Optimal Control and Simulation of PV/T Temperature Based on DMC-PID

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Abstract: Optimal control of PV/T module temperature is of great significance for improving PV/T system's photoelectric efficiency and photothermal efficiency. Due to PV/T system's characteristics of large inertia, large delay and complex temperature distribution, in order to stabilize PV/T module temperature at the optimal temperature quickly and accurately, this paper proposes a cascade control strategy based on DMC-PID. Firstly, DMC-PID cascade control is determined as the optimal control strategy of PV/T system according to the characteristics of PV/T module temperature. Secondly, DMC-PID cascade control is studied on PV/T system, including control system design, transfer function acquisition and model establishment, and the results of optimal control are analyzed. Analysis and comparison of simulation results show that DMC-PID has stronger anti-interference and robustness, and has better optimal control effect on PV/T module temperature.

1. Introduction

In order to reduce the influence of temperature on PV modules, improve their power generation efficiency and recover their heat, photovoltaic/photothermal integration (PV/T) systems have attracted more and more attention [1]. At present, a great deal of research has been done on PV/T system at home and abroad. Document [2] introduces the experimental study of nano-fluid as working medium of photovoltaic heat (PV/T) system. Adding nano-fluid into basic fluid can significantly increase its thermal performance. By changing the volume concentration ratio of nanofluids, the purpose of reducing the temperature of photovoltaic panels is achieved and the overall system efficiency is improved. Literature [3, 4] through analyzing the influencing factors of PV/T module temperature, and according to the temperature curves of different weather, the short-term prediction methods of PV/T module temperature based on RBF neural network and PCA-Elman neural network are proposed respectively, which provide the basis for the next step of temperature optimization control. Relevant literatures have already conducted researches on how to reduce the PV/T module temperature and forecast the PV/T module temperature, but there are few optimal control strategies for photovoltaic and thermal systems, and most of them stay on theoretical and simulation research, so there are not many literatures that can be used for reference.

PV/T system has the characteristics of large inertia, delay, nonlinearity and time variation, which is very similar to the characteristics of boiler temperature control system. Therefore, the optimal control of PV/T system can be realized by referring to the control strategy of boiler temperature.

In this paper, the temperature of PV/T module is optimally controlled. All kinds of interference factors are fully considered. The temperature of PV/T module is stabilized at the optimal temperature by controlling the frequency of water pump. DMC-PID cascade control is determined as the optimal control strategy of PV/T system. The control system structure is designed and the system model is built by using MATLAB/Simulink tools. The simulation results prove that the control strategy has better control effect on the temperature of PV/T module and provides a new control strategy for the temperature control of PV/T module.

2. PV/T System Introduction

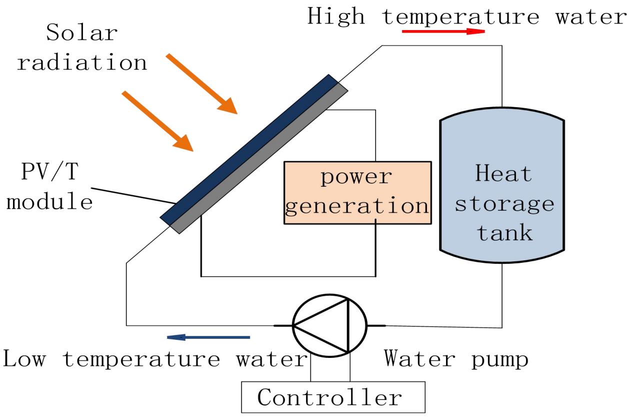

Figure 1: Diagram of pv/t system.

Figure 1 is a schematic diagram of PV/T system [5], showing the main part of this study, including photoelectric system, photothermal system, water pump control and data acquisition part of upper computer. In PVT system, in order to stabilize the temperature of PVT components at the optimal working temperature, it is necessary to turn on the water pump so that the cooling water flows through the PV/T collector to take away the heat on the components. The cooling water flow can be directly controlled by adjusting the frequency of the variable frequency water pump, which is relatively simple and easy to control. Therefore, the regulation of cooling water flow rate is taken as the main regulation means of PV/T module temperature. In this process, PV/T modules are easily affected by many factors, such as illumination intensity, cooling water temperature, cooling water flow rate, etc., which undoubtedly brings certain difficulties to the temperature control of PV/T modules.

