Prescribed-time Adaptive Control for Stand-alone Three-phase Inverters with Current Constraints

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***Abstract*—This paper presents a prescribed-time adaptive control scheme with current constraints for Stand-Alone three-phase inverter systems subject to load disturbances and parameter uncertainties. First, considering that inverters must strictly limit output current to protect power devices during practical operation, a smooth-switching-based current penalty function is introduced. This approach effectively constrains the inductor current within a predefined safety range and prevents system overcurrent. Second, to meet the stringent requirements of microgrids for transient performance, a prescribed-time controller is designed to ensure that the tracking errors converge to zero within a user-specified finite time, which is independent of the system's initial conditions. Furthermore, an adaptive law is developed to provide real-time online estimation and compensation for unknown load fluctuations, thereby enhancing system robustness. Finally, simulation results demonstrate that the proposed scheme achieves fast response, high-precision steady-state tracking, and reliable current-limiting capability under complex operating conditions.**

Keywords—Stand-alone three-phase inverter, prescribed-time control, current constraints.

I. INTRODUCTION

The inverter is a power conversion device that converts direct current (DC) into alternating current (AC), and its control performance is directly related to the stable operation of the power system. However, compared with synchronous generators, the overcurrent capability of power electronic devices is quite limited. In the event of an overload or short circuit, the inverter output current can easily exceed its limits, leading to issues such as power device damage, controller saturation instability, and power supply interruption [1]. Therefore, how to achieve effective current constraints while ensuring output voltage regulation performance has become one of the core issues in the control of stand-alone three-phase inverters [2]-[3].

To achieve superior dynamic performance, various control strategies have been investigated. Traditional asymptotic control ensures system stability over an infinite time horizon, while finite-time and fixed-time control strategies offer faster convergence [4]. However, the settling time in finite-time control depends on initial states, and fixed-time control often requires careful parameter design to guarantee a uniform upper bound on the convergence time[5]. Recently, prescribed-time control has attracted increasing attention because it allows the convergence time to be explicitly assigned by the user, independent of initial conditions, thus providing a more predictable and controllable transient response [6]. In addition to convergence speed, hardware safety is a paramount concern in practical engineering. During transient processes, overload, or sudden load changes, the inverter current may rise rapidly, which can threaten the safe operation of power electronic devices and thus necessitates effective current-limiting protection [7]. Although Barrier Lyapunov Function based methods have been widely adopted to address state-constrained control problems [9], they often lead to relatively complicated controller structures and nontrivial implementation burden, especially for high-order uncertain nonlinear systems [9]. Therefore, developing a control scheme that can enforce current safety bounds while preserving prescribed-time convergence remains a challenging and practically meaningful problem [10].

Based on the aforementioned research background, this paper proposes a prescribed-time adaptive control (PTAC) scheme for stand-alone three-phase inverters with current constraints. By incorporating a smooth-switching-based current penalty function into the controller design, the inductor current is ensured to strictly adhere to predefined safety limits. Meanwhile, the output voltage tracking error is guaranteed to converge to zero within a user-defined time frame. Additionally, an adaptive law is developed to estimate unknown load disturbances online, thereby enhancing the system's robustness against external interference. Finally, the effectiveness of the proposed control strategy is validated through simulations.

II. MATHEMATICAL MODEL OF THE SYSTEM AND PRELIMINARIES

Consider the following stand-alone three-phase voltage-source inverter (VSI) system, whose mathematical model is represented as

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$$\begin{cases} \dot{v}_{od} = \omega v_{oq} + \dfrac{1}{C_f} i_{fd} - \dfrac{1}{C_f} i_{od}(t) \\ \dot{i}_{fd} = -\dfrac{1}{L_f} v_{od} + \omega i_{fq} + \dfrac{1}{L_f} u_d \end{cases} \\ \begin{cases} \dot{v}_{oq} = -\omega v_{od} + \dfrac{1}{C_f} i_{fq} - \dfrac{1}{C_f} i_{oq}(t) \\ \dot{i}_{fq} = -\dfrac{1}{L_f} v_{oq} - \omega i_{fd} + \dfrac{1}{L_f} u_q \end{cases} \tag{1}$$

where v_{od} and v_{oq} represent the output voltages in the dq axis; i_{fd} and i_{fq} denote the inductor currents in the dq axis; i_{od} and i_{oq} are the dq axis load disturbances; $\omega = 2\pi f$ is the rotating angular frequency, and f is the fundamental frequency; L_f and C_f represent the filter inductance and capacitance, respectively.

