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An EV Applications Multilevel Quasi Matrix Converter Design for SRM Drives

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***Abstract**: The main innovation in this research includes designing a complete general choice multilevel asymmetric power converter which operates with SRM technology to meet specific electric vehicle requirements. The type of motor shape determines which inverter circuit system will function best for SRM drives. The motor shape does not influence the inverter structure for drives using sinusoidal voltages and currents.*

The selection process for SRM inverters depends on the quantity of stator and rotor poles while taking into account the dwell angle along with current overlap factors. The use of multilevel power converters enables diverse control possibilities while providing users with adjustable current profiles and reduced switching frequencies that lower converter loss rate. The matrix converter topology uses three dc voltage source terminals at its input to achieve improved control over flexible current profiling methods. The evaluation of the proposed multilevel matrix converter included Simulink modelling while connecting it to a finite element SRM model to show its advantages when used for EV applications.

***Keywords**: Matrix converter, multilevel converter, electric motor, switched reluctance motor, and FE analysis*

I. Introduction

Problematic operation of SRMs occurs because of major defects which include torque ripple and extreme machine vibration producing unneeded acoustic noise. When applying power to the phase it becomes possible to use current profiling which addresses both issues. The multilayer conversion capabilities create the potential to minimize high-frequency torque ripple without increasing the power converter switching losses. The combination of straightforward construction together with motor reliability and high rotational speeds, minimal power switches on the inverter while maintaining a strong and robust drive system have made SRM drives an area of scientific inquiry despite industry reluctance to adopt this technology these drives.

Numerous inverter topologies have been produced as a result of this research endeavor, some of which have been detailed in the literature [1-6]. The motor shape affects which inverter circuit is appropriate for SRM drives. This contrasts with drives that use sinusoidal voltages and currents, where the motor design has no bearing on the inverter structure. In the case of SRM, the choice of inverter is influenced by the number of stator/rotor poles as well as the associated dwell angle and current overlap factors. Many control options are made possible by multilevel power converters, which also offer the advantage of adjustable current profiling and reduced switching frequencies, which reduce converter losses.

The Miller Circuit proves advantageous over other common SRM drive converters when the current overlap occurs during speeds in which the motor-magnetizing voltage remains below the dc-link voltage threshold of half its value. A conventional inverter stands out as the most suitable design choice because most SRMs operate with current overlap throughout their primary speed territory. The size of the inverter directly relates to the starting torque of the SRM. To establish a rated torque starting condition regardless of the rotor position manufacturers must increase the inverter rating several times the required motor-rated power. Starting torque reduces strongly when starting current remains at its rated value while operating from the worst feasible rotor initial position.

The operation at higher dc-link voltages requires implementation of a multiple voltage level approach. The power converter can use lower voltage-rated power switches when our method enables this realization. Higher power converter switching frequencies become achievable through this technique because modern high-voltage power switches are excluded.

II. Multilevel Converter for SRM Topologies

The technological world of business and academia recognizes multilevel converters as one of the best converter options for electronic power conversion in high-power applications. Multilevel converters present numerous challenges since they remain an established enabling technology. Multilevel converters enable research work at such large volumes they continuously expand their depth of research alongside their scope. International research groups dedicate their effort to improving multilevel converters since these converters show greater appeal and competitiveness over traditional topologies. Researchers continue to diversify the areas where these converters can be used.

The matrix converter belongs to direct conversion devices because it employs bidirectional switches to link input and output ac lines directly and requires no storage elements like capacitors or inductors. These converter qualities enable mass reduction and complete operational control which make them suitable for transportation platforms including military vehicles and electric vehicles and more electric aircraft. Current semiconductor arrangements for voltage multiplication are difficult because no storage devices exist at present. Due to these limitations this architecture operated only under specific power ranges and low power conditions.

Research has revealed various multilevel matrix converter layouts over the recent period. The three traditional multilevel topologies—the FC matrix converter, the indirect matrix, and the classical matrix converter—are actually the foundation of the majority of them.