3. Structural Design of Control System

In view of the shortcomings of traditional PID control, this topic proposes to use dynamic matrix (DMC) control algorithm [6] of predictive control algorithm to form DMC-PID cascade control strategy with traditional PID control. The temperature control system of PV/T system is designed to observe the control effect.

In this paper, the temperature of PV/T module is the control quantity, while the light intensity, cooling water temperature and cooling water flow rate will make the temperature of PV/T module change, but the main early interference is from the change of the initial water temperature of cooling water. Therefore, in DMC-PID control system, the frequency of the water pump is adjusted as the inner loop (the optimal frequency is only used in the starting process of the water pump, and then is adjusted and controlled). In the control outer loop, the advanced prediction link of DMC algorithm can solve the control error caused by model mismatch. At the same time, the real-time temperature measured on PV/T module is used as feedback quantity to feedback control the temperature of PV/T module, which is the main control object of the system. The initial temperature of the cooling water and the irradiance of the sun are not controlled by the system, so the two are taken as disturbance factors of the control system to establish the DMC-PID cascade control system structure diagram for the PV/T system, as shown in Figure 2.

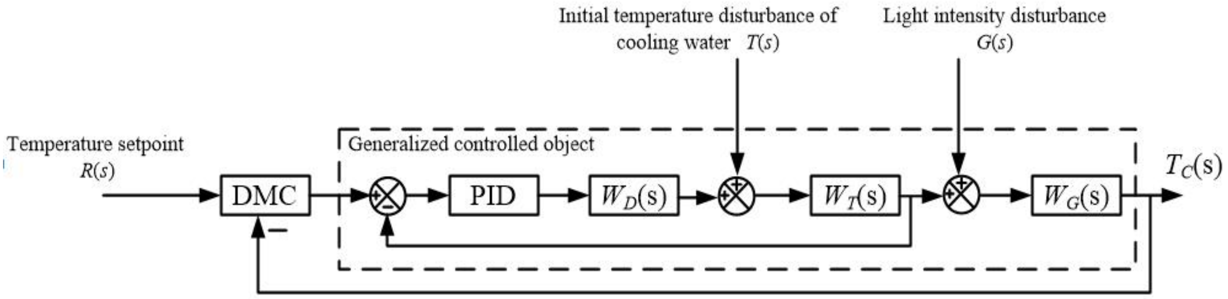

Figure 2: Block diagram of PV/T system for DMC-PID cascade control.

In order to verify whether DMC-PID cascade control has better dynamic performance, this paper also establishes the corresponding PID-PID cascade control system, whose system structure diagram is shown in Figure 3.

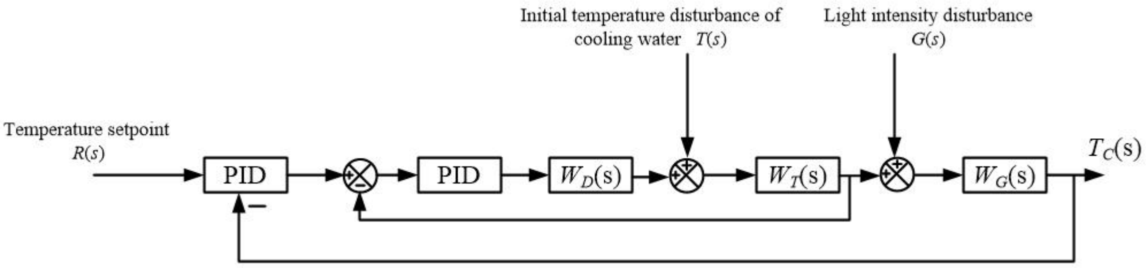

Figure 3: Structural block diagram of PV/T system for PID-PID cascade control.