As we know, excessive current primarily causes thermal failure and magnetic saturation, resulting in protective shutdown in minor cases, or inverter explosion and fire in severe cases. In this brief, to mitigate the risk of current overshoot and inspired by time-varying performance functions[11], a penalty function is designed to protect the system from overcurrent. The penalty function is defined as

$$\phi(i_{fd}) = \begin{cases} 1 - \left(\dfrac{\varpi_1}{\tau_1} - 1 \right)^{\lambda_1}, 0 < \varpi_1 \le \tau_1 \\ 1, \varpi_1 > \tau_1 \end{cases} \\ \phi(i_{fq}) = \begin{cases} 1 - \left(\dfrac{\varpi_2}{\tau_2} - 1 \right)^{\lambda_2}, 0 < \varpi_2 \le \tau_2 \\ 1, \varpi_2 > \tau_2 \end{cases} \tag{2}$$

where $\varpi_1 = M_1^2 - i_{fd}^2$ and $\varpi_2 = M_2^2 - i_{fq}^2$; M_i denotes the upper bound of the constraint, and $\tau_i \in \left(0, M_i^2\right)$; $\lambda_i \ge 2$ is a positive even integer, for $i = 1, 2$. By definition $x_1 = V_{od}$, $x_2 = \dfrac{i_{fd}}{\phi\left(i_{fd}\right)}$, $x_3 = V_{oq}$, $x_4 = \dfrac{i_{fq}}{\phi\left(i_{fq}\right)}$, (1) can be rewritten as

$$\begin{cases} \dot{x}_1 = \omega x_3 + \dfrac{1}{C_f} \phi\left(i_{fd}\right) x_2 - \dfrac{1}{C_f} i_{od}(t) \\ \dot{x}_2 = \mu_1 \left(-\dfrac{1}{L_f} x_1 + \omega \phi\left(i_{fq}\right) x_4 + \dfrac{1}{L_f} u_d \right) \end{cases} \\ \begin{cases} \dot{x}_3 = -\omega x_1 + \dfrac{1}{C_f} \phi\left(i_{fq}\right) x_4 - \dfrac{1}{C_f} i_{oq}(t) \\ \dot{x}_4 = \mu_2 \left(-\dfrac{1}{L_f} x_3 - \omega \phi\left(i_{fd}\right) x_2 + \dfrac{1}{L_f} u_q \right) \end{cases} \tag{3}$$

where $\mu_1 = \begin{cases} \dfrac{1 - \left(\dfrac{\varpi_1}{\tau_1} - 1 \right)^{\lambda_1} - \dfrac{2 i_{fd}^2 \lambda_1}{\tau_1} \left(\dfrac{\varpi_1}{\tau_1} - 1 \right)^{\lambda_1 - 1}}{\left[1 - \left(\dfrac{\varpi_1}{\tau_1} - 1 \right)^{\lambda_1} \right]^2}, 0 < \varpi_1 \le \tau_1 \\ 1, \varpi_1 > \tau_1 \end{cases}$

and $\mu_2 = \begin{cases} \dfrac{1 - \left(\dfrac{\varpi_2}{\tau_2} - 1 \right)^{\lambda_2} - \dfrac{2 i_{fq}^2 \lambda_2}{\tau_2} \left(\dfrac{\varpi_2}{\tau_2} - 1 \right)^{\lambda_2 - 1}}{\left[1 - \left(\dfrac{\varpi_2}{\tau_2} - 1 \right)^{\lambda_2} \right]^2}, 0 < \varpi_2 \le \tau_2 \\ 1, \varpi_2 > \tau_2 \end{cases}$.

