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Effects of Dwell Angles of Current in Switched Reluctance Motors

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Abstract*: The main purpose of studying variable drive systems with Switching Reluctance Motors (SRM) for torque density enhancement and efficiency improvement focuses on minimizing torque fluctuations. This ripple occurs due to the change in excitation current between adjacent phases. A smooth torque requires exact control of how switches turn the motor on and off. Simulation of all possible angle selection consequences appears in this research.*

The excitation current shape in the stator coil and its overlapping point with its adjacent coil depends on how precisely the turn-on and turn-off angles are selected as illustrated by the case of extended turn-on and turn-off excitation timing. Correct selection of turn-on and turn-off angles enables the implementation of transition phase smoothness. Researchers have performed a comprehensive analysis to determine how the modified excitation current interacts with torque ripple based on different dwell angle conditions. Proper selection of these parameters leads to the generation of sinusoidal current forms.

Keywords*: Torque ripple, electric motor, switched reluctance motor, FE analysis, and dwell angle*

I. Introduction

The SRM contains multiple factors that can cause vibration and acoustic noise as well as torque ripple. The torque generating mechanism in SRM operates from the magnetostatic force that exists between rotor and excited stator teeth and this is what generates both inherent vibration and acoustic noise. Beyond the required tangential force direction it produces a substantial amount of radial force. A stator vibration begins whenever phase commutation takes place. The control algorithm must be combined with inverter system enhancements while examining both mechanical and magnetic causes to effectively address these issues. Implementing a multi-level switching design serves to reduce radial forces.

The systematic approach to waveform development is established through switching angle variations. The design optimization of magnetic structures lowers the motor operation range resonances. The study paid attention to phase excitation techniques together with winding topology design. No matter what, the drive efficiency suffers from implementing the full-pitched winding system which creates mutual torque. Symmetrical excitation also results in a reduction of torque production throughout the standard winding configuration. The paper includes extensive assessments about various methods alongside their evaluations.

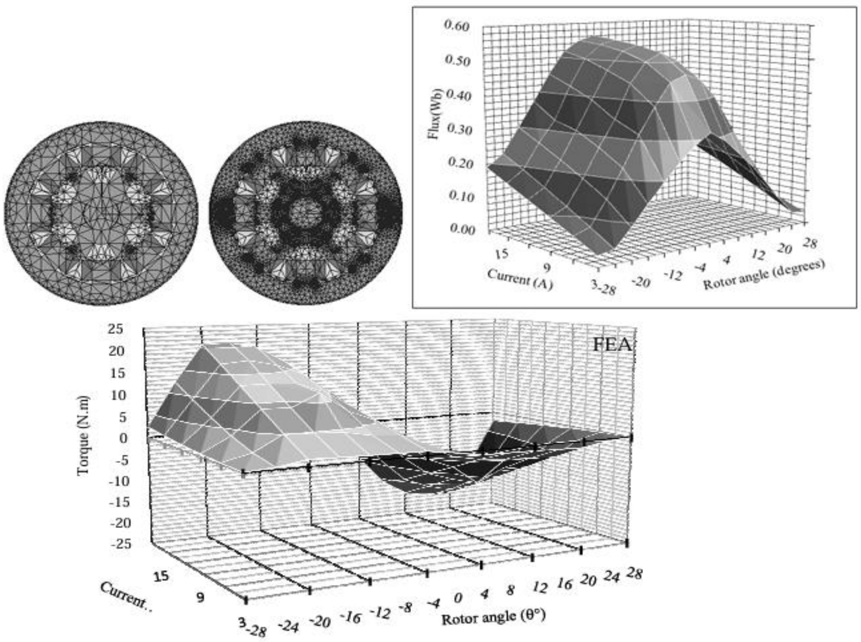
Through the application of continuously changing excitation currents with non-linear fluctuations this study develops a solution which eliminates both torque ripple problems and current shape issues without needing many voltage sources or variable voltage regulation. The low velocity transition of radial MMF lowers both torque ripple and acoustic disturbances. An ac motor requires an appropriate electromagnetic structure to use sinusoidal wave sources. An SRM features an electromagnetic design which enables current pulses for operation.