4. System Simulation

4.1.Establishment of System Simulation Model

In the process of establishing the system simulation model, the transfer function model under the disturbance of cooling water temperature, cooling water flow rate and solar irradiance [7] is as follows:

Initial temperature disturbance of cooling water:

$$W_T(s)=\frac{\xi\left(T+T_c s\right)e^{-\tau s}}{T_w T_c s^2+\left(T_w+T_c+\xi T_c\right)s+\xi} \tag{1}$$

Disturbance of cooling water flow rate:

$$W_D(s)=\frac{(1+T_c s)e^{-\tau s}}{T_w T_c s^2+(T_w+T_c+\xi T_c)s+\xi} \tag{2}$$

Solar irradiance disturbance:

$$W_G(s)=\frac{\eta_{th} S \eta_c K A_c/(hA)\cdot e^{-\tau s}}{T_w T_c s^2+(T_w+T_c+\xi T_c)s+\xi} \tag{3}$$

Where $T_w=\frac{\rho_w f L c_w}{hA_w}$, $\xi=\frac{Dc_w}{hA_w}$, $T_c=\frac{m_c c_c}{hA_w}$, $\rho_w f L c_w$ represent the heat absorbed by all the cooling water in the cooling pipe when the temperature of the cooling water rises by 1°C the heat absorbed by the photovoltaic panel when the temperature rises by 1°C, the heat absorbed by the cooling water whose flow rate is Q in 1s when the temperature rises by 1°C, and the heat passing through the whole heat exchange surface when the temperature difference between the photovoltaic panel and the cooling water in the pipe in 1s is 1°C.

The model of transfer function is proposed above, and a more accurate transfer function is obtained through experiments and using MATLAB's transfer function identification toolbox.

(1) Initial temperature disturbance of cooling water:

The experimental time is from 8: 00 a.m. to 9: 00 a.m. and the measured irradiance is $55W/m^2$, the inlet water temperature is 22.3°C, the flow rate is $1.8L/\min$, and the initial temperature of the photovoltaic cell is 22.4°C. at this time, a proper amount of hot water is added to the heat collection tank to make the inlet water temperature step to 30°C, and then the temperature change of the photovoltaic cell within 30min is measured and the data is subjected to zero initial value processing. finally, the transfer function obtained by identification is as follows:

$$W_T(s)=\frac{5.13e^{-49.8s}}{107387.29s^2+463.35s+1} \tag{4}$$

(2) Disturbance of cooling water flow rate:

The experimental time is also taken from 8: 00 to 9: 00 in the morning, the measured irradiance is $43W/m^2$, the inlet water temperature is 23.1°C, the flow rate is $1.8L/\min$, the initial temperature of the photovoltaic panel is increased to 38.4°C by halogen lamp irradiation, the halogen lamp is cancelled at this time, and the cooling water flow rate is stepped to 5.5L/min, then the temperature change of the photovoltaic cell within 30min is measured and the data is subjected to zero initial value processing, and the transfer function finally identified is as follows:

$$W_D(s)=\frac{-(33.50s+14.05)\cdot e^{-50s}}{101751.6s^2+472.94s+1} \tag{5}$$

(3) Solar irradiance disturbance:

The experimental time is from 8: 00 a.m. to 9: 00 a.m., the measured irradiance is 68W/m^2, the inlet water temperature is 26.1°C, the flow rate is 1.8L/min, the irradiance step is 671W/m^2 by halogen lamp irradiation, then the temperature change of the photovoltaic panel within 30min is measured and the data is subjected to zero initial value processing, and finally the transfer function obtained by identification is as follows:

$$W_G(s)=\frac{5.18e^{-104.05s}}{10262.84s^2+277.28s+1} \tag{6}$$

According to the above transfer functions $W_T(s)$, $W_D(s)$ and $W_G(s)$ obtained after system identification under the disturbance of initial temperature of cooling water, flow rate of cooling water and solar irradiance respectively, Simulink simulation diagram of control system can be established. Figure 4 is a Simulink simulation diagram of DMC-PID cascade control system, and Figure 5 is a Simulink simulation diagram of PID-PID cascade control system.