III. CONTROLLER DESIGN

To guarantee the AC output voltage performance of the three-phase VSI under time-varying load disturbances, this section proposes a dual-loop prescribed-time adaptive control scheme. It follows the conventional cascaded dual-loop structure, consisting of an outer voltage loop and an inner current loop. Based on this cascaded structure, the mismatched load disturbances in (6) and (13) are transformed into matched disturbances within the voltage control loop. A novel adaptive law and a prescribed-time voltage controller are designed to estimate and compensate for the time-varying load disturbances, thereby ensuring the AC output voltage performance. Finally, the stability of the closed-loop stand-alone three-phase VSI system is analyzed.

A. Prescribed-Time Backstepping Controller

First, the tracking error is defined as $z_1 = x_1 - v_{od}^*$, $z_2 = x_2 - \dfrac{i_{fd}^*}{\phi\left(i_{fd}\right)}$, $z_3 = x_3 - v_{oq}^*$, $z_4 = x_4 - \dfrac{i_{fq}^*}{\phi\left(i_{fq}\right)}$.

Let $\dfrac{i_{fd}^*}{\phi\left(i_{fd}\right)} = o_1$, $\dfrac{i_{fq}^*}{\phi\left(i_{fq}\right)} = o_2$, then $z_2 = x_2 - o_1$ $z_4 = x_4 - o_2$, where the superscript "*" denotes the corresponding desired value. The control objective is to ensure that the tracking errors converge to a small neighborhood of zero within a prescribed time.

In this paper, the controller is designed based on the backstepping technique and prescribed-time control theory, where the control laws are derived by constructing appropriate Lyapunov functions. Considering that the VSI is a second-order system, two virtual control laws are introduced to achieve prescribed-time control of the output voltage.

Select the first Lyapunov function as

$$V_1 = \frac{1}{2} z_1^2. \tag{4}$$

Substituting the tracking error of the voltage component on the d-axis into the derivative of V_1 yields

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$$\dot{V}_1 = z_1\dot{z}_1 = z_1\left(\omega x_3 + \frac{1}{C_f}\phi\left(i_{fd}\right)x_2 - \frac{1}{C_f}i_{od}\left(t\right) - \dot{v}_{od}^*\right) \quad (5)$$

To achieve the prescribed-time convergence, the virtual control law is designed as:

$$i_{fd}^* = C_f\begin{pmatrix} -\frac{\pi}{\beta T_s}\left(k_{11}\lfloor z_1\rceil^{1+\beta} + k_{12}\lfloor z_1\rceil^{1-\beta}\right) \\ -\omega x_3 + \frac{1}{C_f}\hat{i}_{od} + \hat{\dot{v}}_{od}^* - \frac{1}{2}z_1 - \frac{1}{2C_f}z_1 \end{pmatrix} \quad (6)$$

Substituting the virtual control law into (6) yields

$$\begin{aligned}\dot{V}_1 = &-\frac{\pi}{\beta T_s}\left(k_{11}z_1\lfloor z_1\rceil^{1+\beta} + k_{12}z_1\lfloor z_1\rceil^{1-\beta}\right) - z_1\tilde{\dot{v}}_{od}^* \\ &+\frac{1}{C_f}z_1z_2\phi\left(i_{fd}\right) - \frac{1}{C_f}z_1\tilde{i}_{od} - \frac{1}{2}z_1^2 - \frac{1}{2C_f}z_1^2\end{aligned} \quad (7)$$

where $\tilde{\dot{v}}_{od}^* = \hat{\dot{v}}_{od}^* - \dot{v}_{od}^*$, the superscript "~" refers to the error term in the interference estimation process. Define the notations $\lfloor x_i\rceil^{\chi} = \mathrm{sign}(x_i)\,|\,x_i\,|^{\chi}$.

