

A Review of Dc Winding Induced Voltage Phenomena and Mitigation Techniques in Multi-Phase Flux Switching Machines

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ABSTRACT

Flux switching machines with stator-based excitation have gained increasing attention as promising alternatives to permanent magnet machines, particularly in applications demanding high reliability and reduced dependence on rare-earth materials. Among these, multi-phase wound field flux switching machines (WFFSMs) offer advantages such as enhanced fault tolerance, improved torque quality, and flexible excitation control. However, the presence of DC windings in these machines introduces a critical parasitic effect known as DC winding induced voltage, which leads to current ripple, excitation instability, and degraded electromagnetic performance.

This review paper presents a comprehensive survey of the mechanisms responsible for DC winding induced voltage in multi-phase flux switching machines, with particular emphasis on non-overlapped winding configurations. Existing analytical, numerical, and experimental studies are examined to identify the root causes of induced voltage pulsations and their dependence on machine topology, rotor-stator pole combinations, and magnetic field modulation. Various mitigation strategies reported in the literature—including rotor geometry modification, pole arc optimization, axial pairing techniques, and winding configuration adjustments—are critically reviewed and compared.

The paper further highlights current research gaps, practical design trade-offs, and emerging trends in mitigation techniques for DC induced voltage suppression. By consolidating dispersed research findings into a unified framework, this review aims to assist researchers and designers in developing robust, low-ripple, and high-performance multi-phase flux switching machines for future electric drive applications.

Keywords:- Flux Switching Machines, DC Winding Induced Voltage, Multi-Phase Machines, Non-Overlapped Windings, Voltage Ripple Mitigation

1. INTRODUCTION

The growing demand for electrified transportation, renewable energy systems, and high-reliability industrial drives has intensified research into electrical machines that can deliver high torque density while minimizing material cost and supply risk. Flux switching machines (FSMs) have emerged as strong candidates due to their robust rotor structure and stator-based excitation, which eliminates the need for rotor windings or permanent magnets.

In recent years, multi-phase wound field flux switching machines have been extensively explored to improve fault tolerance and reduce phase current stress. Despite these advantages, a persistent challenge in such machines is the presence of DC winding induced voltage, which arises even under open-circuit or constant-current excitation conditions. This phenomenon adversely affects excitation stability and complicates control strategies, particularly in high-performance applications.

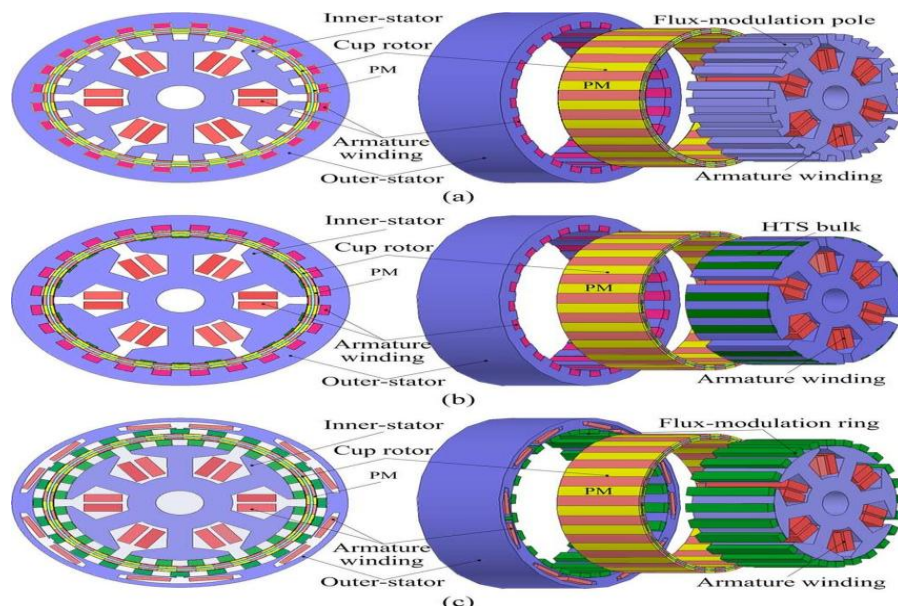
This review consolidates and analyzes existing research on DC induced voltage phenomena in multi-phase flux switching machines, providing a structured understanding of its origin, impact, and mitigation.

2. OVERVIEW OF MULTI-PHASE FLUX SWITCHING MACHINES

Flux Switching Machines (FSMs) represent a class of electrical machines in which both the armature windings and excitation sources are located on the stator, while the rotor is composed entirely of laminated iron without windings or permanent magnets. This structural arrangement offers several advantages, including mechanical robustness, improved thermal management, and suitability for high-speed operation. Over the past decade, FSMs have gained increasing attention as viable alternatives to conventional permanent magnet machines, particularly in applications where reliability, fault tolerance, and cost stability are critical.