Dwell angle parameters operate as a substitute for a split voltage source or multiple voltage sources since they modify phase current shapes to attain a nearly sinusoidal waveform instead of a square waveform. The system operates without limitations and complex equipment during operation. The novel approach extends excitation zone overlap beyond two phases before a single phase turns off. This implements an additional duration compared to traditional methods using one or two phases for excitation. The two neighboring phases operate after the on/off sequence of the previous phase to distribute its abrupt MMF transition in the areas where phases advance and decline.

II. Static SRM Characteristics

The finite-element model computes the air-gap torque value for phase 1 through an evaluation of excitation current together with rotor position (Fig. 1). The geometrical FEA model appears in Figure 1(a) and Figure 1(b) presents rotor position and flux behavior against current while Figure 1(c) shows single-phase excitation torque generation.

The generated torque exhibits a sinusoidal pattern which moves between negative and positive maxima as the rotor shifts its position. The value of torque depends directly on the quantity of applied excitation current. The torque level depends on how the rotor stands in relation to the poling configuration of the stator. Research analysis that investigates this phenomenon will help us determine the requirement for precise phase interrelation control. The sinusoidal form of excitation current results in torque production with reduced fluctuations.



(c)

Fig 1: (a) Initial and final solution 2D mesh (b) Static flux Characteristics (c) Static torque characteristics

The SRM produces excessive noise and vibration because of its doubly-salient design and non-square wave current which generate increased torque ripple. The dynamic behavior of the SRM becomes highly non-linear because the winding inductance demonstrates non-linear characteristics which depend on rotor position and winding current. The combinations of these four elements cause torque ripple to appear. Defining the fundamental parts of an SRM remains essential for developers who need to create vital technologies. The dynamic characteristics along with dwell angle and switching processes of the SRM appear in Figure 3. The illustration in Figure 3 demonstrates both the switching procedure together with dynamic SRM operation.

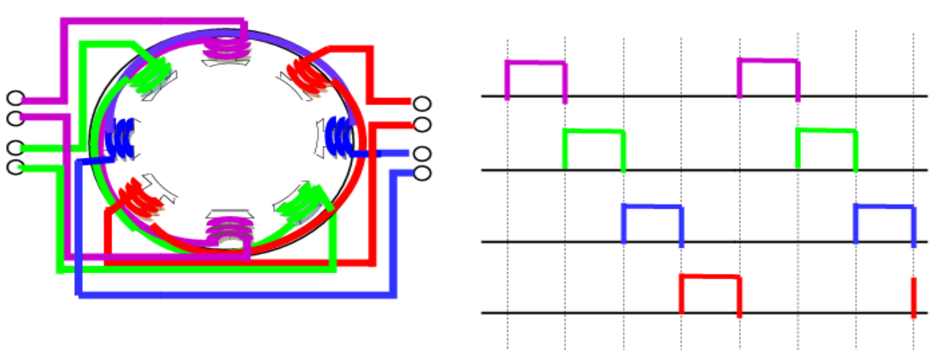


Fig 2: Phase Connections and single-phase excitation sequence excitation sequence

III. Torque Pulsation with Overlapping Phases

Minimizing the ripple formation at the fully aligned location becomes easier through proper adjustment of the excitation current timing between adjacent phases. The figure illustrating this multiple-stage switching operation appears in Fig. 3. During phase operation an established practice overlaps adjacent excitation currents between phases where previous poles control 50% of the process and subsequent poles control an identical 50% of the process. The figure depicts overlapped excitation in Figure 3(a). As Figure 3(b) displays the phase-specific excitation current conduction angles exist. This conduction angle also serves as the definition for dwell angle. The current flow begins at the center of unaligned position while ceasing before reaching the point of alignment according to this figure.

