Key Technology Optimization and Development of New Energy Enterprises of Photovoltaic Power Generation

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Abstract

In order to improve the algorithm of time-varying parameters and unknown parameters adaptability, avoid assuming the approximate part deviation caused by the algorithm, this paper proposes a adaptive control algorithm, the algorithm based on lyapunov direct method to predict the output voltage in the process of estimating each parameter in a reasonable manner to parameter estimation error with the actual output current and current automatic adjustment. The adaptive control of current tracking is realized and the error caused by assuming voltage or current and neglecting line resistance is avoided in the predictive current control algorithm. The simulation results show that the tracking current can track the target current with high precision from t = 0 in the presence of random noise, and the power factor is close to 1, showing a good steady-state performance. Frequency domain waveform, the calculated harmonic distortion rate is 2.2418%, waveform quality is good and each harmonic amplitude is small. Conclusion: adaptive control algorithm can quickly and accurately realize current tracking and greatly suppress the noise.

Keywords: Photovoltaic power generation, adaptive control algorithm, inverter.

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1 Introduction

In recent years, the global attention to environmental protection and the development of new energy, as well as the steady development of renewable energy technology, has brought unprecedented opportunities for the use of new energy such as solar energy, wind energy, etc. Among them, solar energy is one of the cleanest and most abundant new energy sources. On the one hand, there is basically no pollutant emission during the use of solar energy, which is clean and on the other hand, the energy radiated by solar energy to the earth is up to about 1.81011 megawatts, it is many times of the total energy consumption of the earth at present. How to use this energy efficiently for industrial production or residential use, so as to reduce the use of non-renewable energy and reduce the global carbon dioxide emissions is of great strategic significance. At present, solar energy utilization technology includes thermal energy, photovoltaic (PV) and photochemistry. Among them, photovoltaic cells made by using the principle of photovoltaic effect can directly convert the solar light energy into electric energy for utilization, which is called photoelectric conversion, namely photovoltaic power generation.

Photovoltaic cell and photovoltaic inverter are two basic components of photovoltaic power generation system. Photovoltaic cells are responsible for converting solar energy into electricity, which is the first power level of the photovoltaic power generation system. Through photovoltaic cells output characteristics, the study found a photovoltaic cell itself with nonlinear characteristics, which makes the output current and power of the pv cells and its working voltage is related to each set of voltage, current, or each set of voltage and power correspond to the i-v curve or P-V a point on the curve, which is called the working point of photovoltaic cells. Due to the change of season and weather, the light intensity received by the photovoltaic cell will fluctuate greatly, which will change the output power of the photovoltaic cell. This makes how to obtain the maximum energy of the photovoltaic cell become a complex problem, which is collectively referred to as maximum power point tracking (MPPT) in the academic community.

The photovoltaic inverter converts the original direct current (DC) output of the photovoltaic cell into alternating current (AC), which effectively provides power to the local or remote users through the grid. It is the second power level of the photovoltaic power generation system. At the same time, the photovoltaic inverter can adjust the output voltage or output current wave according to the load type through a certain control algorithm. For independent photovoltaic power generation systems, photovoltaic inverter main MPPT and inverter, the MPPT is used to adjust the working point of photovoltaic cell in order to achieve the purpose of extracting maximum power, and the inverter is to guarantee stable output power frequency ac voltage of the grid photovoltaic power generation system, grid, in order to achieve high power factor for inverter to control the output current, in addition to ensuring the waveform quality of the output current, the phase of the output current must be adjusted in real time according to the grid voltage phase.

This paper will take the photovoltaic power generation system as the research object, and carry out in-depth research on the key problems of photovoltaic inverter control algorithm. By analyzing and comparing the technical status of related problems, a new algorithm is proposed to overcome some defects in the existing algorithm and combine with the practice, so that the research results can provide technical and theoretical guidance for the practical application of engineering.

