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Proportional–Resonant Current Control for Six-Phase Induction Machines: Sensitivity and Robustness Analysis

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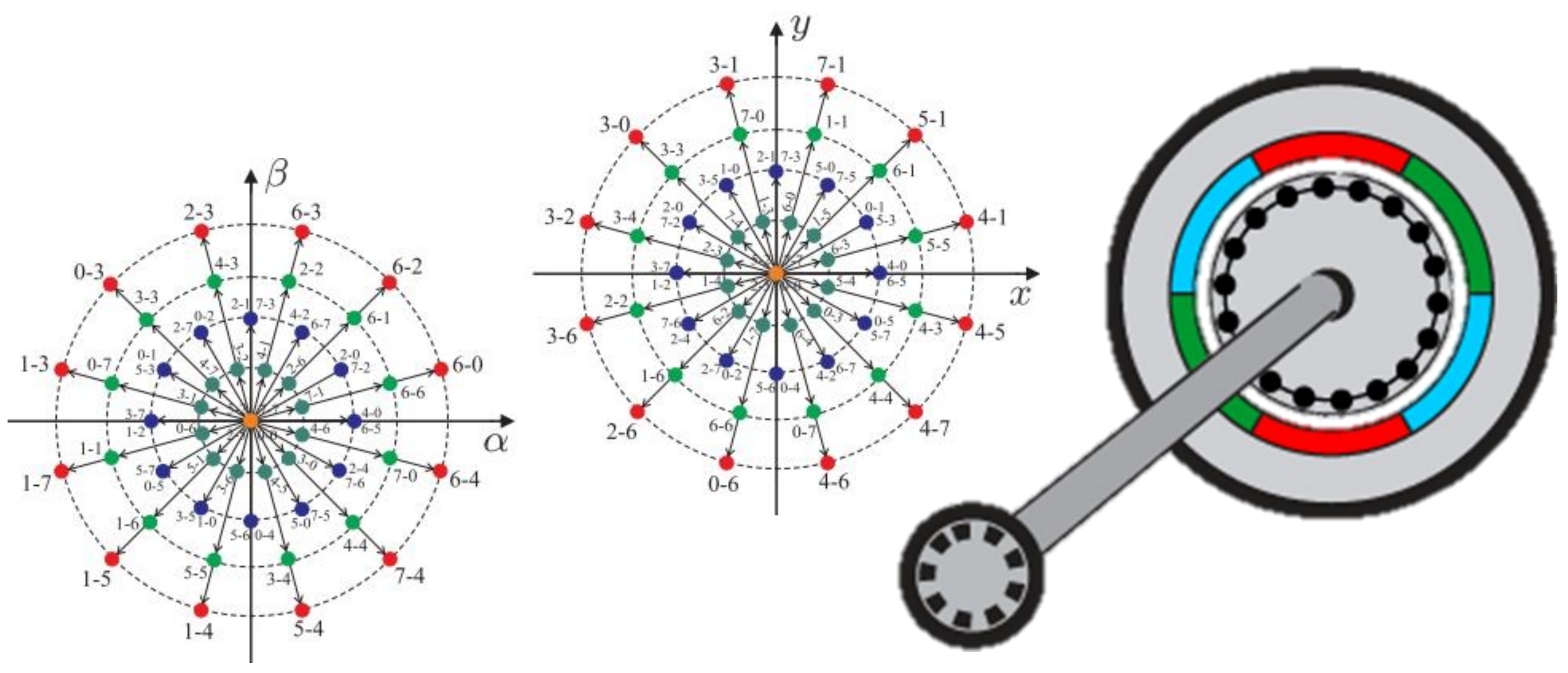
INTRODUCTION & AIM

Six-phase induction machines offer notable advantages in efficiency, fault tolerance, and reliability. To exploit these features, proportional–resonant (PR) controllers provide accurate current tracking in the stationary frame, making them suitable for multiphase drives. In this work, their behavior is simulated under realistic operating conditions, providing insights into their practical applicability.



