

A Variable Switching Frequency Control Method for Optimizing System Efficiency in Motor Drives Through Coupled Analysis

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Motor drive systems are widely used in various industries, and improving their efficiency is essential for energy conservation. This paper presents a variable switching frequency control method for motor drive systems to enhance overall system efficiency. By employing a coupled model that captures the interdependent characteristics of the inverter and motor, the proposed method accurately evaluates losses under different operating conditions. The optimal switching frequencies are identified and compiled into a lookup table embedded in the drive program. Real-time adjustments to the inverter's switching frequency based on system conditions enable the method to achieve optimal efficiency with reduced computational complexity compared to conventional strategies, validated through both simulation and experimental results.

***Index Terms*—Coupled model, energy efficiency, finite element analysis, motor drives.**

I. INTRODUCTION

Motor drive systems are extensively utilized across various domains, and they play a critical role in supporting economic productivity. Enhancing the efficiency of motor drive systems is therefore crucial for achieving energy conservation and mitigating environmental impact. As integral components responsible for energy transfer and conversion, the inverter and motor are pivotal in determining the overall efficiency of the system. The inverter and motor are electrically interconnected, exhibiting a strong coupling where their operational characteristics influence one another. For instance, the harmonic components in the power supplied by the inverter can substantially impact the mechanical and electrical performance of motor, especially the loss characteristics [1]. Similarly, the motor parameters, which fluctuate with operating conditions and are not constant, can influence the power output behavior of the inverter.

To address the demand for optimal energy efficiency in motor systems, current control strategies predominantly emphasize current optimization [2]. Additionally, many methods focus on enhancing motor efficiency or minimizing specific loss components, such as core losses, while overlooking the overall system efficiency [3]. Furthermore, most existing approaches rely on optimization processes that impose significant computational burdens on processors. Some techniques also require precise identification of motor electromagnetic parameters, further complicating the computational demands of the control strategy [4].

In this paper, a variable switching frequency control method with low computational demands is proposed for motor drive systems, aiming to optimize overall system efficiency. By utilizing a coupled model of the motor drive system, the method enables accurate simulation of losses under various operating conditions, evaluating the impact of switching frequency on inverter and motor losses as well as system efficiency. Optimal switching frequencies for different operating conditions are identified and compiled into a lookup table, which is embedded in the drive program. The inverter dynamically adjusts its

switching frequency in real-time based on the operating conditions of the motor drive system, thereby achieving optimal system efficiency.

II. THE COUPLED MODEL AND LOSS ANALYSIS OF MOTOR DRIVE SYSTEM

During the operation of motor drive systems, the control system generates gate trigger signals that are transmitted to the power switching devices of inverter. In a voltage-source inverter, the modulated three-phase voltage serves as the excitation source for the motor. Parameters such as motor speed, rotor position, and stator current are measured using sensors like optical encoders and Hall sensors. These analog signals are converted to digital form and fed back to the control system, where they are used to calculate the required control signals. For this coupled system, the governing equations encompass the control model, the electric circuit model for inverter, the electromagnetic model for motor, and the mechanical motion model.

A coupled model is established for the studied permanent magnet synchronous motor (PMSM) and used to simulate the startup and sudden loading processes. The motor speed is set to 1200rpm, and a sudden load of 6Nm is applied at 20ms. The switching frequency of the power devices is 10kHz. The derived motor speed, three-phase stator currents, and torque waveforms are shown in the Fig. 1.

The losses of inverter are primarily categorized into five distinct types: losses associated with the activation of IGBTs, deactivation of IGBTs, deactivation of diodes, as well as the conduction losses for both IGBTs and diodes. By examining the transient current that flows through these components, it is possible to precisely determine the conduction and switching losses of the power switching devices. Also, the losses of machine, typically including core loss, copper loss, eddy loss of permanent magnet, and mechanical loss, could be derived with the transient current as the excitation source. The losses of inverter and motor at different switching frequencies are evaluated and given in Fig. 2.

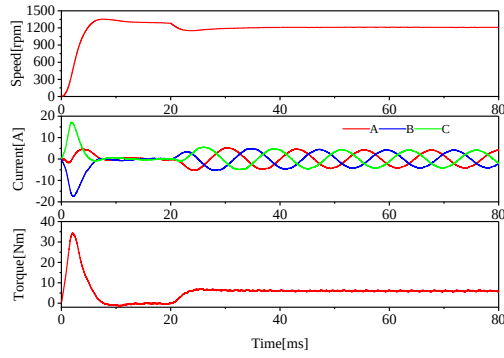


Fig. 1. The speed, stator current, and torque waveforms of the studied PMSM.