III. Non-Sinusoidal Current Motor Matrix Converter

Scholarly studies on the matrix converter have existed for nearly twenty years. The conventional matrix converter represents a complete silicon-based solution for conducting AC-AC power conversions as shown in Fig. 1. The Sparse Matrix Converter enables simplified operation because it functions only with single delivery currents regardless of unnecessary switching states. Most investigations about matrix converters have researched their applications with sinusoidal motors that include induction and permanent magnet synchronous motors. The matrix converter has the ability to drive both sinusoidal and non-sinusoidal output currents with waveforms that are almost rectangular in shape [7].

Special designs of motors enable the use of non-sinusoidal waveforms to achieve superior torque per ampere performance. The "Quasi" name was given to this converter because its structure differs from standard matrix converter standards through its three-level DC operation with EV battery integration. The 3-level DC to 4-phase matrix converter utilizes 16 bi-directional switches that the design arranges to enable connecting any output line to any input line as shown in Figure 2. The intended output waveform emerges from the modulation process of the switches.

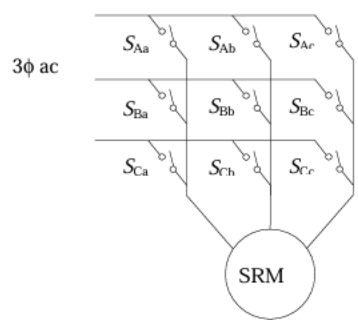

Fig 1: Classical AC-AC Matrix Converter Circuit

The bi-directional matrix converter stands out in EV applications because it can naturally capture energy from the system. The matrix converter system accepts sinusoidal input current while its load type does not affect the supply side displacement factor through the modulation method. The system requires no large capacitors nor inductors which means it can operate with much smaller dimensions than conventional methods. Recent attention focuses on matrix converter advantages because these features suit applications involving electric powertrains and materials such as weight, size and dependability.

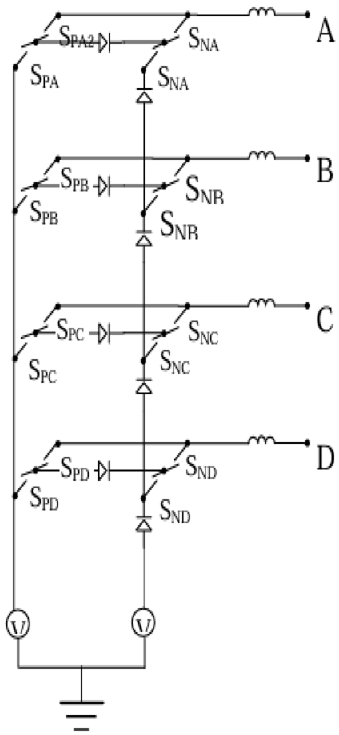

Fig 2: DC-AC Sparse matrix Converter configuration

IV. Mathematical Model

The study employs RB-IGBTs in a quasi-multi-level sparse matrix converter to control an open loop 8/6 four-phase Finite Element model of the SRM. SRM fault-tolerance properties are maintained through an easy modulation technique which independently produces step multi-level output currents for individual phases. The diagram of the proposed multilevel matrix converter is shown in Figure 3.

The input voltage sources of the multilevel converter require both closed input lines and open output loops since the inductive load prevents the loops from remaining open. The bottom section of page two specifies the switching operations for the switches displayed in Figure 4[7]. The direct general form of matrix converter equations appears between (1) to (2). The suggested multilevel matrix converter in Fig. 3 discovers 729 possible switching modes under these limitations. The state table emerges from the combination of switching states and switching strategies according to Fig. 4.

$$\underbrace{\begin{bmatrix} u \\ v \\ w \end{bmatrix}}_{v_o} = \begin{bmatrix} u^* + v_z \\ v^* + v_z \\ w^* + v_z \end{bmatrix} = \underbrace{\begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}}_{M} \underbrace{\begin{bmatrix} R \\ S \\ T \end{bmatrix}}_{v_i} \equiv v_o = \mathbf{M} v_i \ldots (1)$$

$$\underbrace{\begin{bmatrix} i_R \\ i_S \\ i_T \end{bmatrix}}_{i_i} = \underbrace{\begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}^T}_{M^T} \underbrace{\begin{bmatrix} i_u \\ i_v \\ i_w \end{bmatrix}}_{i_o} \equiv i_i = \boldsymbol{M^T} i_o \ldots (2)$$

$$where\ 0 \le m_j \le 1, \sum_{j=i}^{3} m_j \quad i = \{1, 2, 3\}, j = \{1, 2, 3\}$$