METHOD

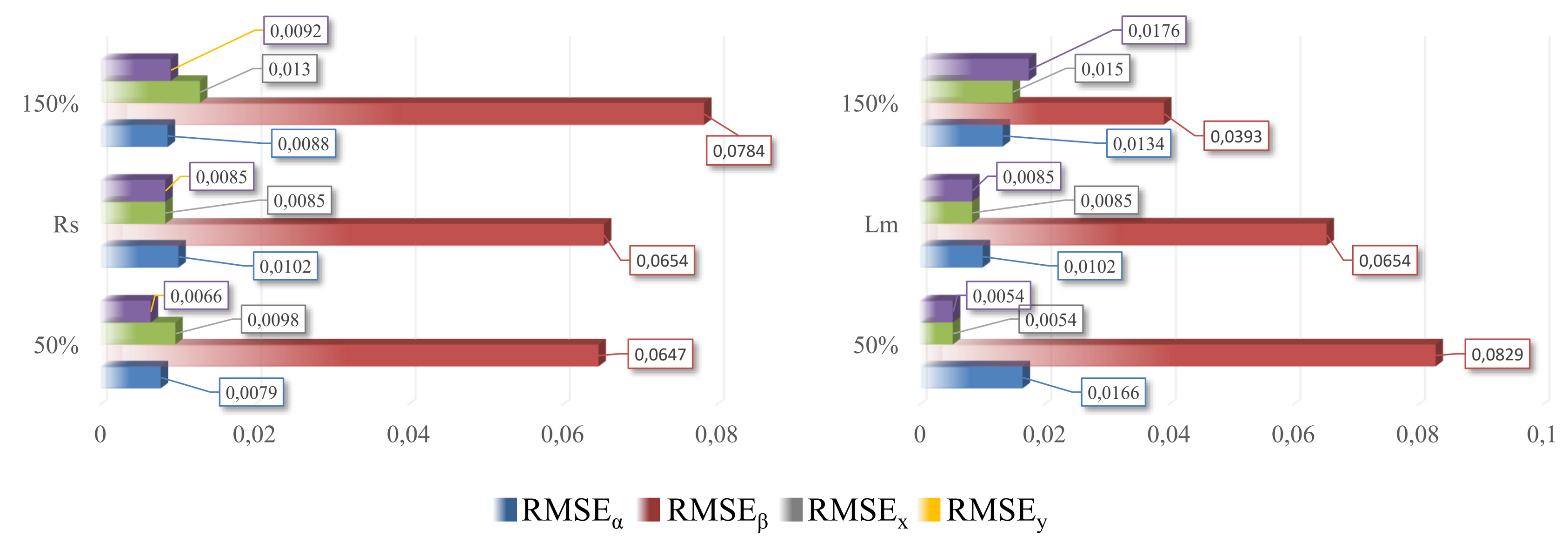
The proposed control scheme builds upon the classical field-oriented indirect control (IFOC) but introduces a fundamental modification in the current loop. Instead of conventional PI controllers in the rotating dq frame, a frequency-adaptive PR controller operates directly in the stationary $\alpha\beta$ frame. This eliminates continuous $dq \leftrightarrow \alpha\beta$ transformations and avoids decoupling terms, simplifying implementation and reducing computational demand. The resonant frequency is dynamically adjusted to the instantaneous electrical frequency, defined as rotor speed plus slip. This ensures sinusoidal current tracking without steady-state error across all operating conditions, from standstill to rated speed, and remains effective even during abrupt reversals.

