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Performance Evaluation of Switched Reluctance Motor and Generator Under Same Operating Conditions

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***Abstract* — this paper, an effort is made to undertake a performance analysis of the motor and generator i.e., a four-phase motor (8/6) and a four-phase generator (8/6). The objectives of SRM machine design analysis involve understanding the complexity for modelling generators and motors but also differentiating them based on inputs and outputs such as total torque, flux, current, and total produced speeds. (Where the input is determined by the resistance value, reference current, and turn-on and turn-off angles.) Two control techniques, voltage control and current control, are used to simulate each type of motor and generator, and the results are recorded and evaluated. Each type of motor and generator is subjected to a load study with each control technique used, with maximum and nominal loads specified with each technique. It is first necessary to model the dynamic equations of the generator and the motor in SIMULINK.**

***Index Terms*— Switch Reluctance Machines, Motor Flux Torques are Index Terms.**

I. INTRODUCTION

SWITCHED reluctance machines (SRM) are becoming more popular among specific electronic machines since of their superior performance, permanent magnet-free design, winding-free rotor, and wide range of industrial interest applications.[1] It is suitable for a wide range of applications, including electric vehicles, high-speed bearings, and superchargers. SRM can be used as a motor to move mechanical loads or as a generator to produce electricity.[2]

A Switched Reluctance Motor (SRM) is a DC motor that emulates the behaviors of an AC motor by switching the DC current between the stator windings.[3] In order to control the switching operation, it is necessary to use a controller. These are the advanced form of the stepper motor, having simple construction because the rotor has no winding. The SR motor is a closed-loop motor, while the stepper motor operates in an open-loop.[4] This machine cannot be simply linked to a dc power supply; instead, an electronic converter is required. It comes in a variety of phase counts, from single to many. Figure 1 depicts a cross-section of a reluctance machine.[5]

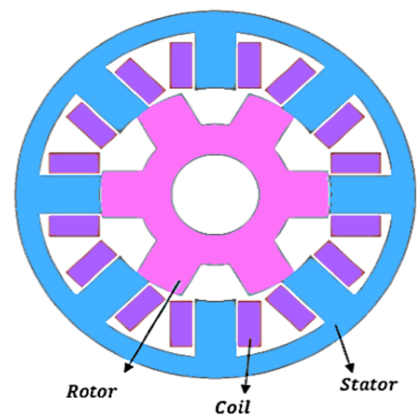

Fig. 1. Crossed Sectional View of Reluctance Machine.

Switched reluctance machine when operated as a motor rotates due to the magnetic attraction of the stator poles to the rotor poles closest to them.[5] When electronic switches, such as Insulated Gate Bipolar Transistor (IGBTs)[6] and Metal Oxide Semiconductor Field Effect Transistor (MOSFETs) are closed, electrical energy is provided to the machine; when the switches are opened, the unutilized energy is sent back to the same energy source.[7] In Figure 1 a three-phase machine with 6/4 phase poles is shown.[8]

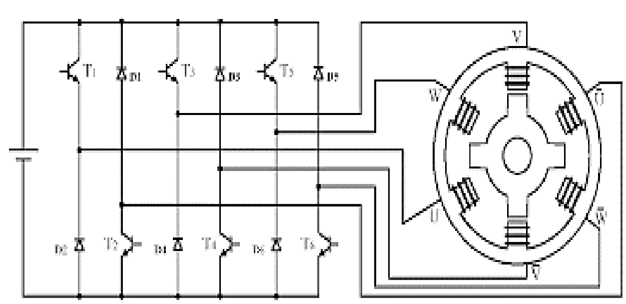

Fig. 1. Circuit Diagram of Switched Reluctance Motor

II. SRM PERFORMANCE AS A GENERATOR

A generator could be made of a switched reluctance machine (SRM). Figure 3 shows the block diagram of SRM as a generator. The prime mover for the turbine is a high-speed turbine [9]. The shaft of the SRM generator is attached to it. The SRM's output voltage is not delivered directly into the system; [10] instead, it is transformed to smooth DC via several converters.

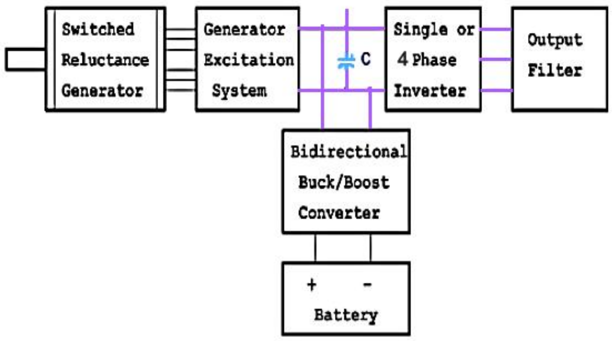

Fig. 3. Block diagram of Switched Reluctance generator.