Considering the d-axis subsystem, select the Lyapunov function as

$$V_2 = V_1 + \frac{1}{2}z_2^2 \quad (8)$$

Taking the derivative of V_2 and considering (3), substituting the tracking error z_2 yields

$$\dot{V}_2 = \dot{V}_1 + z_2\left(\mu_1\left(-\frac{1}{L_f}x_1 + \omega\phi\left(i_{fq}\right)x_4 + \frac{1}{L_f}u_d\right) - \dot{o}_1\right) \quad (9)$$

The actual control law u_d can be constructed as

$$u_d = L_f\begin{pmatrix} -\frac{\pi}{\beta T_s}\left(k_{21}\lfloor z_2\rceil^{1+\beta} + k_{22}\lfloor z_2\rceil^{1-\beta}\right) + \frac{1}{L_f}x_1 \\ -\omega\phi\left(i_{fq}\right)x_4 + \frac{\hat{\dot{o}}_1}{\mu_1} - \frac{1}{\mu_1 C_f}z_1\phi\left(i_{fd}\right) - \frac{1}{2}z_2 \end{pmatrix} \quad (10)$$

Therefore, $\dot{V}_2$ can be rewritten as

$$\begin{aligned}\dot{V}_2 = &\sum_{i=1}^{2}\left(-\frac{\pi}{\beta T_s}\left(k_{i1}z_i\lfloor z_i\rceil^{1+\beta} + k_{i2}z_i\lfloor z_i\rceil^{1-\beta}\right) - \frac{1}{2}z_i^2\right) \\ &-\frac{1}{C_f}z_1\tilde{i}_{od} - z_1\tilde{\dot{v}}_{od}^* - z_2\tilde{\dot{o}}_1 - \frac{1}{2C_f}z_1^2\end{aligned} \quad (11)$$

Similarly, Considering the q-axis subsystem, V_3 can be designed as

$$V_3 = V_2 + \frac{1}{2}z_3^2 \quad (12)$$

By differentiating V_3 and substituting (2) and the tracking error, while satisfying the prescribed-time requirement, the virtual control law is constructed as

$$i_{fq}^* = C_f\begin{pmatrix} \frac{\pi}{\beta T_s}\left(k_{31}\lfloor z_3\rceil^{1+\beta} + k_{32}\lfloor z_3\rceil^{1-\beta}\right) \\ +\omega x_1 + \frac{1}{C_f}\hat{i}_{oq} + \hat{\dot{v}}_{oq}^* - \frac{1}{2}z_3 - \frac{1}{2C_f}z_3 \end{pmatrix} \quad (13)$$

Therefore, $\dot{V}_3$ can be written as

$$\begin{aligned}\dot{V}_3 = &\sum_{i=1}^{3}\left(-\frac{\pi}{\beta T_s}\left(k_{i1}z_i\lfloor z_i\rceil^{1+\beta} + k_{i2}z_i\lfloor z_i\rceil^{1-\beta}\right) - \frac{1}{2}z_i^2\right) - z_2\tilde{\dot{o}}_1 \\ &+\frac{1}{C_f}z_3z_4\phi\left(i_{fq}\right) - \frac{1}{C_f}z_1\tilde{i}_{od} - \frac{1}{C_f}z_3\tilde{i}_{oq} - z_1\tilde{\dot{v}}_{od}^* - z_3\tilde{\dot{v}}_{oq}^* \\ &-\frac{1}{2C_f}z_1^2 - \frac{1}{2C_f}z_3^2\end{aligned} \quad (14)$$

The final Lyapunov function is designed as

$$V_4 = V_3 + \frac{1}{2}z_4^2 \quad (15)$$

Based on (2) and tracking error, taking the derivative of V yields

$$\dot{V}_4 = \dot{V}_3 + z_4\left(\mu_2\left(-\frac{1}{L_f}x_3 + \omega\phi\left(i_{fd}\right)x_2 + \frac{1}{L_f}u_q\right) - \dot{o}_2\right) \quad (16)$$

The actual control law u_q can be constructed as

$$u_q = L_f\begin{pmatrix} -\frac{\pi}{\beta T_s}\left(k_{41}\lfloor z_4\rceil^{1+\beta} + k_{42}\lfloor z_4\rceil^{1-\beta}\right) + \frac{1}{L_f}x_3 \\ +\omega\phi\left(i_{fd}\right)x_2 + \frac{\hat{\dot{o}}_2}{\mu_2} - \frac{1}{\mu_2 C_f}z_3\phi\left(i_{fq}\right) - \frac{1}{2}z_4 \end{pmatrix} \quad (17)$$