Multi-phase flux switching machines extend the conventional three-phase configuration by employing five or more stator phases. The adoption of multi-phase operation provides inherent advantages such as reduced per-

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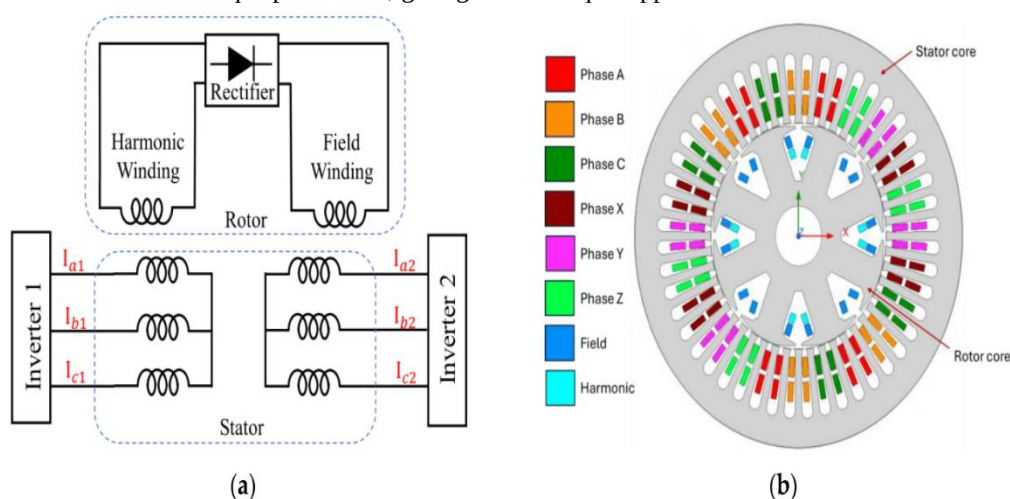
Non-overlapped winding arrangements exacerbate this phenomenon due to their concentrated magnetic paths and higher spatial harmonic content. While such windings offer benefits in terms of reduced copper loss and manufacturing simplicity, they increase sensitivity to permeance variation and magnetic saturation effects. This leads to higher amplitude flux pulsations and, consequently, increased induced voltage in the DC winding. Magnetic saturation also plays a significant role in induced voltage generation. As flux density approaches saturation in certain regions of the magnetic circuit, nonlinear permeability variations distort the flux waveform, introducing additional harmonic components. These nonlinear effects are particularly pronounced under high excitation current or heavy load conditions.

Understanding these fundamental mechanisms is essential for developing effective mitigation strategies. By identifying the dominant sources of flux modulation and harmonic excitation, designers can target specific structural or electromagnetic parameters to suppress DC winding induced voltage without compromising torque production or efficiency.

4. IMPACT OF DC INDUCED VOLTAGE ON MACHINE PERFORMANCE

DC winding induced voltage has a direct and multifaceted impact on the electromagnetic performance, control stability, and operational reliability of multi-phase wound field flux switching machines. Although the induced voltage originates in the excitation circuit, its effects propagate throughout the machine system, influencing both electrical and mechanical behavior.

One of the most significant consequences of DC induced voltage is the introduction of current ripple in the excitation winding. Even when supplied by a regulated DC source, voltage pulsations lead to fluctuating excitation current due to the finite impedance of the excitation circuit. This current ripple causes variations in the air-gap magnetic field, resulting in unstable flux distribution within the machine. Such instability directly affects torque production, giving rise to torque ripple and acoustic noise.



The presence of excitation current ripple also complicates control strategies. Precise control of air-gap flux is essential in multi-phase machines, particularly for applications requiring high dynamic performance or fault-tolerant operation. DC induced voltage introduces uncertainty in excitation control, reducing the effectiveness of flux regulation and increasing the burden on power electronic converters. In severe cases, it may necessitate oversized DC power supplies or additional filtering components, increasing system cost and complexity.

5. CONCLUSION

This review presented a comprehensive analysis of DC winding induced voltage phenomena in multi-phase wound field flux switching machines. By examining the structural characteristics, electromagnetic operating principles, and harmonic interactions inherent to these machines, the study highlighted the fundamental mechanisms responsible for induced voltage generation in DC excitation windings. The review emphasized that induced voltage is not merely a secondary parasitic effect, but a critical factor that directly influences excitation stability, torque quality, thermal performance, and overall system reliability.

Through an extensive synthesis of existing research, the paper identified air-gap permeance variation, rotor saliency, winding configuration, and magnetic saturation as dominant contributors to induced voltage behavior. The analysis further demonstrated that non-overlapped winding arrangements, while advantageous in terms of copper loss and manufacturability, exhibit increased sensitivity to flux modulation effects. As a result, mitigation of DC induced voltage must be considered as a core design objective rather than a post-design correction.

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