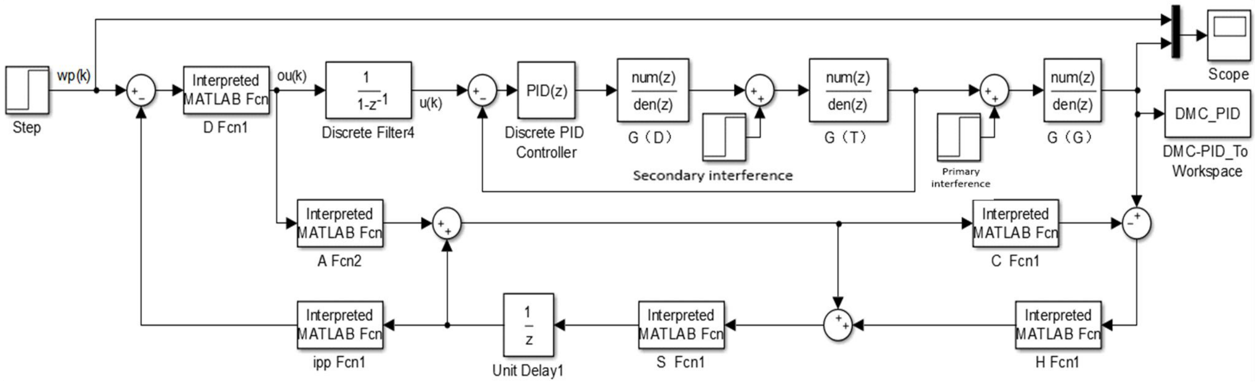

Figure 4: Simulink simulation diagram of DMC-PID cascade control system.

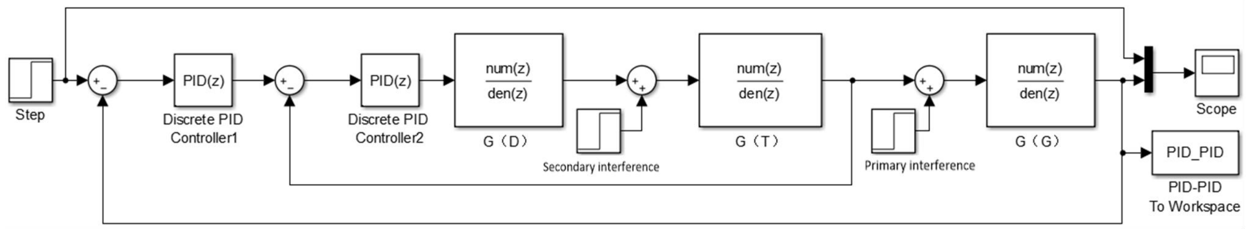

Figure 5: Simulink simulation diagram of PID-PID cascade control system.

4.2.Analysis of Simulation Results

(1)DMC-PID cascade control simulation parameters are set as follows:

Main loop DMC, sampling period T=2s, control time domain M=800, prediction time domain P=1200, model length N=1800

Secondary loop PID, sampling period T=1s, P=0.0024, I=0.00004858, D=0

(2)PID-PID cascade control simulation parameters are set as follows:

Inner loop PID, sampling period T=1s, P=0.03392, I=0.0003778, D=0.446

Outer loop PID, sampling period T=2s, P=0.1223, I=0.001046, D=-11.14

At the time of T=0s, set the temperature of photovoltaic cell at this time to 50℃, the given optimal temperature to 25℃, and add step disturbance with amplitude d=3 when T = 810 s. the response curves of DMC-PID cascade control and PID-PID cascade control are shown in Figure 6.

