Automatic disturbance rejection control of wind power connected T-type inverter based on filter function

Chunling Li
School of Guangxi Polytechnic Of Construction, Nanning, Guangxi, 530007, China
wqky@debyebiz.cn, lclwing@126.com

Abstract: In order to solve the problems of large tracking error and poor ADRC effect of wind power grid connected T-type inverter, this paper studies the active disturbance rejection control method of wind power grid connected T-type inverter based on filter function. By establishing the mathematical model of wind power grid connected T-type inverter, the filter parameters are optimized by using the filter function, and the noise signal generated during the operation of the inverter is processed to reduce the control error. Taking the filtered bus voltage as the feedback input of the controller, the active disturbance rejection control of T-type inverter is realized. The results show that the control error of the filter function is reduced by about 4.57%, which has strong robustness.

1. Introduction
T-type three-level inverter has the advantages of low output harmonic content, low power consumption and low system cost, which is widely used in large-scale photovoltaic grid connected systems. The standard ADRC is a series integrator. The factors that affect the control effect are regarded as the total disturbance, and the extended state observer is used to estimate and compensate the total disturbance to improve the stability of the control method [1-2]. For T-type inverter, the traditional active disturbance rejection control (ADRC) method based on differential feedforward will lead to large tracking error and low control quality due to feedforward control defects and noise interference. In order to solve this problem, this paper will study the active disturbance rejection control method of wind power grid connected T-type inverter based on filter function.

2. Study on the active disturbance rejection control method of Wind power grid-connected T-type inverter based on filter function

2.1 The mathematical model of wind-connected T-type inverter is established
When the generator speed reaches the minimum grid connected speed and the generator is within the allowable range of the rotor excitation converter, the stator no-load voltage can be controlled to track the change of distribution network parameters [3]. When the output voltage, phase, frequency and other parameters of the generator stator are the same as those of the distribution network, the inverter controls the grid connection. Therefore, assuming that the current direction of the distribution network output current flowing into the inverter is positive, the mathematical model of the T-type inverter is established as follows.
In formula (1), $e_a$, $e_b$ and $e_c$ are the voltage of three-phase power grid respectively; $i_a$, $i_b$ and $i_c$ are the current corresponding to the three-phase grid voltage respectively; $u_a$, $u_b$ and $u_c$ are output voltages of inverter on the side of three-phase power grid; $R$ is the equivalent resistance in the three-phase power network; $U_{dc}$ is the capacitor voltage of three-phase power grid DC bus; $i_{dc}$ is the output current of the DC side of three-phase power grid; $S_a$, $S_b$, $S_c$ are the switching functions of each phase bridge arm of T-type inverter. When the switch function value is 1, the upper arm of each phase of t-inverter is disconnected and the lower bridge arm is closed. When the switch function value is 0, the upper and lower bridge arms of each phase of t-inverter are disconnected [4].

In order to avoid the influence of interaction between three-phase grid and three-phase current on the control effect of the controller, the mathematical model of wind power grid connected T-type inverter shown in formula (1) is transformed. In the d-q synchronous rotating coordinate system, the inverter model is transformed into the inverter model by using Parker transform [5]. The principle formula of Parker transformation is shown in formula (2).

$$
\begin{bmatrix}
\cos(\omega_g t) & \sin(\omega_g t) \\
-\sin(\omega_g t) & \cos(\omega_g t)
\end{bmatrix}
$$

In formula (2), $\omega_g$ is the fundamental wave angular frequency of point voltage after photovoltaic grid-connected. Then the mathematical model of t-type inverter after Parker transformation is as shown in formula (3).

In formula (3), $e_d$ is the d-axis component of three-phase power grid voltage in the d-q synchronous rotation coordinate system; $e_q$ is the q-axis component of the three-phase grid voltage rotation coordinate system; $\dot{i}_d$ is the component of grid side current on q-axis; $\dot{i}_q$ is the component of grid side current on q-axis; $u_d$ is the output voltage component of grid-side inverter on d-axis; $u_q$ is the output voltage component of the grid-side inverter on the q-axis. After the establishment of the wind power connected t-type inverter mathematical model, the filter function is introduced to improve the ADRC.

2.2 The filter function improves the ADRC
In order to avoid the influence of noise on ADRC control effect, it is necessary to filter the voltage signal of three-phase power grid. The inductance loss of the filter can be reduced by controlling the
current ripple coefficient passing through the inductor. In practical engineering, the current ripple coefficient is between 20% and 30%, and the calculation formula is as follows:

$$\Delta i_{\text{m}}, \max = \frac{U_{\text{dc}}}{8 L_i f_s} \leq \lambda I_p$$  \hspace{1cm} (4)

$$L_i \approx \frac{U_{\text{dc}}}{1.6 I_{\text{sp}} f_{\text{s}} f_{\text{f}}}$$

In formula (4), $U_{\text{dc}}$ is the peak voltage of the grid phase; $\lambda$ is the ripple coefficient of inductance current; $I_p$ is the phase current rating; $U_{\text{dc}}$ is the bus capacitance voltage in the three-phase power network; $L_i$ is the inductance of the t-type inverter side filter; $f_{\text{sw}}$ is the switching frequency; $f_{\text{s}}$ is the current frequency in the three-phase power grid. The filter capacitor can provide a low impedance branch for the output current of the inverter. The larger the capacitance, the better the filtering effect. Finally, the state variables of the output bus voltage signal are as follows.

$$x_0(s) = \frac{1}{T s + 1} y = \frac{\omega s}{s + \omega} y$$  \hspace{1cm} (5)

In formula (5), $x_0(s)$ is the state variable after filtering; $T$ is time constant; $\omega$ is the cut-off frequency of the filter. The filter function is used to optimize the ADRC, and the control law is designed to realize the ADRC.

