Research on ADRC of Double Buck Inverter

Zixi Zhang, Hejin Xiong and Rongjiang Tang
School of Automation, Wuhan University of Technology, Wuhan, China

Abstract. The traditional double buck full bridge inverter adopts the hysteresis current control mode, and the current is in the half cycle. Because of its no bridge arm through, high voltage utilization and high efficiency, it is widely used. Based on the disturbance caused by power supply fluctuation, external noise and system parameter change, this paper proposes an auto disturbance rejection control (ADRC) strategy. The simulation results show that the ADRC strategy can make the double buck full bridge inverter have good waveform tracking performance, good robustness, stability and high accuracy.

Key words: Double buck full bridge inverter; PID; ADRC; Robustness; Stability

1. Introduction
With the development of industrialization, people's demand for energy is higher and higher. As an essential device of power conversion, inverter is paid more and more attention. The traditional inverter has many problems, such as bridge arm through, large loss, long diode reverse recovery time, etc., while the full bridge inverter based on double buck structure has the characteristics of no bridge arm through, high voltage utilization, high efficiency, continuous current diode can be optimized and so on [1]. The traditional double buck full bridge inverter adopts the double loop control strategy. The control method of voltage outer loop and current inner loop has the advantages of easy realization, high reliability, good stability, etc. it has become a wide range of converter control methods. However, the current hysteresis double loop control has poor anti-interference ability, poor load carrying ability, low steady-state accuracy and soft external characteristics. And other problems cannot be ignored. In order to improve the dynamic performance and anti-interference ability of the double buck inverter, this paper adopts the ADRC strategy for the double buck inverter circuit. The contradiction between the rapidity and overshoot of classical PID control and the limitation of modern control theory depending on control object model are solved. It has the advantages of no dependence on the precise model of the controlled object, good dynamic and static performance, strong disturbance rejection ability, etc.

2. PID Control of Double Buck full Bridge Inverter

2.1. Schematic Diagram of Double Buck Full Bridge Inverter
The double buck inverter consists of two buck circuits, as shown in Figure 1. Switch tubes S1 and S4, diodes D1 and D4, filter capacitor CF and filter inductor L1 constitute buck circuit 1; switch tubes S2 and S3, diodes D2 and D3, filter capacitor CF and filter inductor L2 constitute buck circuit 2, with topology of current half cycle working mode; inductors L1 and L2 respectively work in positive and negative half cycle of output voltage, and L1 = L2 = L. UD is the input power supply and U0 is the output voltage. When U0 > 0, S2 and S3 are off, and S1 and S4 are modulated; when U0 < 0, S1 and S4 are off, and S2 and S3 are modulated.
2.2. PID Control Model Establishment of Double Buck Full Bridge Inverter

The double buck inverter adopts the slope comparison current control mode. The output of the voltage regulator is the given signal of the sum of the inductive current. The output of the current regulator, its inverse signal and the triangle wave intercept the driving signals of the two power tubes. Therefore, the traditional double loop control of the double buck inverter is shown in Figure 2 (a), and its transfer function control block diagram is shown in Figure 2 (b) [2].

According to figure 2 (b), the equivalent controlled object of voltage loop can be obtained as follows:

\[
G_p(s) = \frac{K_i R}{RLC f s^2 + (K_i RC f + L)s + R + K_i}
\]  

and \(G_p(s) = K_{up} + \frac{1}{\tau_s}\), \(K_{up}\) is the voltage loop proportion, \(\tau_s\) is the integral time constant, when using PID controller for control, it is equivalent to PID controller, \(K_i\) includes current loop equivalent coefficient and modulation ratio [4].

For double Buck full bridge inverter, \(i_L(t) = i_{L2}(t) = i_{L1}(t)\), \(L1 = L2 = L\), because the positive and negative half cycles of the inverter are symmetrical, so only the positive and half cycles are analyzed here, \(U_A(t) = U(t)\), The inverter system model is as follows:

\[
\begin{align*}
\frac{d u_C(t)}{dt} &= i_L(t) - i_R(t) \\
\frac{L}{C} \frac{d i_L(t)}{dt} &= U(t) - U_C(t)
\end{align*}
\]  

The capacitor voltage \(U_C\) and inductor current \(i_L\) are selected as the state variables, the inverter AC output voltage \(U(T)\) and load current \(i_R(T)\) are selected as the input, and the capacitor voltage is the...
system output. $x(t) = [u_c(t), i_L(t)]$, $u(t) = [U(t), i_R(t)]$, $y(t) = u_c(t)$. The system state equation of the inverter is:

$$
\begin{align*}
    x(t) &= Ax(t) + Bu(t) \\
    y(t) &= Cx(t)
\end{align*}
$$

(3)

where, 

$$
A = \begin{pmatrix}
0 & \frac{1}{c} \\
-\frac{1}{L} & 0
\end{pmatrix},
B = \begin{pmatrix}
0 & -\frac{1}{c} \\
\frac{1}{L} & 0
\end{pmatrix},
C = (1 \ 0).
$$