Substituting the actual control law u_q into (16) yields

$$\begin{aligned}\dot{V}_4 = &\sum_{i=1}^{4}\left(-\frac{\pi}{\beta T_s}\left(k_{i1}z_i\lfloor z_i\rceil^{1+\beta} + k_{i2}z_i\lfloor z_i\rceil^{1-\beta}\right) - \frac{1}{2}z_i^2\right) \\ &-\frac{1}{C_f}z_1\tilde{i}_{od} - \frac{1}{C_f}z_3\tilde{i}_{oq} - z_1\tilde{\dot{v}}_{od}^* - z_2\tilde{\dot{o}}_1 - z_3\tilde{\dot{v}}_{oq}^* - z_2\tilde{\dot{o}}_2 \\ &-\frac{1}{2C_f}z_1^2 - \frac{1}{2C_f}z_3^2\end{aligned} \quad (18)$$

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where $k_{i1}=\left(\frac{1}{2}\right)^{1+\frac{3\beta}{2}}$, $k_{i2}=\left(\frac{1}{2}\right)^{1-\frac{\beta}{2}}$, i=1,2…,4.

B. Differentiator and Adaptive Law

Although numerical differentiation can provide derivative signals, it inevitably introduces random noise components, which may lead to system instability. Therefore, a differentiator [4] is introduced to obtain the required derivative signals, the detailed structure of which is as follows.

$$\begin{cases}\dot{\varphi}_1=\varphi_2\\ \dot{\varphi}_2=\frac{1}{\zeta^2}\left(-\rho_1\tanh\left(\varphi_1-\tilde{x}\right)-\rho_2\tanh\left(\zeta\varphi_2\right)\right)\end{cases} \tag{19}$$

where the input signal is $\tilde{x}=\begin{bmatrix}v_{od}^* & o_1 & v_{oq}^* & o_2\end{bmatrix}$ and the output signal is $\varphi_2=\begin{bmatrix}\hat{v}_{od}^* & \hat{o}_1 & \hat{v}_{oq}^* & \hat{o}_2\end{bmatrix}$, ρ_1 and ρ_2 are design parameters.

According to [4], the estimation errors satisfy

$$\begin{aligned}&|\hat{v}_{od}^*-\dot{v}_{od}^*|\le\varepsilon,|\,\hat{o}_1-\dot{o}_1\,|\le\varepsilon\\ &|\hat{v}_{oq}^*-\dot{v}_{oq}^*|\le\varepsilon,|\,\hat{o}_1-\dot{o}_1\,|\le\varepsilon\end{aligned}. \tag{20}$$

In (6) and (13), $\hat{i}_{od}$ and $\hat{i}_{oq}$ are the estimated values of the time-varying load disturbances, which are described by the following adaptive laws:

$$\begin{cases}\dot{\hat{i}}_{od}=-\frac{\pi}{\beta T_s}\left(\xi_1\left\lfloor\tilde{i}_{od}\right\rceil^{1+\beta}+\xi_2\left\lfloor\tilde{i}_{od}\right\rceil^{1-\beta}\right)-\frac{1}{2}\tilde{i}_{od}-\frac{1}{2C_f}\tilde{i}_{od}\\ \dot{\hat{i}}_{oq}=-\frac{\pi}{\beta T_s}\left(\xi_1\left\lfloor\tilde{i}_{oq}\right\rceil^{1+\beta}+\xi_2\left\lfloor\tilde{i}_{oq}\right\rceil^{1-\beta}\right)-\frac{1}{2}\tilde{i}_{oq}-\frac{1}{2C_f}\tilde{i}_{oq}\end{cases} \tag{21}$$

where $\tilde{i}_{od}=\hat{i}_{od}-i_{od}$ and $\tilde{i}_{oq}=\hat{i}_{oq}-i_{oq}$ are disturbance estimation errors, $\xi_1=\left(\frac{1}{2}\right)^{1+\beta}$ and $\xi_1=\left(\frac{1}{2}\right)^{1-\frac{\beta}{2}}$.

