Design of sliding mode adaptive DC-DC converter based on function approximation

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Abstract. The output power and voltage of solar photovoltaic power generation are easily affected by climate and load changes, so it is necessary to use DC-DC converter at its output to provide stable output voltage. DC-DC converter is a time-varying nonlinear system. When the output load of the converter varies widely, the output waveform distortion and dynamic response speed of the DC-DC converter will slow down. The essence of sliding mode control is a kind of switch control method, and the DC-DC converter needs the switch of switch tube to realize voltage regulation. In this paper, a sliding mode adaptive control strategy based on orthogonal polynomial function approximation is proposed, and Laguerre polynomial is selected as the basis function of DC-DC transformation system. The output voltage error and its first derivative of the system are taken as the input of the network, and the output of the network is taken as the approximation term of the system uncertainty, and the network weight is updated according to the adaptive law. Through simulation and comparison, the adaptive controller designed in this paper is superior to the ordinary sliding mode controller in reducing chattering, adaptive load change and reducing the influence of system interference.

1 Introduction
DC-DC converter is a kind of voltage type power electronic conversion device, which can change one form of DC voltage into another form of DC voltage through conversion, and realize controllable regulation of output voltage. When the load changes in a wide range, especially in the case of nonlinear load, DC-DC converter will produce output waveform distortion and slow dynamic response. The essence of sliding mode control is a kind of switch control method, and DC-DC converter needs to realize voltage regulation through the switch of switch tube. This essential connection between the two can make sliding mode control be applied to DC-DC converter.

In reference [1], an adaptive terminal sliding mode control scheme for buck converter is proposed, which can achieve fast output voltage response and excellent control performance when the system load changes.

In reference [2], a sliding mode control method based on PID controller is designed to track the required voltage when the load resistance of the converter changes periodically.
In reference [3], a fixed frequency sliding mode control scheme is proposed, and a solution is proposed to solve the problem that the frequency of the converter changes when the sliding mode control parameters change.

In reference [4], an adaptive robust controller based on Fourier series function approximation for buck converter is designed to realize the bounded tracking of the system.

In this paper, an adaptive controller based on orthogonal polynomial function approximation method is designed to solve the chattering problem of common sliding mode variable structure control and further improve the control performance of the controller. In the MATLAB simulation environment, the ordinary sliding mode variable structure controller and the modified sliding mode adaptive controller are simulated, and the performance differences between the two control strategies are compared.

2 Sliding mode buffeting

In the analysis and design of sliding mode control, buffeting is an important factor, which is caused by the frequent switching of system control state in the working process of the system. It will increase the switching loss, transformer loss, inductance loss of the switching converter, and produce high-frequency self-excited oscillation, resulting in electromagnetic interference and a series of problems, which can not be ignored in the actual process.

The causes of buffeting are as follows:

1. Time lag of switch. Due to the time lag of the switch and the influence of the state variables on the amplitude of the control variables, an attenuated triangular wave will appear on the sliding surface.

2. Space lag of the switch. The space lag of the switch is equivalent to that there is a dead zone in the state space of the state variable, and the triangle wave with equal amplitude will appear on the sliding surface.

3. The influence of system inertia. In the actual motion, the speed of the control variable can not reach infinity, but it will produce a delayed behavior, which will produce an attenuated triangular wave on the sliding surface.

4. The delay caused by the discrete system itself. The sliding mode motion of discrete-time system under the action of sliding mode control is a quasi sliding process and an attenuated chattering.

Therefore, the existence of buffeting is inevitable, it can not be completely eliminated, can only be weakened. In this paper, the adaptive law of function approximation is used to reduce chattering by adjusting the dynamic quality of the approach phase of sliding mode control.

3 Sliding mode adaptive controller

In this paper, the orthogonal polynomial function approximation method is used to transform the sliding mode variable structure controller. The adaptive controller approximates these uncertainties through the function approximation method, so as to reduce the influence of interference on the system and improve the control performance of the sliding mode variable structure controller [5-7].

3.1 Sliding mode equation

Let the state equation of the system be [8]:

\[ \dot{x} = f(x, u, t) = 0, x \in \mathbb{R}, t \in \mathbb{R} \]  \hspace{1cm} (1)

Where u is the control input of the system and t is the time. If the system enters the sliding surface and moves along the sliding surface to the ideal end point, then \( s = 0 \).

\[ \dot{s} = s = 0 \]  \hspace{1cm} (2)

The state space equation of the system is as follows:

\[ \dot{x} = Ax + Bu, x \in \mathbb{R}^n, t \in \mathbb{R}^m \]  \hspace{1cm} (3)
Where $s(x)$ is the sliding surface function, $u$ is the control input, and $s(x) = 0$. When the system moves on the sliding surface, it should meet the following requirements.

$$s(x) = 0, s(x) = 0$$

From this, the smoothing value $u_{cp}$ of variable structure discrete control can be obtained.

$$u_{cp} = -B^{-1}Ax(\frac{\partial s}{\partial x} \neq 0)$$

When the sliding mode moves, the system moves along the switching surface $s(x) = 0$, and when it reaches the ideal end point, $s = 0$ is satisfied. In fact, the equivalent control is the average motion equation of the sliding mode variable structure control system near the sliding mode, which describes the main dynamic characteristics of the system in the sliding mode. It is usually expected that this dynamic property is asymptotically stable and has excellent dynamic quality.

