Theory and Practice of Science and Technology
2025, VOL. 6, NO. 7, 60-64
DOI: 10.47297/taposatWSP2633-456912.20250607

High-Power-Factor PMSM Drive via Repetitive Control

Lan Xu, Pinger Luo, Lifen Han

Suzhou Vocational Institute of Industrial Technology, Suzhou, Jiangsu, 215104, China

ABSTRACT
Permanent Magnet Synchronous Motor (PMSM) has been widely applied in household appliances due to its significant advantages in cost control and service life. However, traditional motor speed control systems suffer from current distortion, delayed dynamic response, and low grid-side Power Factor. Therefore, a Permanent Magnet Synchronous Motor drive system based on Repetitive Control is proposed to effectively achieve high Power Factor, which has been experimentally verified to meet expectations.

KEYWORDS
Repetitive control; Permanent magnet synchronous motor; High power factor

1 Introduction

With the increasing demand for high-efficiency, intelligent, and highly reliable drive systems in industrial manufacturing, household appliances, and new energy vehicles, the Permanent Magnet Synchronous Motor (PMSM) has become a core drive component in these fields due to its compact size, light weight, and low operating noise[1]. However, a large number of devices in these applications still adopt the Single-phase Uncontrolled Rectification power supply mode, which produces a DC voltage with significant ripple and is accompanied by low Power Factor and severe Harmonic Pollution, fundamentally limiting the efficient and stable operation of the PMSM.

To address this issue, this paper proposes a high Power Factor optimization scheme for the PMSM drive system based on Repetitive Control. The proposed scheme first analyzes the intrinsic correlation between the RMS value of DC Bus Voltage Ripple and the grid-side Power Factor, revealing the coupling relationship between reducing the Supporting Capacitor capacity and improving the characteristics of Grid-side Current. Subsequently, a dynamic power balance equation is established among Rectifier Side Power, Supporting Capacitor power, and Inverter Side Power. Considering that Inverter Side Power must follow the Grid-side Voltage and exhibit Double Frequency periodic fluctuations, a Repetitive Control strategy is introduced to achieve high-precision tracking of the sinusoidal periodic inner-loop q-axis current. Finally, an experimental study is conducted based on a dual 15 kW PMSM Back-to-back Speed Regulation test platform, and the effectiveness and feasibility of the proposed method are verified through experimental data.

2 Establish the mathematical model of the drive system

A single-phase bridge uncontrolled rectifier circuit consists of four diodes forming a bridge structure, with the input connected to an AC power source and the output connected to a load[2]. The circuit's working principle directly affects the waveform characteristics. As shown in Figure 1, the grid current, capacitor current, and inverter current maintain corresponding vibration trends. The corresponding mathematical model of the DC bus circuit is as follows:

Voltage equation:

$$\begin{aligned} V_{dc} &= V_{pk}\left|\sin\left(\omega_{in}t\right)\right| \\ &= V_{pk}\sin\left(\omega_{in}t\right)\cdot \operatorname{sgn}\left[\sin\left(\omega_{in}t\right)\right] \end{aligned} \tag{1}$$

Current equation:

$$\begin{aligned} i_c &= C_{dc}\frac{dV_{dc}}{dt} \\ &= \omega_{in}C_{dc}V_{pk}\cos\left(\omega_{in}t\right)\cdot\left[\operatorname{sgn}\sin\left(\omega_{in}t\right)\right] \end{aligned} \tag{2}$$

Power equation:

$$\begin{aligned} p_c &= V_{dc}i_c \\ &= \omega_{in}C_{dc}V_{pk}^2\sin\left(\omega_{in}t\right)\cos\left(\omega_{in}t\right) \\ &= \frac{1}{2}\omega_{in}C_{dc}V_{pk}^2\sin\left(2\omega_{in}t\right) \end{aligned} \tag{3}$$

Where: V_{dc} is the DC bus voltage; i_c is the capacitor branch current; P_c is the charging and discharging power of the DC capacitor; V_{pk} is the peak value of the grid voltage phase voltage; C_{dc} is the Supporting Capacitor capacitance; sgn is the sign function.

3 The relationship between equivalent average voltage and grid-side power factor

According to the analysis of equations (1) to (3), the DC bus voltage, current, and power are all periodic 100Hz fluctuating signals. To facilitate the analysis of the uncontrolled rectifier system grid-side power factor, the concept of "equivalent average voltage" is introduced here, which is the average bus voltage value within each rated period of 20ms. Fig.1 shows the relationship curves of grid-side voltage, grid-side current, and equivalent average voltage.

