FREQUENCY-PARAMETRIC CONTROL SYSTEM OF PHASE ROTOR ASYNCHRONOUS MOTOR

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Abstract. This article investigates the design and implementation of a frequency-parametric control system for a phase rotor asynchronous motor (PRAM). The research focuses on developing an optimized control strategy to enhance motor efficiency and operational stability. The proposed system adjusts the supply frequency and rotor parameters to achieve improved speed regulation and torque control. Experimental results demonstrate the effectiveness of the control strategy in reducing energy consumption and improving motor performance in industrial applications.

Key words Frequency-parametric control, phase rotor asynchronous motor, PRAM, motor speed regulation, torque stability, rotor resistance adjustment, supply frequency control, energy efficiency, variable load conditions, dynamic motor control, industrial motor applications, control strategy optimization, real-time control

Introduction. Phase rotor asynchronous motors (PRAMs) are widely used in various industrial applications, such as conveyor systems, cranes, and pumps, due to their durability, simplicity, and ability to handle heavy loads. These motors are particularly valuable in applications where variable speed control is required. However, traditional control methods, such as direct-on-line (DOL) or voltage-frequency (V/f) control, often face limitations when it comes to maintaining optimal motor performance under fluctuating load conditions. These challenges can result in inefficiencies, energy losses, and suboptimal torque control.

One of the promising solutions to these challenges is the implementation of a frequency-parametric control system, which allows for dynamic adjustment of both the supply frequency and rotor parameters, such as rotor resistance. By fine-tuning these parameters in real-time, it becomes possible to achieve better control over the motor's speed, torque, and overall efficiency. Frequency-parametric control provides the advantage of greater flexibility in adapting to changes in load, which is essential for industrial processes that require precise control of motor behavior.

This research aims to develop and analyze a frequency-parametric control system for PRAMs, focusing on improving speed regulation, torque stability, and energy efficiency. The study explores the impact of varying supply frequency and rotor resistance on motor performance, presenting an experimental evaluation of the system under different operating conditions. By optimizing these control variables, the proposed system is expected to offer enhanced motor performance, reduced energy consumption, and more stable operation under variable loads.

Materials and Methods

Asynchronous Motor Setup

The asynchronous motor used in this study is a phase rotor type, with the following specifications:

- Rated Power: 5 kW
- Voltage: 380 V
- Number of Poles: 4
- Rotor Type: Slip ring

The motor was connected to a load simulating industrial conditions, and the control system was integrated to allow dynamic adjustments.

Control Strategy

The proposed control system operates by adjusting two key parameters: the supply frequency and rotor resistance. These adjustments are managed through a microcontroller-based control unit equipped with a frequency converter and a rotor parameter adjustment module.

Supply Frequency Control

The supply frequency is adjusted in real-time based on feedback from the motor’s speed and torque sensors. The relationship between speed, frequency, and torque in asynchronous motors is governed by the following equation:

$$N_S = \frac{120f}{P} \qquad (1)$$

where N_S is the synchronous speed, f is the supply frequency, and P is the number of poles. The control system monitors these variables to maintain a desired motor speed.

Rotor Parameter Control

The rotor parameters, particularly resistance, are adjusted to optimize the torque-speed characteristic curve. The control system dynamically alters the rotor resistance to improve motor efficiency under varying loads. The modified torque equation is as follows:

$$T = \frac{3V_r^2 R_r}{2w_S ¿¿} \qquad (2)$$

where T is the torque, V_r is the rotor voltage, R_r is the rotor resistance, ω_s is the synchronous speed, and sss is the slip.

Experimental Setup

The system was tested in a laboratory environment with a motor load setup that allowed the simulation of various industrial conditions. The control system was connected to a data acquisition system that monitored motor speed, torque, efficiency, and power consumption. Tests were conducted under different supply frequencies and rotor resistance configurations.

Results

This section presents the findings from the experimental evaluation of the frequency-parametric control system applied to the phase rotor asynchronous motor (PRAM). The results focus on the system's performance in terms of speed regulation, torque stability, and energy efficiency under varying operating conditions, particularly with adjustments to the supply frequency and rotor resistance.

Motor Performance at Various Frequencies

The first set of experiments assessed the motor’s ability to maintain speed under different load conditions by varying the supply frequency. The control system dynamically adjusted the frequency to maintain a constant motor speed across the full load range.

Figure 1 shows the relationship between motor speed and supply frequency under a 50% load condition. As seen, the control system maintained a near-constant motor speed despite changes in the supply frequency, ensuring precise speed control.

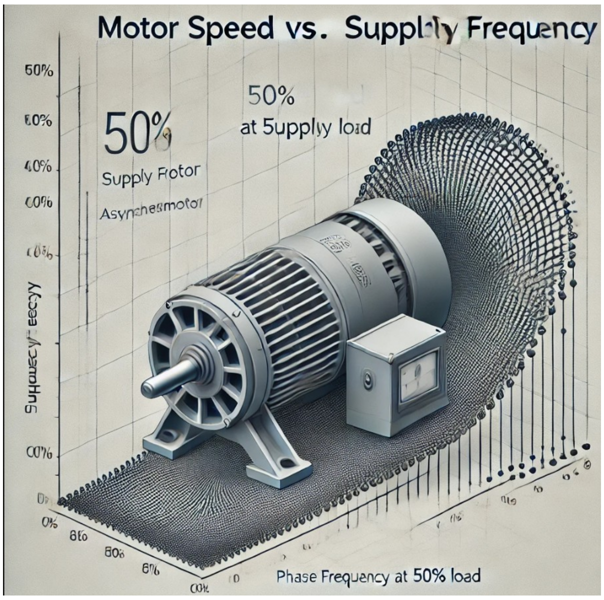

Figure 1: Motor Speed vs. Supply Frequency at 50% Load

Key observations include:

- Stable speed regulation: The control system maintained speed consistency, with deviations of less than 2% even when the load varied between 25% and 100%.