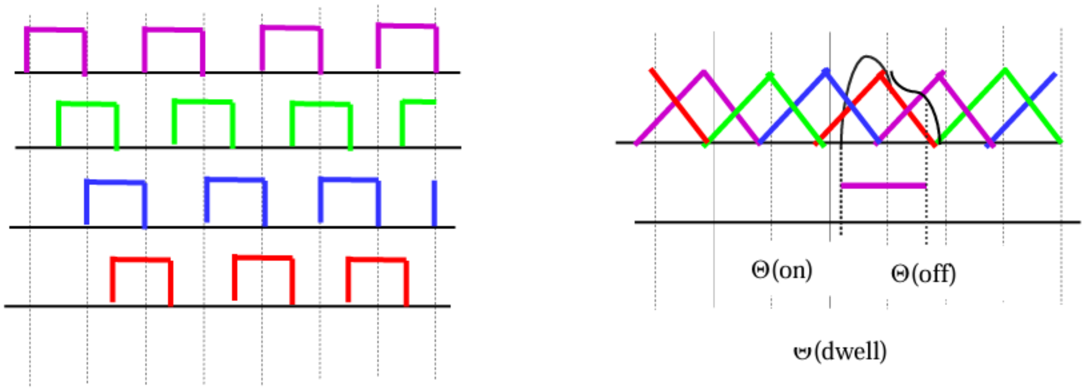


Fig 3: (a) Multiphase excitation switching scheme (Dwell angles overlapped with adjacent pole). (b) traditional profile of dwell angle (turn-on and turn-off).

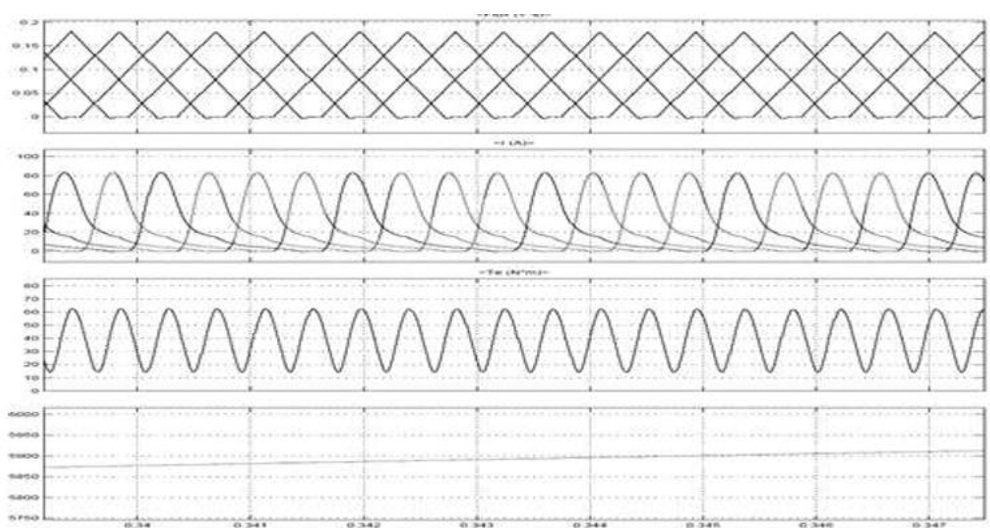


Fig 4: Narrow-overlap between the phases

IV. Multilevel Extinction

The coil current requires adjustment whenever other coils transmit power although both share the same connection point. Such compensation method balances major torque ripples by regulating the supply voltage either upward or downward. The bi-polar (3 level square wave current) switching technique operates as a method to control the current profile of the stimulated winding. Using multiple voltage supplies or split voltage supplies leads to complex voltage supply systems thus making the concept less desirable. The essential attributes which distinguish the SRM from alternative motor types need multiple supply voltage variations when using sinusoidal voltage with correct phasing applied to stator windings. SRM possesses crucial operational attributes that need to be reduced for electric vehicle use.