Energy shortage and environmental pollution have become obstacles to the sustainable development of human society, and the development of green and renewable energy has become a development trend. Photovoltaic power generation with its unique advantages to become the future of the most potential alternative energy. Chen et al. mainly analyzed the development prospects and investment risks of the photovoltaic industry in this paper [3]. Zhang et al., from the perspective of new energy technologies, mainly introduced wind power generation technology and photovoltaic power generation technology [5]. Wang et al. studied solar photovoltaic power generation technology in this paper, including grid-connected solar photovoltaic power generation technology, solar photovoltaic micro-inverter technology, and electric automation technology of solar photovoltaic power generation, and put forward suggestions for solar photovoltaic power generation [13].

Photovoltaic power generation technology has been constantly developing, push into the new. Wen et al. combined with the principle of maximum power point tracking control, expounded the commonly used maximum power point tracking algorithm of photovoltaic power generation system at present, and proposed an improved optimization method, in order to better guarantee the operation stability of photovoltaic power generation system [1]. Fernandez et al. analyzed the influence of design variables (collector size and collector spacing) of a biaxial tracking photovoltaic power station on its energy conversion [2]. Tian et al. analyzed control technologies such as maximum power point tracking, energy storage, charge and discharge control, as well as grid-connected control that has an important influence on the development of solar photovoltaic system [4]. Through solar irradiance calculation, photovoltaic array mathematical model, booster chopper circuit, MPPT control, inverter and other modular design, Jiang et al. simulated the technological process of photovoltaic power station [6]. Manoharan et al. discussed an improved P&O-MPPT algorithm, which not only considered the change of output voltage (DV) and output power (DP) of photovoltaic modules, but also considered the change of current (DI) [7]. In this paper, Hwang et al. analyzed the types of defects formed in photovoltaic power generation panels, and proposed a method to determine the defects of aging photovoltaic modules based on temperature, power output and panel images, so as to improve the productivity and efficiency of photovoltaic power stations [9]. Huang et al. established a simulation model of high-power photovoltaic grid-connected system based on matlab/simulink to solve the problems faced by the photovoltaic grid-connected system after distributed energy is connected to the distribution network, studied and gave the working mechanism of the system, and proposed ways to improve the stability of the system. Harmonic linearization method was used to establish the output impedance model of the photovoltaic inverter, and then nyquist stability criterion was used to analyze the stability of the whole system [10].

This article according to the mathematical model of the photovoltaic (pv) grid inverter, based on the theory of lyapunov direct method proposed an adaptive control algorithm, on the premise of guarantee the stability of the closed-loop system, and implement all inverter unknown or time-varying parameter adaptive prediction, and according to the real-time data to predict parameters of automatic adjustment, improve the robustness of the controller, to improve the noise suppression capability.

2 Research Methods

2.1 Adaptive Control Algorithm for Grid-connected Photovoltaic Inverter

Lyapunov's second method is also called the direct method. Its basic idea is to directly judge the stability of the system equilibrium state by means of a lyapunov function. Lyapunov direct method is used to analyze the stability of the system, which can be summarized as the following stability criteria.

Let the state equation of the system be:

$$\dot{x} = f(x) \tag{1}$$

Equilibrium $\mathrm{x_e} = 0$, satisfies $\mathrm{f(x_e)} = 0$.

If I have a scalar function V_x, it satisfies

1. V_x has a continuous first partial derivative with respect to all x
2. V_x is positive definite, that is, when $x = 0$, $V_x = 0$; $x \neq 0, V_x > 0$;
3. The time derivative $\dot{V}(x) = dV(x)/dt$ of V_x calculated along the direction of state trajectory satisfies: $\dot{V}(x)$ is negative definite or semi-negative definite.

Then the system is asymptotically stable at equilibrium at the origin.

