagram of Elman neural network structure, including the input layer, the hidden layer, the output layer and the continuation layer with dynamic memory function.

From the above analysis, it can be seen that the heat transfer coefficient of the heat pump at a certain time has a strong correlation with the transfer coefficient of the previous two times and the meteorological data. In order to improve the prediction accuracy, this paper selects Elman neural network to conduct dynamic modeling of heat transfer coefficient of heat pump. The mathematical model of Elman neural network is:

\[ x(k) = f(\omega_1 x_c(k) + \omega_2 u(k-1)) \]  \hspace{1cm} (2)
\[ x_c(k) = x(k-1) \]  \hspace{1cm} (3)
\[ y_2 = \omega_3 x(k) \]  \hspace{1cm} (4)
Where, \( f(x) \) is taken as the sigmoid function, i.e.

\[
f(x) = \frac{1}{1 + e^{-x}}
\]  

(5)

4. Prediction example analysis

4.1. Data sample selection and standardization

In this paper, heat transfer coefficient data of heat pump under sunny and cloudy weather on July 1, 2018 and October 1, 2018 were selected as the data source. The heat pump heat transfer coefficient data of July 1, 2018, solstice, September 15, 2018 from the data source were selected as the network training data, with a total of 500 samples. The prediction model was established. The heat pump heat transfer coefficient data of September 16, 2018, solstice, October 1, 2018 were selected to test the prediction accuracy of the network, with a total of 100 samples.

Due to different dimensions of irradiance, temperature, humidity, wind speed and other data and large size differences, so for a group of data to perform the following standardized transformation:

\[
x_i = (x_i - \bar{x}) / \sigma(x)
\]  

(6)

where, \( \bar{x} \) —— mean, \( \sigma(x) \) —— standard deviation.

4.2. Predictive evaluation criteria

In this paper, relative error \( RE \) and mean absolute percentage error \( MAPE \) were used to evaluate the prediction accuracy of heat transfer coefficient Elman model of heat pump.

\[
RE = \frac{|Y_i' - Y_i|}{Y_i} \times 100%
\]  

(7)

\[
MAPE = \frac{1}{n} \sum_{i=1}^{n} \frac{|Y_i' - Y_i|}{Y_i}
\]  

(8)

where, \( Y_i \) —— true value; \( Y_i' \) —— forecast value of mathematical model, \( n \) —— number of model iterations.

4.3. Forecast result

After the above prediction system was modeled by MATLAB, the prediction results of Elman neural network under sunny and cloudy conditions were obtained. Fig.4 and Fig.5 respectively show the predicted and true values of heat transfer coefficient of Elman neural network model under sunny and cloudy conditions. Fig.6 is the relative error of Elman neural network model under two weather conditions. Table 3 is the evaluation index of prediction error of Elman model under two weather conditions.

| Table 3. Elman model prediction error evaluation index. |
|-------------------------------------------------------|
| Weather conditions | RE-MAX/% | RE-MIN/% | MAPE/% |
| Sunny days         | 5.4      | 0.1      | 2.57   |
| Cloudy days        | 7.2      | 0.8      | 2.69   |
Figure 4. Forecast Results of Elman Model in Sunny Days.

Figure 5. Forecast Results of Elman Model in Cloudy Days.
As can be seen from Fig.4 and Fig.5, the prediction results of Elman neural network model are consistent with the weather change. According to Fig.6 and Table 3, the relative error of the prediction results under sunny and cloudy conditions is less than 10%, most of which are concentrated in the range of 1% to 6%, and the prediction accuracy is relatively high.

5. Conclusion
In this paper, after using Elman neural network to predict heat transfer coefficient of heat pump and simplifying the complex heat transfer process of heat pump, a dynamic prediction model of heat transfer coefficient of heat pump was established for PV/t-sahp-5 system. The accuracy of the dynamic model is verified by selecting typical sunny and cloudy days. The results show that the maximum relative error of the predicted value is 5.4% and the average relative error is 2.57%. The maximum relative error and average relative error were 7.2% and 2.69% respectively. This prediction model can be used to help establish the model of PV/t-sahp system, and can be used to realize nonlinear control of PV/t-sahp system or thermoelectric decoupling control system.

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