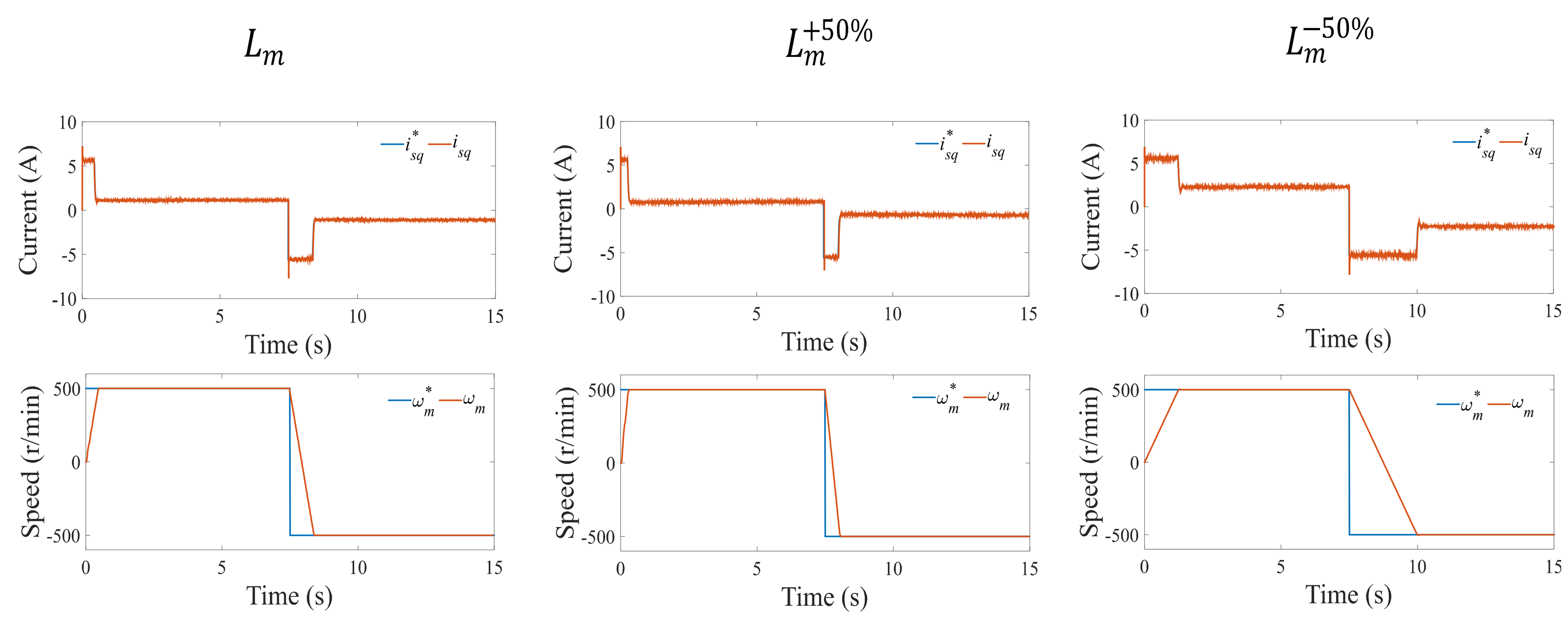
To further improve current quality, additional resonant blocks tuned to the 5th and 7th harmonics are incorporated. These selectively attenuate inverter-induced distortions, reducing THD and enhancing energy efficiency. The proportional and resonant gains are derived analytically from the motor's inductance parameters—specifically magnetizing and leakage inductances—eliminating the need for rotor time constant identification, empirical tuning, or optimization algorithms. This analytical design provides a parsimonious yet robust solution, ensuring reliable performance under parameter mismatches and dynamic conditions. Overall, the method combines simplicity, adaptability, and harmonic compensation, validating the feasibility of PR-based control for high-performance six-phase induction machine drives operating under variable scenarios.

RESULTS & DISCUSSION

The first chart presents a sensitivity analysis of RMSE for four variables (α, β, x, y) under variations in stator resistance (Rs) and magnetizing inductance (Lm). Values labeled "150%" correspond to a 50% increase above nominal, while "50%" denotes a 50% reduction. Results show β as the most sensitive, reaching 0.0829 when Lm decreases, while α also deteriorates. In contrast, x and y remain stable, except for a rise in y when Lm increases.

The second plot shows current and speed tracking under nominal L_m ,$L_m^{+50\%}$, and $L_m^{-50\%}$ .With nominal values, i_{sq} and ω_m closely follow their references, with minimal error. Increasing L_m slows current dynamics and introduces slight speed lag, while decreasing L_m yields faster current response but with overshoot and oscillations affecting speed regulation. The stator currents i_α, i_β were transformed into i_{ds}, i_{qs} solely for visualization.





CONCLUSION

The analysis shows that the PR controller ensures precise current tracking and robust dynamics in six-phase induction machines. Magnetizing inductance variations mainly affect β, while Rs has minor influence. Even under speed reversals, stability is quickly restored. Across all scenarios, RMSE remains below 0.02 A and THD under 0.35%, confirming efficiency.

FUTURE WORK / REFERENCES

Future work will extend experimental validation of the PR controller to hardware prototypes, explore adaptive schemes for parameter estimation, and benchmark performance against nonlinear control strategies under diverse operating conditions and fault scenarios.