In order to enhance the system with unknown parameters and the adaptability of time-varying parameters, improve the versatility of the algorithm, consider using lyapunov function recursive design method of adaptive controller design of photovoltaic (pv) grid inverter device, not only can guarantee the stability of the closed-loop system, but also can avoid dealing with the unknown term brings to the controller design difficulty, state equation is as follows:

$$V_{inv} = L\dot{i} + iR_L + V_s \tag{2}$$

The final control goal of the grid-connected inverter is to achieve current tracking, that is, the actual output current of the inverter power follows the reference current $\dot{i}^*$, after the control target of the system is given, the output voltage V_{inv} required for system stability is calculated according to Equation (2), then adjust the duty ratio of the power switch S1 to S4 to make the inverter output the voltage value, then the current tracking can be realized.

According to the properties of the first-order linear homogeneous difference equation, let the control objective be shown in Equation (3)

$$L\dot{e} = -K_0 e \tag{3}$$

Where, e – current error, $e = i - i^*$
K_0 – constant, constant is positive.

From the above formula, we can get:

$$e = e^{-\frac{K_0}{L}t} \tag{4}$$

As can be seen from the above equation, the current error decreases with the increase of time and finally $e \to 0$.

2.2 Adaptive Control Algorithm Under Interference Signals

In the actual system, there are often random noise and other interference signals, which will change the original state equation of the system and affect the stability and control effect of the system. In order to enhance the anti-interference ability of the system to noise signals and further improve the robustness of the control algorithm, another adaptive control algorithm is proposed for the inverter circuit with interference signals.

The topology of single-phase grid-connected photovoltaic inverter is provided with the following state equation:

$$V_{inv} = L\dot{i} + iR_L + V_s + d \tag{5}$$

Where, d – interference signal voltage. The disturbance may be caused by random disturbance, or by abrupt changes in circuit parameters or load.

If the gas required to meet the system stability and output current control objectives is calculated according to the above formula, and then the duty ratio of the power switch tube is adjusted to make the inverter output the voltage value, the system stability can be achieved in the presence of interference signals and the target value of the output current can be achieved.

3 Results Analysis and Discussion

In order to verify the aforementioned theoretical analysis, a complete current tracking single-phase grid-connected inverter model based on adaptive control algorithm is established in the matlab/simulink environment. The model consists of three parts: the first is the main circuit of inverter, the second is the adaptive predictive current control, and the third is the conversion of duty cycle to control signal. Disturbance signals are generated by random noise. $\widehat{d}$, $\widehat{R}$ and $\widehat{L}$ estimated by the function module are respectively sent to the MATLAB embedded module to calculate the target output voltage,the voltage is converted into the duty cycle of control signal of inverter switching device by triangular wave comparison. In order to verify the consistency between the output current and the grid voltage phase under normal conditions, the reference current is 50 Hz/40 A sine wave. The same initial phase of the two can be adjusted by setting waveform parameters. To verify the tracking situation of the current when the grid voltage changes, a mutation model should be used for mutation simulation. Parameter Settings of the simulation process are shown in Table 1, in which switching frequencies of switch tubes S1 and S2 are 10 kHz, and switching frequencies of switch tubes S3 and S4 are 50 Hz. Power switch adopts IGBT, 10% current drop time is 110–5 s.

Shown in Figure 1 for grid case 5-2 sinusoidal reference current and tracking current waveform comparison, dotted and solid lines represent the

Table 1 Parameter settings

Parameter	Parameter SetPoint
Refer to the current	50 Hz/40 A sine wave
Current 10% drop time	110^{-5} s
Power switch tube	IGBT
Switching frequency of switch tube S_1 and S_2	10 kHz
Switching frequency of switch tube S_3 and S_4	50 Hz