Fig 3: a. AC-AC sparse matrix Converter b. DC-AC sparse matrix multi-level Converter

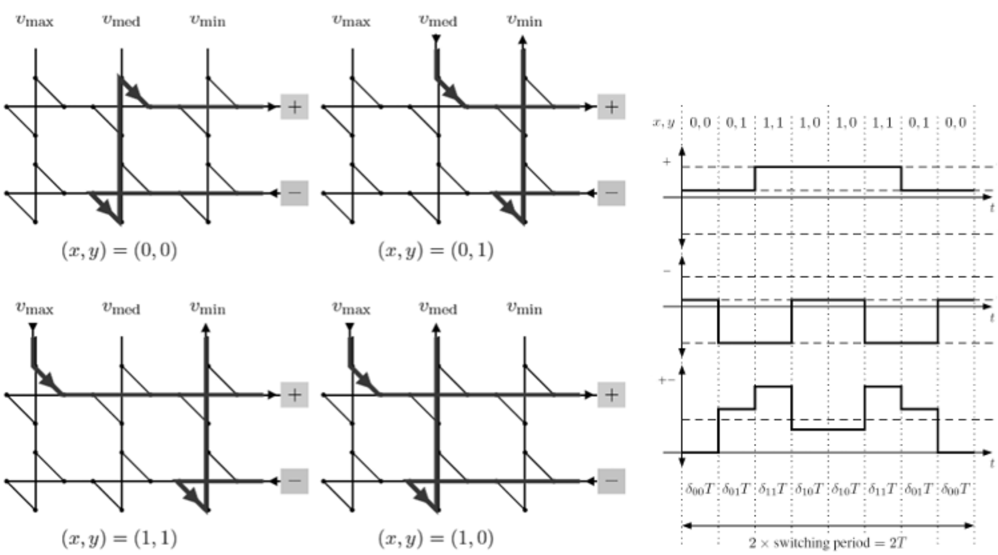

Fig 4: Communication strategies for allowed switching states

V. Virtual Machine Interface

The testing takes place with the proposed sparse matrix converter parameters under consideration. The implementation process of the system within virtual machine interfaces and simulations is discussed in this segment. The displayed Fig. 5 depicts the real switching reluctance motor designed for Finite Element Analysis modelling.

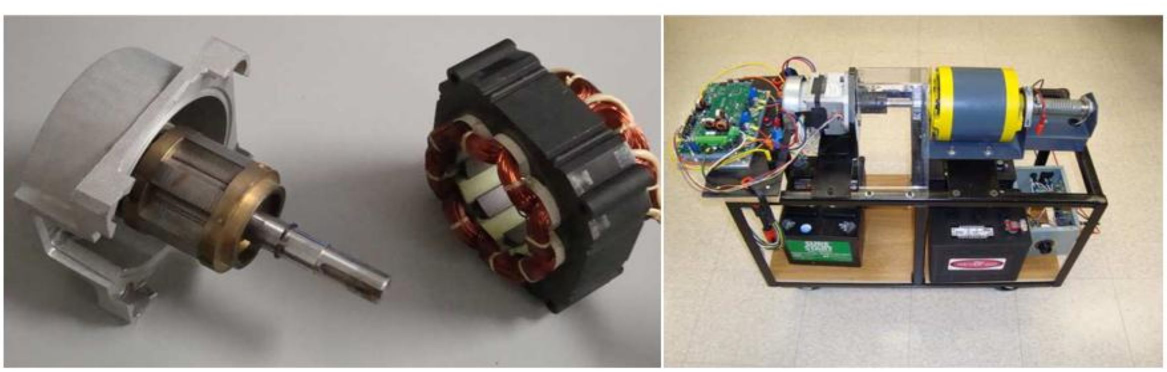

Fig 5: Experimental Switched Reluctance motor used for simulation model

VI. Conclusion

The testing takes place with the proposed sparse matrix converter parameters under consideration. The implementation process of the system within virtual machine interfaces and simulations is discussed in this segment. The displayed Fig. 5 depicts the real switching reluctance motor designed for Finite Element Analysis modelling.

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