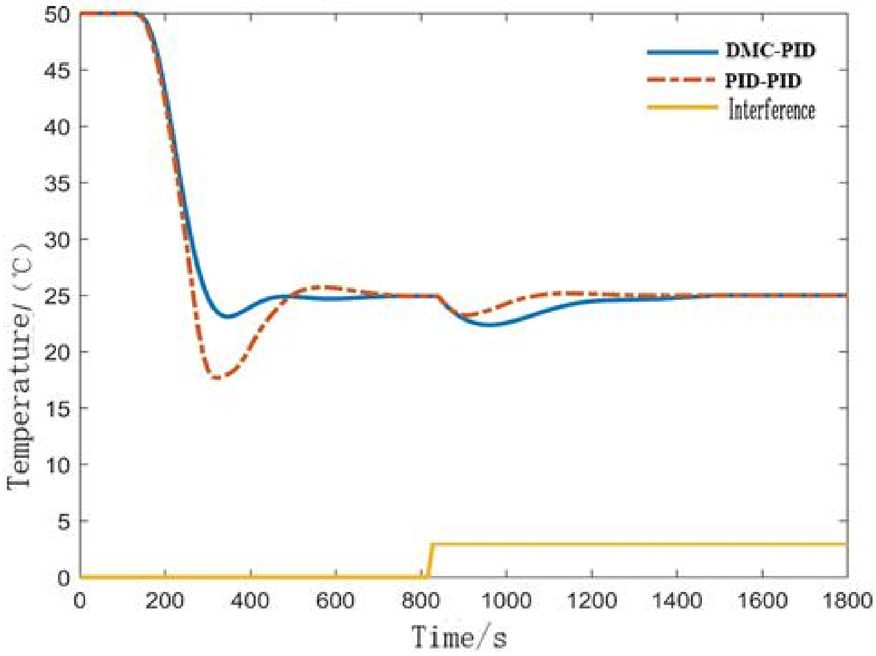

Figure 6: Comparison of response curves between DMC-PID cascade control and PID-PID cascade control.

As can be seen from Figure 6, the overshoot of PID-PID cascade control is too large, causing the photovoltaic panel temperature to drop to about 18°C and the oscillation time to lengthen. in some cases, the system may enter an unstable state, while the overshoot and oscillation time of DMC-PID cascade control are better than those of traditional PID cascade control. From the simulation results, it can be seen that DMC-PID cascade control has better tracking performance and robustness than PID-PID cascade control, in which the parameters are set by using MATLAB PID tuner toolbox, which means that it has better dynamic performance in the simulation. Considering the overall control performance, DMC-PID cascade control is better than PID-PID cascade control.

5. Conclusions

In this paper, the optimal control strategy design is carried out for the component temperature of PV/T system. Firstly, the selection of control strategy is carried out, and DMC-PID cascade control is determined as the optimal control algorithm of PV/T system. Then, according to the structure diagram of PV/T module temperature control system based on DMC-PID cascade control, the control process is described. Secondly, according to the characteristics of PV/T module temperature system, the transfer function is established, and the temperature simulation diagram of DMC-PID cascade control PV/T module is obtained. At the same time, the temperature simulation diagram of PV/T module based on PID-PID cascade control is also established. Finally, through the analysis and comparison of simulation results, DMC-PID control has stronger anti-interference and robustness than PID-PID control, and has the characteristics of short adjustment and fast response speed. Therefore, DMC-PID cascade control has better control effect on the temperature of PV/T module and provides a new control strategy for the temperature control of PV/T module.

Acknowledgments

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References

[1] Li Guangming, Liu Zuming, Li Jingtian, et al. Experimental Study on New PV/T Solar Energy Utilization Composite System [J]. Journal of China Electrical Engineering, 2013, 33(17): 83-89+16.

[2] Saber Ragab Abdallah,Hind Saidani-Scott,Osama Ezzat Abdellatif. Performance analysis for hybrid PV/T system using low concentration MWCNT (water-based) nanofluid[J]. Solar Energy, 2019, 181.

[3] Li Jiyong, Zhao Zhendong, Nan Junpei, Xiao Jing, Li Yisheng, Tang Yunfeng. Short-term temperature prediction of PV/T module based on RBF neural network [J]. Journal of Guangxi University (Natural Science Edition), 2017,42(03): 1035-1041.

[4] Li Jiyong, Zhao Zhendong, Li Yisheng, et al. Short-term PV/T module temperature prediction based on PCA-Elman neural network [J]. Renewable Energy, 2017, 35(12): 1779-1785.

[5] SandnesB., Rekstad J. A photovoltaic/thermal (PV/T) collector with a polymer absorber plate Experimental study and analytical model[J]. Solar Energy, 2002, 72: 63-73.

[6] Xu Jianzhong, Zhang Yanbin, Jia Lixin, et al. DMC —PID Cascade Control and Its Application [J]. Journal of Xi 'an Jiaotong University, 1996(11): 88-96.

[7] Cao Ding-yuan, Jin Xiu-zhang, Sun Xiaolin, et al. Mechanism modeling and research of solar heat exchange system [J]. Electric Power Science and Engineering, 2014, 30(08): 57-62.