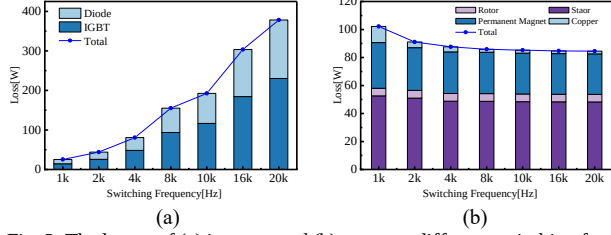


Fig. 2. The losses of (a) inverter and (b) motor at different switching frequencies.

III. THE PROPOSED METHOD AND RESULTS

The impact that the switching frequency has on losses could be analyzed, and the derived losses of motor and inverter under different load, speed, and switching frequency are given in Fig. 3. Further, the optimal switching frequency could be searched for the entire working domain of the motor drive system (see Fig. 4), and could be used to control the drive to optimize the system efficiency. The effectiveness of the proposed method is verified by simulation and experiment. The primary results are shown in Fig. 5 and Fig. 6, illustrating that the switching frequency dynamically adjusts in response to changes in load and speed.

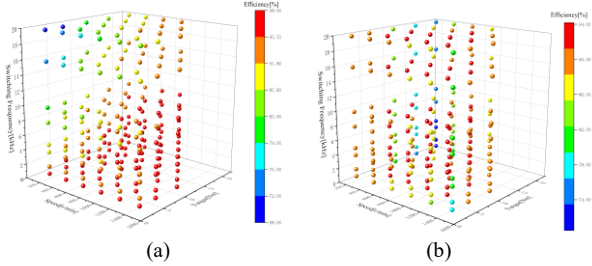


Fig. 3. The efficiency chart of (a) inverter and (b) motor under various operating conditions at different switching frequencies.

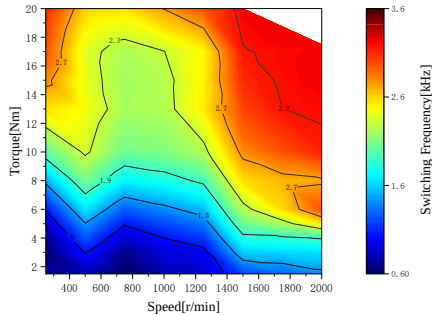


Fig. 4. Optimal switching frequency selection for motor drive systems.

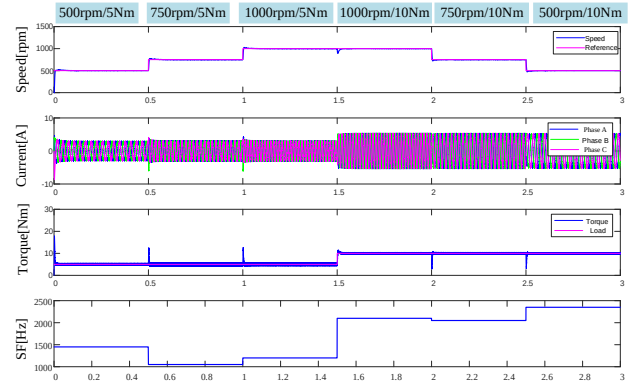


Fig. 5. Simulation curves of motor speed, three-phase current, torque, and switching frequency (SF) under six operating conditions.

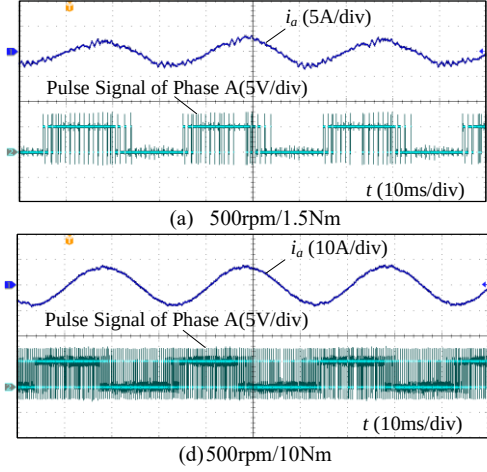


Fig. 6. The experimental waveform of phase A current and pulse under certain operating conditions.

IV. CONCLUSION

In this paper, a variable switching frequency control method was proposed to optimize the overall efficiency of motor drive systems. By employing a comprehensive coupled model, the method accurately evaluated the losses of the inverter and motor under various operating conditions and identified optimal switching frequencies across the entire working domain. These frequencies were compiled into a lookup table and embedded into the drive program to enable real-time adjustments of the switching frequency based on system conditions. The findings highlight the potential of the method to enhance system energy efficiency, offering a computationally efficient and practical solution for high-performance motor applications.

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