Sliding Mode ADRC Control Strategy for Three-Phase Vienna Rectifier

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Abstract. Vienna rectifier is a nonlinear, strong coupling, multi-variable system. In order to improve the static and dynamic response of the Vienna rectifier output voltage performance, this paper adopts the combination of sliding mode and the ADRC(auto-disturbance rejection control) control strategy in the voltage outer loop. When the system is started, the output voltage can quickly track the given value without overshoot. When the load is switched, the output voltage fluctuates less and can quickly recover to the given value, which improves the anti-interference ability of the system. Simulation results verify the accuracy and effectiveness of the proposed control strategy.

1. Introduction
As a power electronic device with power factor correction, three-phase PWM rectifier has been widely used. Compared with the traditional three-phase PWM rectifier, three-phase three-level Vienna rectifier has the advantages of low input total harmonic distortion rate, high power density and high efficiency, so it is widely used in power communication system, wind power, motor drive and other fields [1-3]. In order to improve the input current and output voltage of Vienna rectifier performance, the control method of Vienna rectifier controlled by conventional linear extended to nonlinear control, such as the sliding mode control, model predictive control, ADRC and so on, these control methods have improved the performance of the Vienna rectifier.

ADRC is a new controller based on error feedback control. The traditional PID control directly takes the difference between the reference value of the output voltage and the output feedback as the control signal, resulting in the contradiction between the response speed of the output voltage and the overshoot. Therefore, the ADRC introduces the tracking differential controller (TD) to arrange the transition process for the reference value of the output voltage, which solves this contradiction. Based on extended state observer (ESO) on the output voltage, the system of the inner disturbance and outside disturbance due to system disturbance, the disturbance observer is by introducing an extended state, through the nonlinear state error feedback controller to control error, and then the total disturbance to the system for real-time compensation, so as to improve the stability and robustness of the output voltage. Conventional nonlinear ADRC has many parameters and complex parameter setting. Although linear state error feedback control can simplify the setting of controller parameters, its dynamic response speed and stability are correspondingly reduced [4-5]. Sliding mode variable structure control (SMC) is a kind of nonlinear control in nature, it has some advantages such as fast response and simple implementation. However, the main disadvantage of this control method is that when the state trajectory reaches the sliding mode surface, it is difficult to slide strictly along the
sliding mode to the equilibrium point, but to pass back and forth on both sides of the sliding mode surface, which results in chattering and limits its application [6-8].

In order to improve the performance of the output voltage of the Vienna rectifier, Sliding-mode auto-disturbance rejection control strategy is adopted in the voltage outer loop to make the output voltage reach the given value quickly without overshoot, meanwhile, the stability of the system is improved and the output voltage has strong robustness. The effectiveness of the scheme is verified by simulation.

2. Sliding mode auto-disturbance rejection control

In this paper, using the combination of ADRC and sliding mode variable structure of composite control strategy, by improving the continuity and derivative of the sign function in the sliding mode approach law, which can overcome the problem of the chattering of sliding mode controller, and then with the improved sliding mode controller as the ADRC state feedback control law, so as to improve the performance of the ADRC.

Ignoring the loss of the rectifier bridge itself, the ac measured active power \( P_{ac} \) of the three-phase Vienna rectifier is equal to the active power \( P_{dc} \) of the dc side, i.e., \( P_{ac}=P_{dc} \), according to which formula (1) can be obtained.

\[
ed_{d}i_{d}+e_{q}i_{q} = \frac{1}{2} \frac{dv_{dc}}{dt} + \frac{v_{dc}^2}{R_L} \tag{1}\]

Three-phase power supply symmetry, Substitute \( e_{q}=0 \) and \( e_{d} = \sqrt{3}U \) into equation (1) to obtain:

\[
\frac{dv_{dc}^2}{dt} = -\frac{4}{R_L C} v_{dc}^2 + \frac{4\sqrt{3}U}{C} i_d \tag{2}\]

Let \( \alpha(t) = -4v_{dc}^2 / R_L C \), \( R_L = \sqrt{3}U i_L \), equation (2) can be changed into:

\[
\frac{dv_{dc}^2}{dt} = \alpha(t) + \frac{4}{C} P_0 \tag{3}\]

According to equation (3), the total disturbance \( \alpha(t) \) of the system contains the load \( R_L \). If the \( R_L \) changes during the system operation, the system can be rapidly estimated and compensated by the expanded state observer.

In order to realize fast tracking of input signal without overshoot. For this purpose, the tracking microcontroller is designed and formula (4) is obtained:

\[
\begin{align*}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= -1.73rx_2 - r^2(x_1 - u_{dc})
\end{align*} \tag{4}\]

Where \( r \) is the velocity factor, the larger \( r \) is, the faster the tracking speed is; \( X_t \) is the transition process arranged for a voltage given value \( U_{ref} \). The output (dc voltage) and the integrated disturbance (internal disturbance and external disturbance) of the real-time observation system are realized through the extended state observer. For this reason, the extended state observer is designed as follows:

\[
\begin{align*}
\dot{z}_1 &= z_2 - \beta_1(z_1 - v_{dc}) + bP_{ref} \\
\dot{z}_2 &= -\beta_2(z_1 - v_{dc})
\end{align*} \tag{5}\]

Where, \( z_1 \) is the voltage state estimation, and \( z_2 \) is the estimated value of disturbance \( \alpha(t) \). \( \beta_1 \) and \( \beta_2 \) are adjustable parameters.