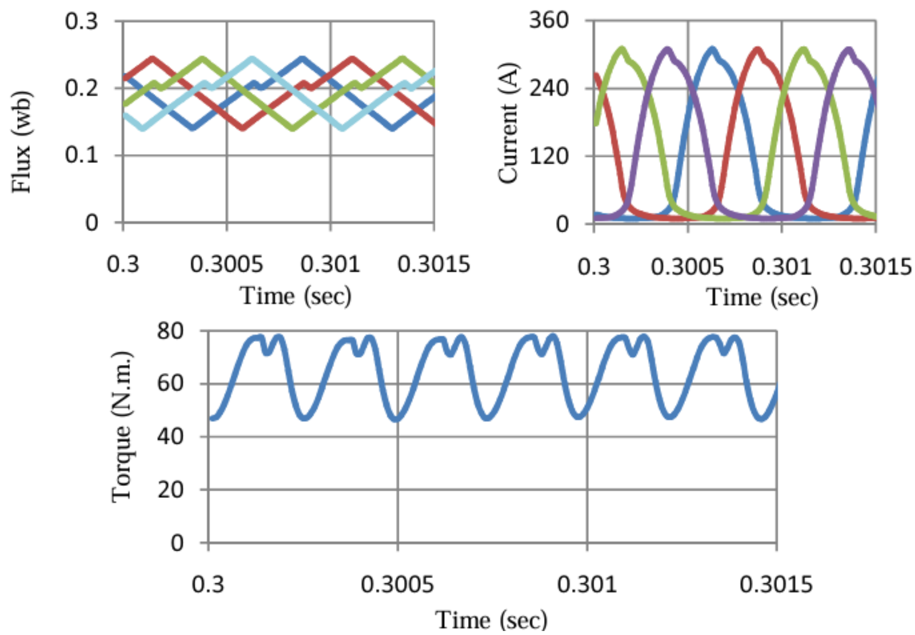


Fig 5: SRM Multiphase Extinction a. flux b. current c. torque

V. Suggested Current Excitement Control

This section proposes using multi-level, multiphase excitation to shape excitation currents thus minimizing torque ripple as well as vibrations. An SRM needs multiphase excitation for current profile control because this approach enables simultaneous current application to different phases to build magnetic energy and remove coils by changing current levels.

A phase torque production area forms its overlapping excitation section after the succeeding phase receives its initial excitation before the phase turns off. The previous phase turns off in a controlled manner because of the flowing current from the subsequent phase[5]. The commutation stage requires the subsequent winding to take in the magnetic power that the demagnetizing phase releases in the area where its excitation coincides with the magnetization reversal of the prior phase. A magnetic energy absorption process speeds up and makes smoother the phase commutation process.