2.3 Realize active disturbance rejection control

The second-order ADRC is used to control the grid connected inverter, and the error feedback law of the control state is as follows.

$$u_s = k_y (z_1 - z_s) - k_z z_2 - z_3$$  \hspace{1cm} (6)

In formula (6), $z_1$ is the observed state of convergent current by the extended observer; $z_2$ is the observed state of differential current by the extended observer; $z_3$ is the observed state of the total disturbance of the inverter by the extended observer. According to the ADRC designed above, the ADRC is used for closed-loop control of the output voltage signal of the power grid, thus completing the control of the T-type inverter.

3. Control method performance testing and analysis

3.1 Test content

In this experiment, the active disturbance rejection control method based on differential feedforward is used as the comparison group method, and the design method as the experimental group method. The tracking error of control signal and the distortion rate of inverter output current under different resistance loads are compared.

3.2 Test preparation and process

The experiment will be carried out on the wind power grid connected T-type inverter experimental platform, and the relevant parameters are as follows.

| Serial number | Parameter term | Specific numerical | Serial number | Parameter term | Specific numerical |
|---------------|----------------|--------------------|---------------|----------------|--------------------|
| 1             | Bus voltage    | 380V               | 8             | Grid voltage   | 220V               |
| 2             | Inverter side inductance | 3.8mH             | 9             | Grid side inductance | 2.2mH             |
| 3             | Inverter side | 4.3μF              | 10            | Grid side      | 6.6μF              |
The devices in the experimental platform mainly include filter, voltage and current sensor, LCD, data acquisition card, three-phase three wire photovoltaic inverter and data processing computer. The experimental group and the control group are respectively loaded on the experimental platform of grid connected T-type inverter. The input current signal of the inverter is read by the signal oscilloscope, and the tracking signal error is analyzed. By changing the resistance of the inverter on the experimental platform, the distortion rate of the inverter output current is measured and calculated to verify the effectiveness of the proposed control method.

### 3.3 Test results and analysis

When using the two methods, the output current distortion rate of the inverter is as follows.

| Load resistance value /Ω | Voltage fluctuations /V | Experimental group method | Comparison group method |
|-------------------------|------------------------|---------------------------|------------------------|
| 6.8                     | 8                      | 2.41                       | 2.45                   |
| 10                      | 10                     | 2.49                       | 2.68                   |
| 12.5                    | 14                     | 2.56                       | 3.21                   |
| 15.6                    | 18                     | 2.64                       | 3.88                   |
| 18.6                    | 22                     | 2.72                       | 4.47                   |
| 21.3                    | 25                     | 2.73                       | 4.93                   |
| 23.4                    | 29                     | 2.75                       | 5.36                   |
| 25.6                    | 32                     | 2.75                       | 5.82                   |
| 27.8                    | 35                     | 2.75                       | 6.40                   |
| 30.0                    | 37                     | 2.75                       | 7.32                   |

It can be seen from table 2 that when the inverter load is 6.8 Ω, the current distortion rate difference between the two groups can be ignored; with the increase of the inverter load, the output current distortion rate of the control group continues to increase, while the experimental group remains basically unchanged, which verifies the control effect of the design method. Then two methods are used to control the inverter experimental platform, and the input current and grid voltage signals are obtained as follows.

![Figure 1. Comparison of tracking signal errors](image)

It can be seen from Figure 1 that the access current of the inverter side controlled by the comparison group is obviously lagging behind, while the quality of the access current of the inverter side controlled by the experimental group is significantly improved, and there is no phase lag between
the current signal and the grid voltage signal, which effectively proves the control effect of the design method. Then step interference is applied on the experimental platform for 0.02s, and the change of inverter side current is shown in Fig. 2.

![Figure 2. Comparison of inverter current changes under perturbation conditions](image)

It can be seen from Figure 2 that the inverter current under the control of the experimental group and the control group returns to steady state after 0.04s and 0.09s respectively. In addition, when the step disturbance is applied on the experimental platform, the current deviation amplitude of the experimental group is about 1 A, while that of the control group is about 4.5 A. This shows that the method can adjust the abnormal state quickly and restore it to the steady state quickly. It has good robustness, which effectively proves the effectiveness of the method.

4. Conclusion
This paper studies the active disturbance rejection control method of wind power grid connected T-type inverter based on filter function. The results show that the control effect of this method is good and the robustness is strong. It is suitable for practical application and has a certain application prospect.

Reference
[1] NIU LH, HE GF, WU Y. (2020) Design of active disturbance rejection controller based on discrete-control for photovoltaic grid-connected system [J]. Journal of Henan University of Urban Construction,29(01):71-76+87.
[2] LV Q, WANG JY, ZHOU ZJ. (2020) Active Disturbance Rejection Control of LCL Filtered Grid-connected Inverter [J]. Power Electronics,54(01):5-9.
[3] WANG Y, JIANG HH, XING PX. (2019) Auxiliary frequency regulation algorithm for grid-connected inverter with auto-disturbance rejection control in stand-alone micro-grid [J]. Electric Machines and Control,23(04):8-19.
[4] YANG L, ZENG J, HUANG ZL. (2019) Application of Linear Active Disturbance Rejection Technique in Grid-Connected Current Control and Active Damping of LCL Type Inverter [J]. Power System Technology,43(04):1378-1386.
[5] LI HS, LI H, ZHANG YJ. (2019) Z-source inverter grid-connected control based on active disturbances rejected control strategy [J]. Journal of Beijing Information Science & Technology University,34(01):42-48.