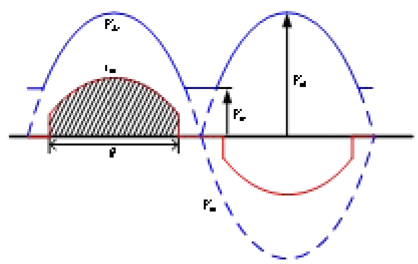

Figure 1 The relationship curves of grid-side voltage, grid-side current, and equivalent average voltage

Assuming the desired value of grid-side current is a sine wave related to the diode conduction width θ, the grid-side current steps to zero when the conduction angle θ is between (π-θ)/2 and (π+θ)/2[3]. Therefore, the relational equation between the average bus voltage V_m and the conduction width θ can be derived as follows:

$$\cos\left(\frac{\theta}{2}\right)=\frac{V_m}{V_M} \tag{4}$$

It can be seen that the larger the value of equivalent average voltage V_m, the smaller the system grid-side power factor θ. Conversely, reducing the value of V_m will be beneficial to the optimization of the system power factor, that is, reducing the DC bus capacitance value can improve the system power factor. Further calculation shows that the grid-side input active power P_{conv} of the single-phase diode uncontrolled rectifier is:

$$\begin{aligned} P_{\text{conv}} &= \frac{1}{T}\int_0^T \left[V_{pk}\sin\left(\omega_{\text{in}}t\right) I_{pk}\sin\left(\omega_{\text{in}}t\right)\right]dt \\ &= \frac{V_{pk}I_{pk}}{2\pi}\left(\theta+\sin\theta\right) \end{aligned} \tag{5}$$

Thus, the relationship between Single-phase Uncontrolled Rectification grid-side power factor cosφ and the diode conduction width θ can be obtained as follows:

$$\begin{aligned} \cos\varphi &= \frac{P}{S}=\frac{P}{V_{rms}I_{rms}} \\ &= \sqrt{\frac{\theta+\sin\theta}{2\pi}} \end{aligned} \tag{6}$$

As indicated in equations (5) and (6), synchronous regulation of the grid-side power Pconv can be achieved by adjusting the inverter-side active power P_{inv}. In this paper, the active power with periodic fluctuation at twice the frequency of grid-side voltage is injected into the inverter side, thereby controlling the Inverter Side Power P_{inv} to achieve active regulation of the conduction angle θ of the grid-side uncontrolled rectifier.

4 Power balance method on grid side and load side

By controlling the periodic fluctuation of the load-side power P_{inv} at twice the frequency of the grid-side voltage vin, high sinusoidal grid-side current i_{in} and high Power Factor control can be achieved. Thus, the control system design is transformed into the control problem of the inverter-side load power P_{inv}.

Fig.2 shows based on the tracking error between the desired inverter-side power Pinv* and the actual power Pinv, an additional power regulator is introduced between the speed regulator and the current regulator in the vector control system. While ensuring the speed regulation of the PMSM drive system, a periodic sinusoidal component can be superimposed on the torque q-axis current component[4].

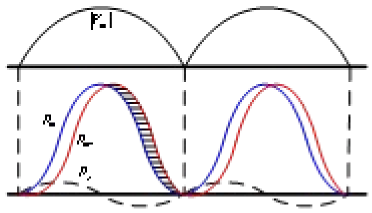

Figure 2 Relationship diagram of grid-side input power, DC capacitor power, and inverter output power

5 Torque current repetitive control

The Repetitive Control method is introduced to improve the torque q-axis current response performance, which can achieve the goal of rapid balancing of grid-side and load-side power. The Repetitive Control controller can accumulate the 100Hz repetitive power fluctuation signal, so as to realize the correction of PWM control signal in the form of an internal model.

Fig. 3 shows the schematic diagram of the repetitive regulator for inverter power, where the internal model of the repetitive regulator is composed of a delay element with a delay time of one period of an external signal after positive feedback.

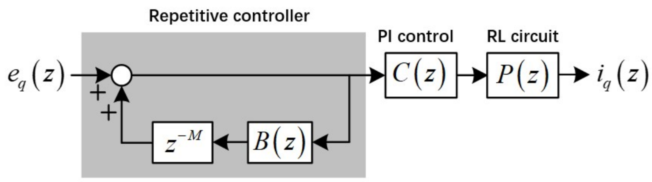

Figure 3 Inverter power repetitive regulator schematic

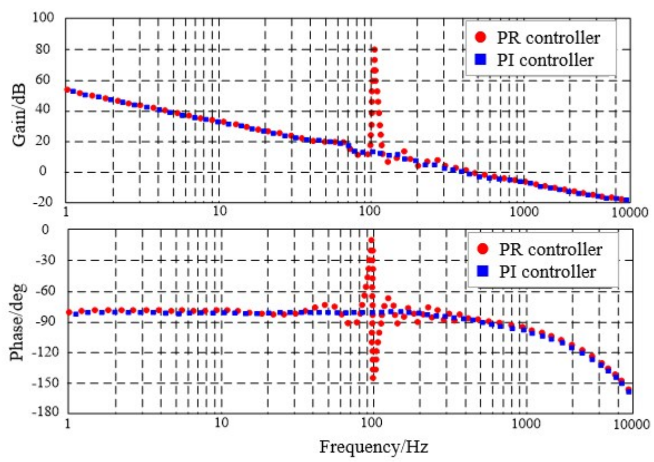

Figure 4 Global system block diagram of constant torque tracking power matching control