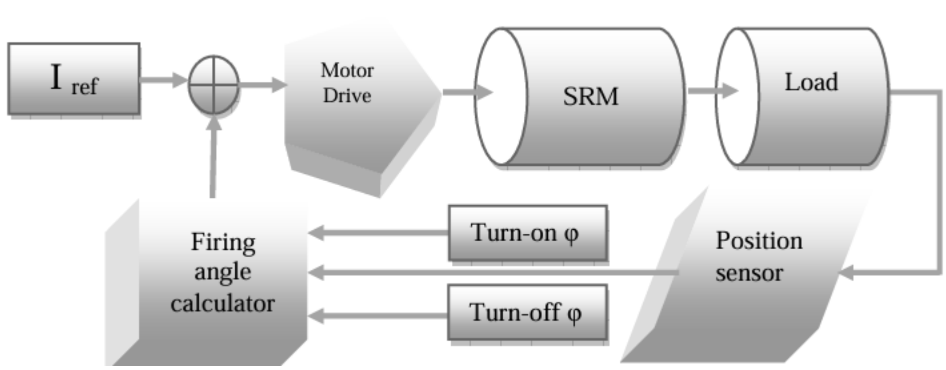


Fig 6: Feedback control system of SRM block diagram

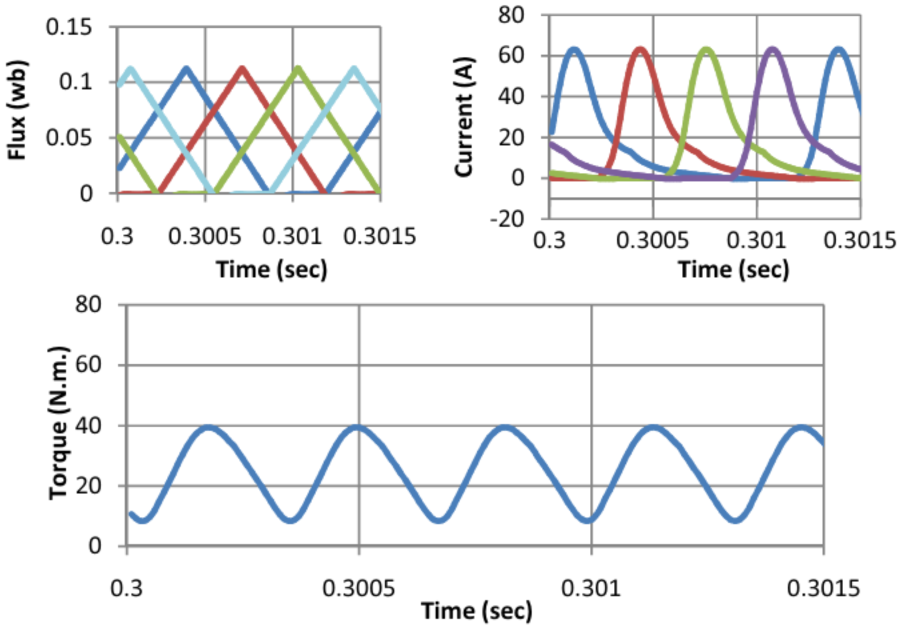


Fig 7: Multiphase excitation (and multi-level) of SRM. (a) flux (b) excitation current (c) torque.

The three key adjustable factors in controlling systems consist of turn-on angle and turn-off angle as well as dwell angle breadth. Selection of these factors allows for modifications of the excitation current. The reference current enables the alteration of current output shape. An excitation current with continuous and smooth variations can be achieved through proper determination of the three main adjustable parameters. The dwell angle determines system operation through a control system that uses rotor position sensor feedback data traditionally.