The nonlinear state error feedback controller based on sliding mode control is as follows:
Where, $s$ is the designed sliding mode surface, $k$ represents the exponential coefficient of the sliding mode approaching law, whose value is greater than 0, and $\varepsilon$ represents the velocity of the approaching switching surface of the sliding mode approaching law, whose value is greater than 0.

Replace $v_{dc}$ in equation (3) with $z_1$ to obtain equation (7):

$$\frac{dz_1^2}{dt} = -\frac{4z_1^2}{C} + \frac{4}{L} P_0$$

(7)

Where, $u_0$ is the given signal of the inner loop without disturbance compensation.

The hyperbolic tangent function is a monotone increasing and smooth continuous nonlinear function, which is continuous near the origin and has the characteristic of fast linear response, thus making up for the high frequency chattering caused by the discontinuity of the general exponential approaching law sign function at the origin. The $\tanh(s)$ function in equation (6) is:

$$\tanh(s) = \frac{e^s - e^{-s}}{e^s + e^{-s}}$$

(8)

According to the internal disturbance and external disturbance of the observing system of the extended state observer as the total disturbance of the system, the compensation method is as follows:

$$P_{ref} = P_0 - \frac{z_2}{b}$$

(9)

Where, $P_{ref}$ is the given power value of the inner ring after compensation, and $\frac{z_2}{b}$ is the total disturbance compensation component of the system.

In conclusion, the control block diagram of Vienna rectifier is shown in figure 1.

![Control strategy for three-phase Vienna rectifier](image)

**Figure 1.** Control strategy for three-phase Vienna rectifier

### 3. Simulation analysis

In order to verify the effectiveness of the proposed control strategy, a simulation model was built in MATLAB/Simulink, and SVPWM modulation method with mid-point potential balance factor was adopted. Parameters used in system simulation: RMS value of the grid voltage $e=220V$, dc-bus voltage...
\( v_{dc} = 600 \text{V}, \) dc-bus capacitor \( C = 3300 \text{ uF}, \) Input resistance \( R_S = 0.5 \Omega, \) Inductance of reactors \( L_S = 4 \text{mH}, \) Load resistance \( R_L = 50 \Omega. \)

Figure 2 shows the steady-state simulation waveform of the system when the proposed control strategy is adopted. As can be seen from figure 2-a), the simulation results show that the input voltage \( e_a \) and the input current \( i_a \) are in the same phase and the current can reach a steady state quickly. At the same time, figure 2-b) shows the output waveform at steady state. The output voltage \( v_{dc} \) is relatively stable and close to its reference value of 600V. When the system starts up, the output voltage can be stabilized at the given value after 0.03s. In this paper, the output voltage under the control strategy is almost not overregulated, and the output voltage ripple is small and stable in the steady state.

![Steady-state simulation waveforms of \( e_a \) and \( i_a \)](image1)

![Steady-state simulation waveform of output voltage \( V_{dc} \)](image2)

**Figure 2. Steady-state simulation waveform**

In order to verify the dynamic performance of the control strategy proposed in this paper, the load was switched from semi-load to full load at 0.2s. figure 3 shows the simulation waveform when the load is suddenly changed. figure 3-a) shows the waveform of active power \( p \) and reactive power \( q \) when the load is switched. The reactive power \( q \) keeps the given value of 0 almost unchanged, while the active power \( p \) changes rapidly to a new stable state. It can be seen from figure 3-c) that although the output voltage has a small fluctuation, it can be recovered to the given value within 0.06s, indicating that the control method can further improve the dynamic characteristics of the system. The input current waveform is shown in figure 3-b). When the load is switched, the input current produces a small distortion, but it always follows the input voltage waveform and reaches a new stable state.

![Simulation waveforms of \( p \) and \( q \) during load switching](image3)

![Simulation waveforms of \( e_a \) and \( i_a \) during load switching](image4)
The simulation results show the correctness and effectiveness of the proposed control strategy, which can improve the stability of the system and reduce the distortion rate of the network side current and ensure the quality of the input current.

4. Conclusion
In this paper, the outer voltage loop of three-phase Vienna rectifier adopts sliding-mode auto-disturbance rejection control, which solves the overshoot and dynamic response problems of the output voltage of Vienna rectifier. When the system is started, the output voltage can reach the given value quickly without overshoot. When the load is switched, the output voltage fluctuation does not exceed 5V and can quickly recover to the given value within 0.06s, effectively improving the static and dynamic performance of the output voltage.

5. References
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