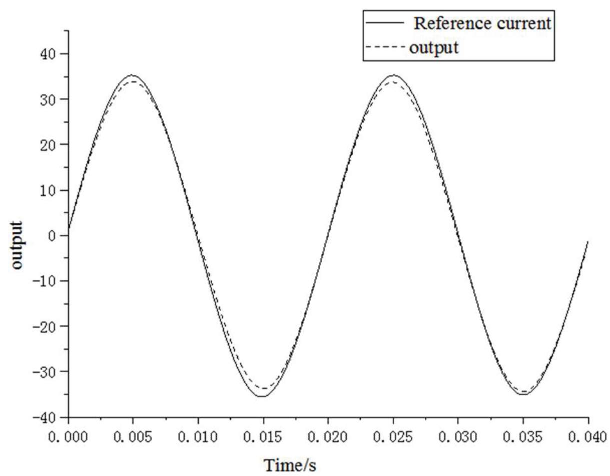

Figure 1 Waveform comparison between reference current and tracking current.

tracking, and the reference current, current tracking in the presence of random noise, since t = 0 is able to form a high precision tracking target current, power factor is close to 1, showing good steady state performance.

The current error between the actual output current and the reference current when the adaptive control algorithm proposed in this paper is used to control the output current. Will decay according to the law shown in Equation (4). It can be seen from the equation that the decay rate of the error is determined by the coefficient K0. The larger K0 is, the faster the decay rate of the exponential function will be and the faster the error will decline. The smaller K0 is, the slower the exponential function decays and the longer the error takes to stabilize.

Figures 2 and 3 show the verification of the adaptive control algorithm proposed in this chapter in two special cases. Figure 2 shows the tracking

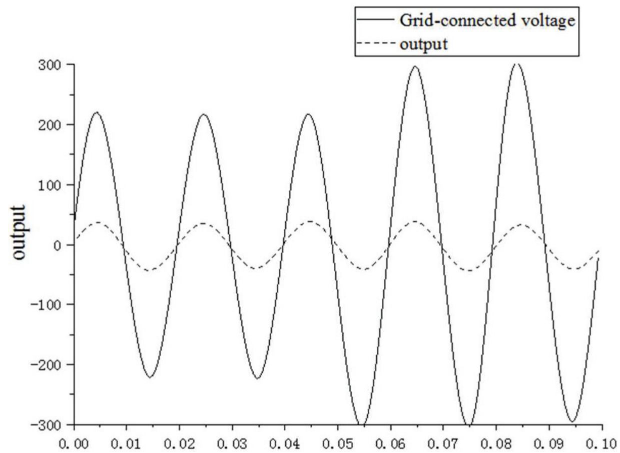

Figure 2 Waveform comparison of grid-connected voltage and output current when grid voltage has step jump at t = 0.05 s.

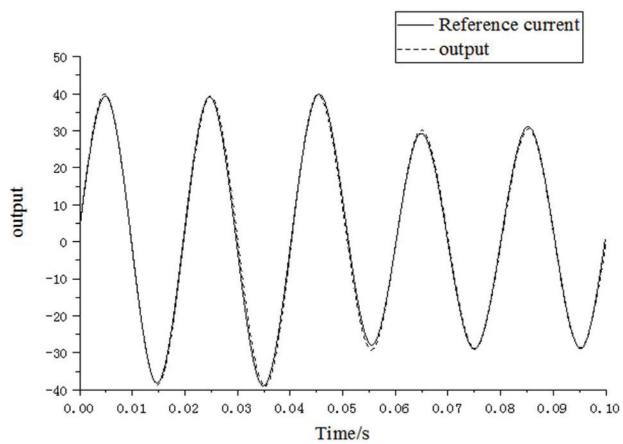

Figure 3 Waveform comparison of reference current and tracking current when the reference current has a step change at t = 0.05.

current waveform when the grid voltage changes from 220 V to 300 V at t = 0.05 s. Such a situation often occurs in practical applications. In practice, the grid voltage is often affected by noise and other factors, resulting in sudden changes or burrs. By Figure 2 shows, even in the instantaneous power grid voltage mutation, and different amplitude, the parameter estimates can be adaptive adjustment according to actual condition, to ensure that the actual output current tracking target current, prove that the presented algorithm and prediction model in terms of tracking the stability and rapidity of has a good effect.