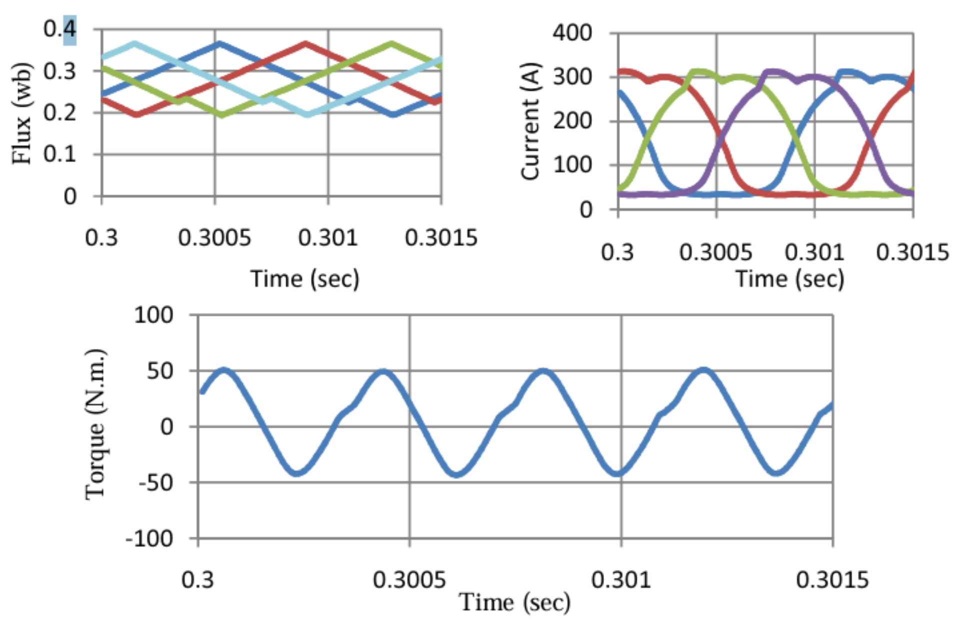


Fig 8: Multiphase excitation a. Flux b. Current C. Torque

Fig. 5 displays the system's block diagram. The implementation section of this paper introduces multi-level, multiphase excitation as a method to both mold excitation currents and minimize torque fluctuations while reducing system vibrations. The SRM system uses multiphase excitation to apply simultaneous current flows to create magnetic energy and remove magnetic fields with different current values.

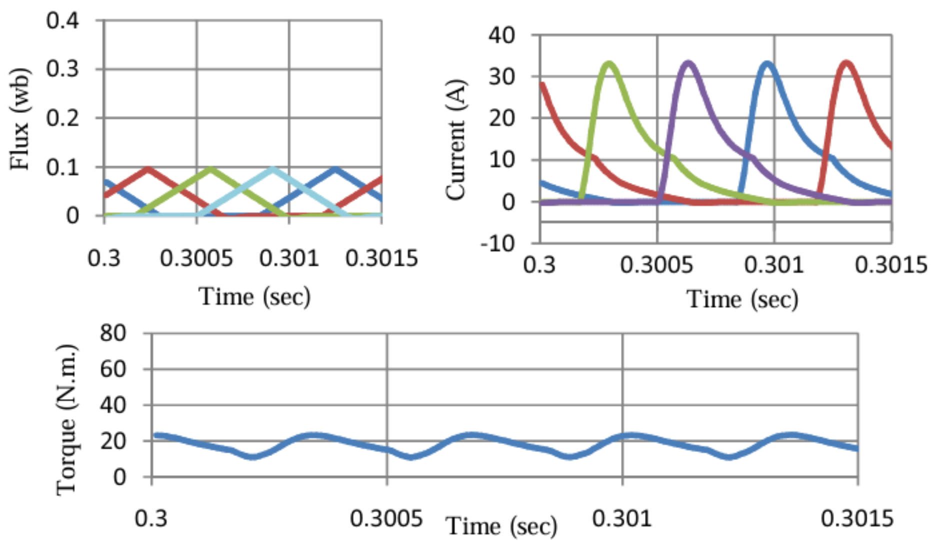


Fig 9: Excitation (multi-level) with sharp turn-on and increased tail. (a) Flux (b) Excitation Current (c) Torque

VI. Angle Advancement's Effect (Turn on Angle)

When winding resistance is ignored, the shape of the current waveform at the start of the torque generating run changes if the switch-on angle changes. These changes are almost proportionate to the advance angle. Additionally, due of the positive or negative variation rate of current, the phase current waveforms demonstrate that the generated torque is not constant and that the torque pulsation is severe across the torque generation range.

Consequently, the torque loss brought on by the larger tail angle can be counterbalanced by choosing this advance angle. If the fluctuation rate of inductance is uniform, a uniform torque is generated and the torque pulsation is not severe, as indicated by a waveform of gradually changing excitation current during the torque generating range[4]. In order to properly run the motor, that current must become the standard current. In this case, the effects of the preceding phase's tail angle will be neutralized by the advance angle of the subsequent phase. The torque genuinely shifts with a longer advanced commutation without an elongated tail current, and the motor may enter regenerative mode.

VII. Conclusion

An ac motor's electromagnetic structure has been engineered to function with a sinusoidal wave source. An SRM, on the other hand, has an electromagnetic structure that can be used with a current pulse. The SRM's torque generating system is the source of the intrinsic torque ripple and noise. This work proposes a precise dwell angle control approach for multi-level and multiphase stimulation to minimize vibrations and torque ripple in SRM. To obtain optimal values, the effects of dwell angle parameters are thoroughly examined. By using dispersed and balanced excitation, the method lessens rapid fluctuations in excitation level, which in turn minimizes ripple, vibration, and acoustic noise.

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