3. Adrc of Double Buck Full Bridge Inverter

3.1. Structure of ADRC System

The ADRC consists tracking differentiator (TD), extended state observer (ESO) and nonlinear state error feedback control law (NLSEF) [7]. The process of parameter input conversion is realized by TD, which makes the input signal smooth and gets the corresponding differential signal. ADRC only needs the input and output of the system as the information source. Through ESO, it can not only get the estimation of each state variable, but also estimate the real-time action of the uncertain model and external disturbance, and compensate in the feedback, so as to achieve the goal of reconstructing the object. NLSEF is a non-linear combination of the errors between the estimation of state variables produced by TD and ESO. It constitutes a control quantity together with the compensation quantity of ESO to the total disturbance [6].

3.2. Design of ADRC

The block diagram of ADRC is shown in the figure below. The PID control has been built before. The ADRC control in the figure below replaces the traditional double loop PID control. The control object remains unchanged, and the value is its transfer function $G(s)$. Add ADRC and transfer function package to the system, adjust the parameters of ADRC by manual trial method [3].

Figure 3. Structure diagram of ADRC.

4. Simulation Analysis

This paper builds a model in MATLAB to verify the correctness and feasibility of ADRC strategy. Specific parameter design is as follows: inductance $L_1=L_2=660\,\text{mH}$, capacitance $C_f=10\,\text{mH}$, load resistance $R=50\,\Omega$, $U_d=360\,\text{V}$ dc input voltage, output voltage reference $U_{ref}=220\,\text{V}$, output frequency $f_0=50\,\text{Hz}$, rated power $P_0=1000\,\text{W}$, rated current $I_0=4.545\,\text{A}$, the switching frequency $f_s=100\,\text{KHz}$ [8]. Adjust the parameters of simulation circuit and ADRC. Under the condition that the system parameters are basically stable and can work normally, a white noise disturbance, a pulse disturbance and a change of load resistance are respectively given to the system. The robustness, accuracy and stability of the traditional PID control system and the ADRC system are studied. The simulation results are shown in the following figure [5].
Figure 4. System output reference voltage.

Figure 5. PID control and ADRC output voltage without interference.

Figure 6. White noise interference PID control and ADRC output voltage.

Figure 7. Pulse interference PID control and ADRC output voltage.

Figure 8. Change the load PID control and ADRC output voltage.

Figure 4 shows the output reference voltage of the system, which is the standard amplitude of 220 V and frequency of 50 Hz. Figure 5 shows the output voltage of PID control and ADRC control when there is no interference. When adjusting the control system parameters, it can be seen that the system can maintain a good output when there is no interference. Figure 6 shows that the white noise interference signal is added in the system of 0.3s-0.6s. It can be seen that under the condition of ADRC, the system robustness of the system is better. Figure 7 shows the PID and ADRC voltage output of the system under pulse interference. It can be seen that the waveform changes significantly under PID control, while the ADRC waveform quickly tracks the original waveform and has good follow-up. Figure 8 shows that the output waveform of the ADRC can still be maintained at 220V after amplification to change the PID control parameters of the controlled object and the output voltage of the ADRC. It is more stable than PID. For the comparison of the above simulation results, the comparison results are shown in Table 1, table 2 and table 3.
Table 1. Comparison under white noise interference.

| Disturbance          | Control mode | Maximum amplitude / (V) | Minimum amplitude/V |
|----------------------|--------------|-------------------------|---------------------|
| White noise jamming  | PID          | +208.8                  | -253                |
|                      | ADRC         | +225.6                  | -220.5              |

Table 2. Comparison under pulse interference.

| Disturbance          | Control mode | Maximum amplitude of disturbance/ (V) | Overshoot/V |
|----------------------|--------------|--------------------------------------|-------------|
| Pulse jamming        | PID          | 52.9                                 | 52.9        |
|                      | ADRC         | 6.22                                 | 6.22        |

Table 3. Comparison of system parameter changes.

| Disturbance | Control mode | Maximum amplitude / (V) | Overshoot/% |
|-------------|--------------|-------------------------|-------------|
| Change load | PID          | 216.3                   | 1.68        |
|             | ADRC         | 219.9                   | 0.045       |

5. Summary
Based on the problem of anti-interference of double buck full bridge inverter, this paper adopts two control strategies. The error fluctuation of ADRC in Table 1 and table 2 is 0.125 of PID control, which means that adopting ADRC has better stability and anti-interference ability. In Table 3, the overshoot of ADRC control is 0.045%, while PID control is 1.68%, and which shows that adopting ADRC has better robustness when controlling double buck inverter.

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