As shown in Figure 4, the blue dashed line represents the amplitude-frequency response of the traditional PI regulator, and the red dashed line represents the amplitude-frequency response of the repetitive controller. It can be seen that the repetitive controller has a larger gain and a 180° abrupt change in amplitude at 100Hz, which means it has better response characteristics to the 100Hz torque q-axis current.

6 Experimental verification

Fig. 5 Shows the circuit diagram of the single-phase rectified power supply PMSM drive system with high Power Factor control system. The system consists of three parts: high Power Factor control, PMSM vector control, and SVPWM modulation.

Fig.6 Shows the core processor of the control system is Texas Instruments' TMS320F28335, with a maximum operating frequency of 150MHz. The coprocessor is an Altera FPGA, communicating externally via the PROFIBUS process field bus. Simultaneously, the FPGA completes functions such as PWM status detection, dead-time compensation, and pulse blocking. The PMSM drive motor and load motor have identical parameters, featuring a salient-pole structure with 4 pole pairs, dq-axis inductance of 2.5mH, and a stator resistance of 0.5Ω. The PMSM drive system is kept running at the rated speed of 750 r/min, and the load torque is gradually increased to 100% in three stages.

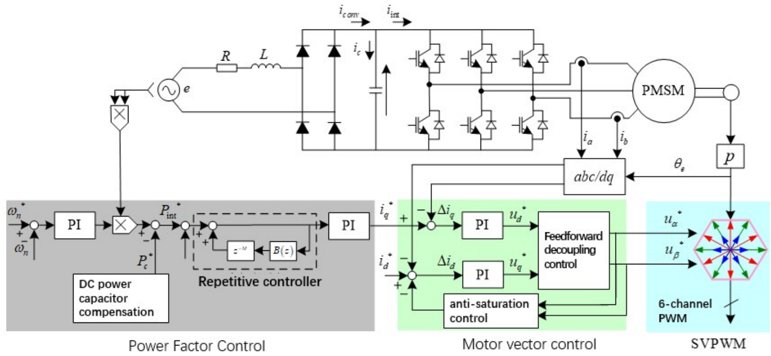

Figure 5 Circuit diagram of single-phase rectifier power supply PMSM drive system high power factor control system

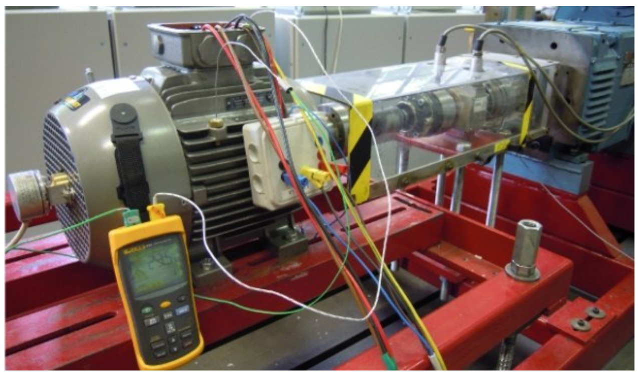

Figure 6 Single-phase rectifier-fed pmsm drive system high power factor control system experimental platform

Fig. 7 shows the FFT spectrum analysis results of the grid-side input current I_{in}. Referring to the 2015 edition of the grid standard IEC61000-3-2, the overall Power Factor of the PMSM drive system reaches over 97% at this time, which meets the design requirements of single-phase power supply systems for white goods.