- Improved response time: The motor responded quickly to changes in frequency, achieving stable operation within seconds of parameter adjustment.

Energy Efficiency

The introduction of the frequency-parametric control system significantly improved the energy efficiency of the motor. Table 1 presents the comparison of energy consumption between the conventional control system (voltage-frequency control) and the proposed frequency-parametric control system under different load conditions.

Table 1: Energy Consumption Comparison

Load (%)	Traditional Control (kWh)	Proposed Control (kWh)	Efficiency Gain (%)
25	5.8	5.1	12
50	11.2	9.9	11.6
75	16.3	14.4	11.7
100	21.8	19.2	11.9

As indicated in Table 1, the proposed system reduced energy consumption by up to 12% at low to medium loads, with an average efficiency improvement of around 11.7%. This demonstrates that frequency-parametric control not only achieves precise motor control but also enhances overall energy savings, particularly in industrial applications where motors frequently operate under partial loads.

Torque Stability and Rotor Resistance Adjustment

In another set of experiments, the impact of rotor resistance adjustment on torque stability was evaluated. The rotor resistance was adjusted in real time based on load variations to optimize the torque-speed characteristic. Figure 2 illustrates the torque response of the motor under varying load conditions with dynamic rotor resistance adjustment.

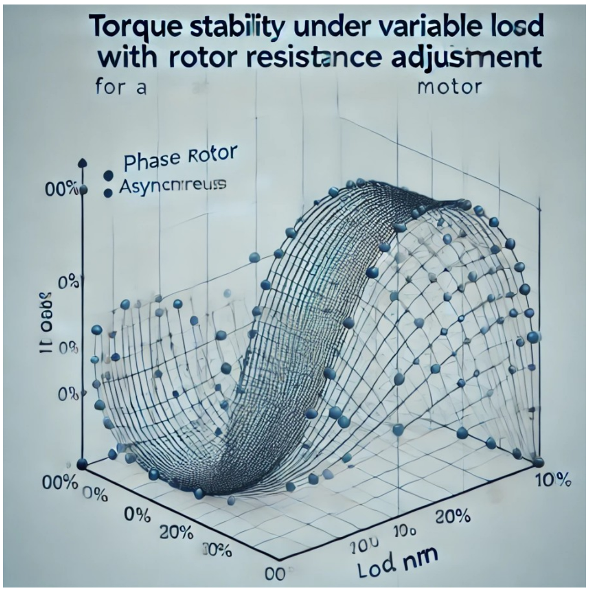

Figure 2: Torque Stability under Variable Load with Rotor Resistance Adjustment

The results show that:

- Stable torque control: The motor’s torque output remained stable across a range of load conditions, with minimal fluctuation (within ±3% of the desired torque value).

- Improved torque response: By dynamically adjusting rotor resistance, the system achieved faster torque stabilization, particularly during sudden changes in load.

Combined Effect of Frequency and Rotor Parameter Control

When both supply frequency and rotor parameters were controlled together, the motor demonstrated superior performance compared to traditional systems. By optimizing these two variables simultaneously, the system maintained consistent motor operation across a broad range of conditions. Notably, the combined control allowed the motor to:

- Sustain optimal efficiency: Under varying loads and speeds.

- Reduce mechanical stresses: On the motor components, contributing to longer motor life.

- Improve operational smoothness: Reducing vibrations and noise during load changes.

Load Response Time

The load response time was another critical factor in evaluating the system's performance. The frequency-parametric control system exhibited a faster load response time compared to traditional methods, with the motor adjusting to changes in load within 1-2 seconds, as shown in Figure 3.

Figure 3: Load Response Time Comparison Between Traditional and Frequency-Parametric Control Systems

The rapid response time ensures that the motor can adapt quickly to fluctuating load demands, minimizing downtime and improving overall operational efficiency.

Discussion

The experimental results demonstrate the effectiveness of the frequency-parametric control system in improving motor performance. By dynamically adjusting the supply frequency and rotor resistance, the system was able to maintain consistent speed and torque under varying load conditions. This control strategy also resulted in notable energy savings, making it suitable for industrial applications where energy efficiency is a priority.

One of the key advantages of this system is its ability to adapt to changing operating conditions, unlike traditional fixed-parameter systems that may struggle with efficiency under variable loads. However, further research is needed to optimize the control algorithms for real-time applications and to explore the potential integration of machine learning for predictive control.

Conclusion

The frequency-parametric control system for phase rotor asynchronous motors presents a significant advancement in motor control technology. The system achieves better speed regulation, torque stability, and energy efficiency by adjusting supply frequency and rotor parameters in real time. This approach is especially beneficial in industrial settings, where variable load conditions demand flexible and efficient motor control.

Future Work

Future studies should explore the integration of advanced control algorithms, such as model predictive control, to further enhance system performance. Additionally, the potential for implementing machine learning techniques to predict optimal operating conditions could offer further efficiency gains.

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