Figure 3 shows the waveform comparison diagram between the tracking current and the target current when the reference current has step change in amplitude at t = 0.05 s. Since the phase of the reference current is the same as the grid voltage, the reference current amplitude changes with the tracking result of the maximum power point. When the illumination suddenly increases, the maximum current that the photovoltaic panel can provide will increase, and so will the reference current amplitude. Similarly, when the illumination suddenly decreases, the reference current amplitude will also decrease. Therefore, it is of great practical significance to verify the tracking effect of the output current when the reference current has step mutation. As can be seen from Figure 3, the adaptive control algorithm and prediction model proposed in this paper can make the controlled current quickly track the reference value, which once again proves that the algorithm performs well in stability and rapidity.

In order to further verify the theoretical analysis and simulation results, the experimental verification is carried out. As can be seen from the waveform comparison between the tracking current and the reference current shown in Figure 4, the tracking current can track the reference current more accurately

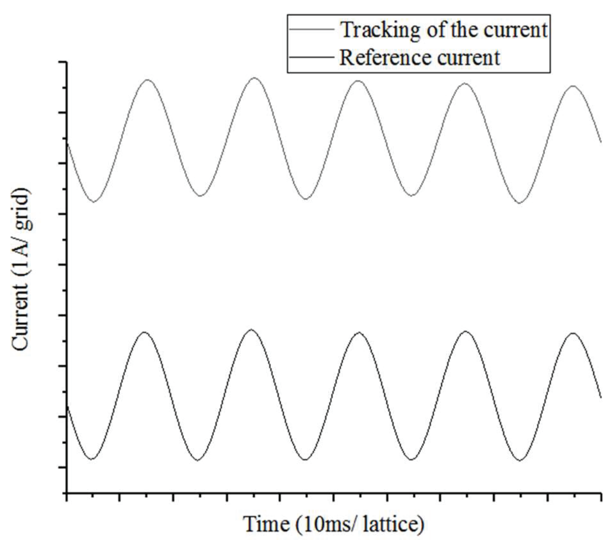

Figure 4 Comparison of experimental waveforms between the tracking current and the reference current.

under the action of the adaptive control algorithm proposed in this paper, so that the frequency, phase and amplitude are consistent.

4 Conclusions

This paper proposes a suitable light v grid inverter adaptive control algorithm, the algorithm based on lyapunov direct method to carry on the design, in under the premise of realize the goal of control and guarantee the stability of system, current control algorithm avoids the prediction line resistance is used to estimate the output voltage of the defect, all the unknown parameters for the circuit of adaptive adjustment, on this basis, the influence of interference signals on the algorithm is further studied, and the real-time prediction of interference signals is realized, which greatly improves the anti-interference ability of the system. In the case of random noise, the target current can be tracked with high precision from $t = 0$, and the power factor is close to 1, which shows a good steady-state performance. The calculated harmonic distortion rate is 2.2418%, the waveform quality is good, and each harmonic amplitude is small. The simulation and experimental results show that the new algorithm can realize current tracking quickly and accurately, and greatly enhance the ability of noise suppression.

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Biography

Jiangping Nan, female, associate professor of the School of Electrical Engineering, her research field is the research of multi-sensor information fusion technology. Published more than 10 papers, applied for multiple patents and software works, edited and participated in editing multiple textbooks. Presided over and completed the industry-university cooperative research project of the Ministry of Education and the Youth Fund Project of the Shaanxi Provincial Department of Education. Participated in the school's second classroom lecture competition in 2020, won the second prize, and was promoted to participate in the provincial competition. In 2018, she instructed vocational students to participate in the "Mechatronics Project of Shaanxi Higher Vocational Education" competition and won the third prize. In 2014, instructed students to participate in the Northwest Region Robot Competition and won the first prize.