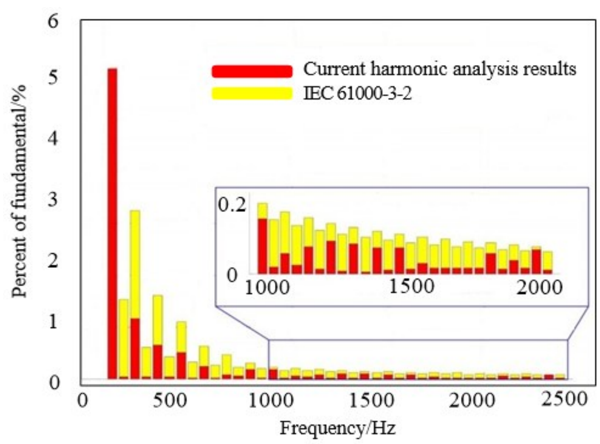

Figure 7 Grid-side current FFT analysis results

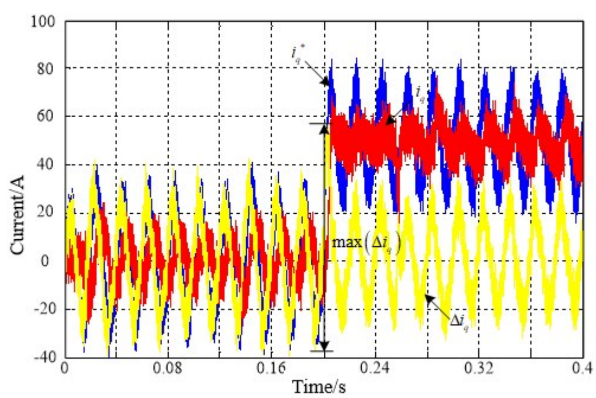

Figure 8 PI control

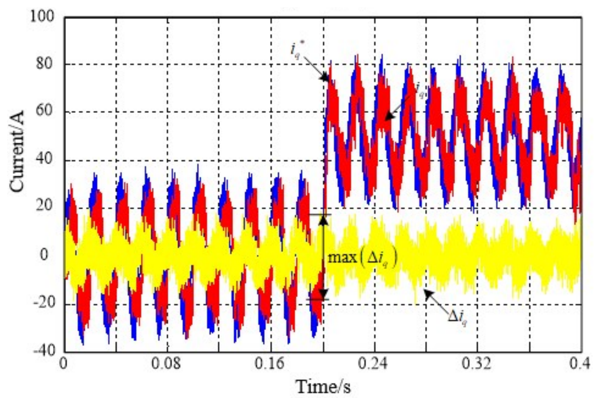

Figure 9 Repetitive controller

FIG.8. Comparative analysis of dynamic response performance of torque current repetitive control controller

Fig. 8-9, shows the full-load sudden increase experiment conducted at the rated speed of 780 r/min. Benefiting from the excellent decoupling performance of the vector control system, the torque current i_q rapidly achieved tracking response after the load mutation. However, due to the introduction of a 100Hz periodic disturbance component in the q-axis current reference i_q^*. The traditional PI regulator has limited ability to suppress this high-frequency error, resulting in a steady-state tracking error $\triangle i_q$ in the torque current. In contrast, the repetitive controller significantly reduced the instantaneous maximum tracking error value max($\triangle i_q$) of the current at the instant of load mutation, decreasing it from 60A under the PI regulator to 20A. This result simultaneously verifies the superiority of the Repetitive Control in dynamic tracking performance.

7 Conclusion

Aiming at the problems of low grid-side power factor, serious distortion, and motor torque ripple in the speed regulation system powered by traditional Single-phase Uncontrolled Rectification[5], this paper proposes a high power factor implementation method for a single-phase rectified PMSM drive system based on basic Repetitive Control. The following conclusions can be drawn from the verification and analysis using a dual 35kW Permanent Magnet Synchronous Motor dynamometer:

(1) The high power factor method based on Repetitive Control can optimize the grid-side current quality of the Single-phase Uncontrolled Rectification system and effectively improve the grid-side power factor of the system.

(2) The introduced Repetitive Control link can effectively improve the dynamic and steady-state accuracy of the response to 100Hz high-frequency power fluctuations. Compared with the traditional PI regulator, the performance is more excellent, which ensures the stability of introducing an additional power link on the basis of the vector control dual closed-loop regulation.

Funding

Project supported by Qinglan Project of Jiangsu Colleges and Universities (2020); Horizontal Industry-University Cooperation Project "Improvement of Efficiency in Motor Drive Systems" (NO: SIITHT2025006635)

References

[1] Ali M H, Ramadan A A R, Abass D M, et al. Analysis and simulation model of three phase Permanent Magnet Synchronous Motor Drive (PMSM) [J]. E3S Web of Conferences, 2024, 542: 01011.

[2] Maulik S, John V. Diode Bridge Rectifier with low THD for Weak Grids [C]. 2019 IEEE Transportation Electrification Conference (ITEC-India), 2019: 1–6.

[3] Alduraibi, Abdulrahman, et al. "Impacts of Grid Voltage Harmonics Amplitude and Phase Angle Values on Power Converters in Distribution Networks." IEEE Access, vol. 9, 2021, pp. 92017–92029.

[4] Qian Z, Li X, Wang Q, et al. Torque Ripple and Acoustic Noise Suppression for Sensorless PMSM Drive Based on Biaxial Random Signal Injection [J]. IEEE Transactions on Transportation Electrification, 2025, 11(3): 7287–7299.

[5] Xu D, Liang Y, Tian Y. A Design of Improving the Single-Phase Uncontrollable Rectifier Circuit's Power Factor Based on UCC28019 [M]//Lecture Notes in Electrical Engineering. Springer Nature Singapore, 2022: 736–743.