### 3.2 Orthogonal polynomial function

Let $N_m(X) = \lambda N$, for the DC-DC converter system model, assume that the unknown bounded uncertainty term $N_m(X)$ is square integrable in any finite time, that is $N_m(X) \in L^2(E)$, then $N_m(X)$ can be replaced by a combination of orthogonal basis functions.

$$N_m(X) = W^T Z(X) + \varepsilon$$

Among them, $Z(X)$ is the basis function, Laguerre polynomial is selected as the basis function of the sliding mode adaptive controller, $W$ is the coefficient of the basis function, and $\varepsilon$ is the approximation error of the approximation term.

### 3.3 Adaptive law

**Definition:**

$$\tilde{W}^T Z(X) = W^T Z(X) - \tilde{W}^T Z(X)$$

The adaptive law is selected as follows.

$$\tilde{W}^T = \eta_1 \eta_2 sZ(X)$$

among, $\eta_1 > 0$, $\eta_2 > 0$.

In this paper, Lyapunov direct method is used to obtain the sliding mode adaptive controller with orthogonal polynomial function approximation.

$$U = \int \frac{u_1}{L} + \frac{u_0}{L} (\lambda B)^{-1} \int (sat(s) \cdot \lambda A|X| + N_m(X) + k \cdot sat(s))$$

### 4. Simulation results and analysis

The adaptive controller selects the gale polynomial as the basis function, the current loop adopts PID control, and the voltage loop is compared with the conventional sliding mode controller (SMC) and the sliding mode adaptive controller based on Laguerre polynomial approximation (FASMAC-LA).

Figure 1 shows the voltage response simulation curves of SMC and FASMAC-LA under the same simulation conditions.
Figure 1. voltage response simulation curves of SMC and FASMAC-LA

Table 1. voltage response performance comparison between SMC and FASMA-LA

| controller     | Time adjustment/ms | Disturbance quantity% | steady-state error% |
|----------------|--------------------|-----------------------|---------------------|
| SMC            | 19.3               | 21.9                  | 2.06                |
| FASMAC-LA      | 18.7               | 21.6                  | 1.99                |

It can be found from table 1 that, compared with the ordinary sliding mode variable structure controller, the output performance of the modified adaptive variable structure controller in voltage response has been improved to a certain extent, and the characteristics of fast response are well reflected in the adaptive variable structure controller.

Figure 2 shows the voltage tracking simulation curve when the load resistance of the two control strategies jumps from 40 Ω to 20 Ω in 0.15s.

Figure 2. load disturbance simulation comparison curve of SMC and FASMAC-LA

Table 2. comparison of load disturbance performance between SMC and FASMA-LA

| controller     | Time adjustment/ms | Disturbance quantity% | steady-state error% |
|----------------|--------------------|-----------------------|---------------------|
| SMC            | 23.9               | 1.23                  | 0.33                |
| FASMAC-LA      | 18.8               | 1.02                  | 0.23                |
It can be found from table 2 that in the load disturbance simulation experiment, when the resistance value of the load jumps, the system under the adaptive variable structure control of the function approximation algorithm can make a rapid response to the disturbance, the regulation time is about 5ms less than that of the unmodified sliding mode control, and the voltage disturbance after the load disturbance is only about 1%, so the modified sliding mode variable structure control strategy has stronger robustness.

When the system is in a stable state, the steady-state error of the modified sliding mode variable structure control is obviously smaller than that of the ordinary sliding mode variable structure control, which shows that the control strategy of orthogonal polynomial function approximation can effectively approximate the system uncertainty, to a certain extent, it can effectively reduce the error caused by sliding mode chattering.

The two output curves in Fig. 3 are the voltage tracking simulation curves of the sliding mode adaptive controller modified by function approximation and the ordinary sliding mode controller without function approximation when the input voltage changes from 5V to 6V in 0.25s.

![Power Supply Disturbance Simulation Comparison Curve of SMC and FASMA-LA](image)

Table 3. Comparison of Power Supply Disturbance Performance between SMC and FASMA-LA

| Controller   | Time Adjustment/ ms | Disturbance Quantity % | Steady-State Error % |
|--------------|---------------------|-------------------------|----------------------|
| SMC          | 21.1                | 0.70                    | 0.30                 |
| FASMA-LA     | 13.9                | 0.54                    | 0.20                 |

It can be seen from table 3 that the system controlled by the modified adaptive variable structure controller has good voltage output performance, and the most obvious one is that the power disturbance regulation time of the modified sliding mode adaptive controller is about 7 ms shorter than that of the ordinary sliding mode control.

Through the simulation of the above three cases, it is verified that the control performance of the proposed sliding mode adaptive controller based on orthogonal term function approximation is better than the ordinary sliding mode controller under the same conditions.

5. Conclusion

In this paper, a function approximation algorithm is added to the common sliding mode variable structure controller, and a new state variable is introduced. A new system state equation is established, and the sliding mode variable with adaptive approximation term is obtained. Then, the adaptive law is
designed, and the sliding mode adaptive controller based on orthogonal polynomial approximation is obtained. Through simulation and comparison, the adaptive controller designed in this paper is superior to the conventional sliding mode controller in reducing chattering, adaptive load change and system disturbance. This design has completed the design goal.

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