C. Stability Proof

Next, the effectiveness of the prescribed-time backstepping control strategy is theoretically proven. To simultaneously account for the adaptive law, the Lyapunov function is chosen as

$$V=V_4+\frac{1}{2}\tilde{i}_{od}^2+\frac{1}{2}\tilde{i}_{oq}^2. \tag{22}$$

Substituting (18) and (21) into the derivative of (22), we have:

$$\begin{aligned}\dot{V}=&\sum_{i=1}^{4}\left(-\frac{\pi}{\beta T_s}\left(k_{i1}z_i\left\lfloor z_i\right\rceil^{1+\beta}+k_{i2}z_i\left\lfloor z_i\right\rceil^{1-\beta}\right)-\frac{1}{2}z_i^2\right)\\ &-\frac{1}{C_f}z_1\tilde{i}_{od}-\frac{1}{C_f}z_3\tilde{i}_{oq}-z_1\tilde{v}_{od}^*-z_2\tilde{o}_1-z_3\tilde{v}_{oq}^*-z_4\tilde{o}_2\\ &-\tilde{i}_{od}\dot{i}_{od}-\frac{\pi}{\beta T_s}\left(\xi_1\tilde{i}_{od}\left\lfloor\tilde{i}_{od}\right\rceil^{1+\beta}+\xi_2\tilde{i}_{od}\left\lfloor\tilde{i}_{od}\right\rceil^{1-\beta}\right)\\ &-\tilde{i}_{oq}\dot{i}_{oq}-\frac{\pi}{\beta T_s}\left(\xi_1\tilde{i}_{oq}\left\lfloor\tilde{i}_{oq}\right\rceil^{1+\beta}+\xi_2\tilde{i}_{oq}\left\lfloor\tilde{i}_{oq}\right\rceil^{1-\beta}\right)\\ &-\frac{1}{2C_f}z_1^2-\frac{1}{2C_f}z_3^2-\frac{1}{2}\tilde{i}_{od}{}^2-\frac{1}{2}\tilde{i}_{oq}{}^2-\frac{1}{2C_f}\tilde{i}_{od}{}^2-\frac{1}{2C_f}\tilde{i}_{oq}{}^2\end{aligned}. \tag{23}$$

According to Young's inequality, we have

$$\begin{aligned}&-z_1\tilde{v}_{od}^*\le\frac{1}{2}z_1^2+\frac{1}{2}\varepsilon_1^2,\quad -z_2\tilde{o}_1\le\frac{1}{2}z_2^2+\frac{1}{2}\varepsilon_1^2,\\ &-z_3\tilde{v}_{oq}^*\le\frac{1}{2}z_3^2+\frac{1}{2}\varepsilon_1^2,\quad -z_4\tilde{o}_2\le\frac{1}{2}z_4^2+\frac{1}{2}\varepsilon_1^2\\ &\frac{1}{C_f}z_1\tilde{i}_{od}\le\frac{1}{2C_f}z_1^2+\frac{1}{2C_f}\tilde{i}_{od}{}^2,\quad \frac{1}{C_f}z_3\tilde{i}_{oq}\le\frac{1}{2C_f}z_3^2+\frac{1}{2C_f}\tilde{i}_{oq}{}^2\\ &\tilde{i}_{od}\dot{i}_{od}\le\frac{1}{2}\tilde{i}_{od}^2+\frac{1}{2}\varepsilon_2^2,\quad \tilde{i}_{oq}\dot{i}_{oq}\le\frac{1}{2}\tilde{i}_{oq}^2+\frac{1}{2}\varepsilon_2^2\end{aligned} \tag{24}$$

where ε_2 is the maximum of $\dot{i}_{od}$ and $\dot{i}_{oq}$ substituting (24) into (23), we obtain

$$\dot{V}\le-\frac{\pi}{\beta T_s}\left(V^{1+\frac{\beta}{2}}+V^{1-\frac{\beta}{2}}\right)+\varepsilon \tag{25}$$

where $\varepsilon=2\varepsilon_1^2+\varepsilon_2^2$, the definition of T_s is omitted.

The prescribed-time theorem in [6] is satisfied, and the proof is completed.

IV. Simulation Results

The model of the three-phase VSI is constructed in MATLAB/Simulink to verify the effectiveness of the proposed prescribed-time adaptive control (PTAC). According to the parameter tuning suggestions and procedures in [12], the control parameters of the PTAC method are fine-tuned as: $\beta=0.4$, $M_1=M_2=10$, $\tau_1=\tau_2=50$, $\zeta=0.001$, $\rho_1=0.1$, and $\rho_2=0.2$.

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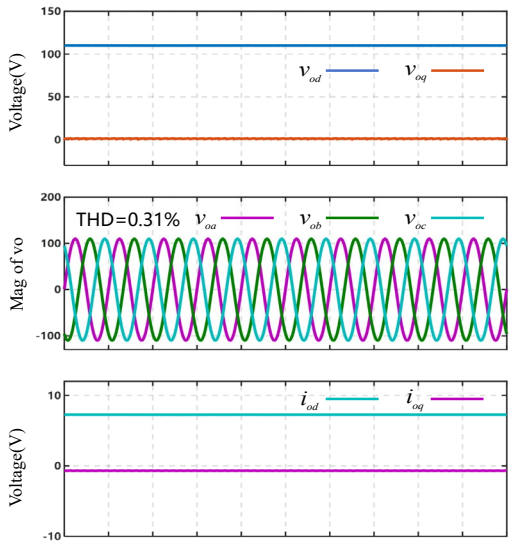

Fig. 1. Test results of control performance under linear RL loads

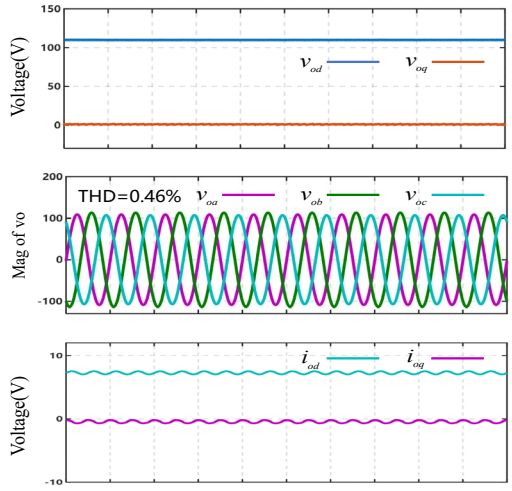

Fig. 2. Test results of control performance under unbalanced loads

Fig. 1 and Fig. 2 illustrate the control performance test results of the proposed PTAC method under linear load and unbalanced load conditions, respectively. It is worth noting that the unbalanced load condition can be obtained by replacing phase A of the linear RL load with a pure resistive load. As indicated by the results, the PTAC method achieves superior steady-state control performance in both operating scenarios and provides balanced three-phase AC output voltages. Furthermore, the output voltage exhibits a small root-mean-square error (RMSE) and low total harmonic distortion (THD). Meanwhile, it can be observed from the figures that the currents are strictly limited within the predefined safety range.

V. Conclusion

This paper proposes a prescribed-time adaptive control scheme with current constraints for stand-alone three-phase inverter systems subject to load disturbances and parameter uncertainties. First, considering that inverters must strictly limit output current to protect power devices during practical operation, a smooth-switching-based current penalty function is introduced. This approach effectively constrains the inductor current within a predefined safety range and prevents system overcurrent. Second, to meet the stringent requirements of microgrids for transient performance, a prescribed-time controller is designed to ensure that the tracking errors converge to zero within a user-specified finite time, which is independent of the system's initial conditions. Finally, simulation results demonstrate that the proposed scheme achieves fast response, high-precision steady-state tracking, and reliable current-limiting capability under complex operating conditions.

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