The rotor and stator of a switched resistance generator (SRG) are "toothed," and the rotor is devoid of both permanent magnets and windings. [11] They require an excitation unit whose control is based on the position of the rotor angle. During operation, the nearest rotor poles are repelled by the active stator poles (in other words, those with winding circuits whereby the current flows). When the poles are sufficiently attracted, the phase current via diodes begins to charge the DC link capacitor. Depending on the voltage of the DC link capacitor, the excitation current is switched to the subsequent phase using power electronic switches. In this manner, the device produces electricity and maintains a constant DC voltage. [12]

III. METHODLOGY

Significant study has been done on the SRM operating as a motor and generator as well in which different operating conditions for analyzing performance as a motor and generator have been analyzed. But very few or no study have been conducted to analyze the performance of Motoring and generating under the same operating condition. In the previous studies various different methods and conditions have been used to analyze the performance of the motor and generator; these approaches are time intensive and require more efforts to analyze each machine separately and require different technologies for each Switch reluctance machine (SRM). Switch reluctance motor under same operating conditions is missing in the literature. However, SRM performance as generator and is largely available.

Using A mathematical model of a Switched Reluctance Machine (SRM) with just an asymmetrical half-bridge converter layout that can function in both motoring and generating modes was developed using the MATLAB/Simulink environment [13]. The load is disconnected in driving mode, but connected in producing mode, when phase demagnetization creates electricity for the load and prime mover. Linear switching reluctance generators are the subject of a thorough mathematical model. A mathematical model is used to mimic the behaviors of a tubular linear switching reluctance generator in an ocean wave point absorber device as a power take-off system. In this work, a switching reluctance generator (SRG) transmits energy in response to commands from a controller. The building of the SRG controller for speed & voltage regulation applications is investigated after just a review of generating electromechanics. [14]

The currents in an SRM's phases must point toward the rotor position in order for positive torque to be developed [15]. The optimal waveforms for Phase A inductance & current in a 6/4 SRM are depicted in the next image. Turn-on & turn-off angles describe the positions of the rotor at which the converter's power switch is switched on and off, respectively. [16]

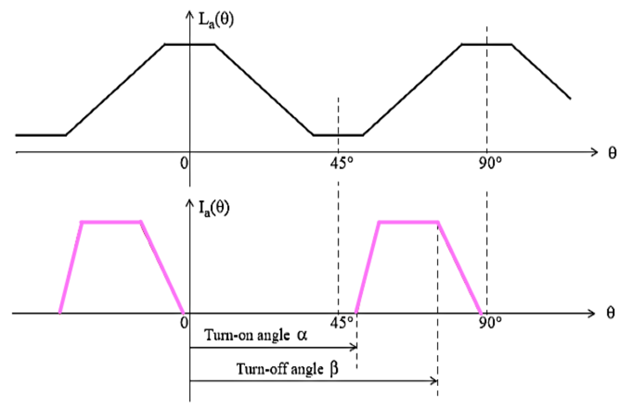

Fig. 4. Switching angles for Motor and Generator operations of SRM

IV. SIMULATION MODEL

Using the MATLAB/Simulink environment, a mathematical model for a Switched Reluctance Machine (SRM) was created that functions in both motoring and generating mode and has an asymmetrical half-bridge converter topology. The load is disconnected in driving mode, but connected in producing mode, when phase demagnetization creates electricity for the load and prime mover[16]. The switching reluctance generator (SRG) transfers energy as instructed by a controller in this study. Starting with a review of generation electromechanics, The SRG controller's construction for speed and power control applications is explored.

The SRM is supplied by a four-phase imbalanced power converter with four legs, which are made up of two IGBTs and two free-wheeling diodes. Active IGBTs drive positive currents into the phase windings during conduction periods by applying a positive input signal to the stator windings.[6] Negative voltage applied to a winding during free-wheeling times, and the energy that has been stored is then transferred back to power DC source via the diodes. Thus, it is possible to shorten the current fall time in motor windings. Utilizing a position sensor connected to the rotor allows for exact imposition of the turn-on and turn-off angles of a motor phase. To regulate the generated torque waveform, use these switching angles. By measuring currents with references, three hysteresis regulators independently regulate the phase currents and produce the driving signals for the IGBTs. The hysteresis band is the primary factor that affects IGBT switching frequency.

A DC voltage level of 240 V is being used in the proposed simulation model. In two separate scenarios, the output is exhibited by setting the converter's turn-on & turn-off angles to 0-30 degrees for generator, and 30-60 degrees respectively for motor, and by using reference currents of 50-100 A and 240V respectively. +10 A is selected as the hysteresis band. The step reference is used to regulation input to initiate the SRM.

the currents were controlled, thus if the system's mechanical dynamics change, for motor as well as for generator. On the scope, the SRM drive waveforms are shown, including grid voltage, magnetic flux, winding currents, motor torque, motor speed, motor current and generator Flux, generator torque, generator current waveforms. As seen in figure 8 and figure 9. In the simulation model the transitions of the currents through one phase to the next are what cause the SRM torque, as can be seen, to have a very high starting torque ripple component. The turn-on & turn-off angles of the converter have a significant impact on the torque ripple, which is a unique feature of the SRM. We may note from the drive's waveforms that SRM operation speed range can be split into two areas depending on the converter operating mode: current-controlled.

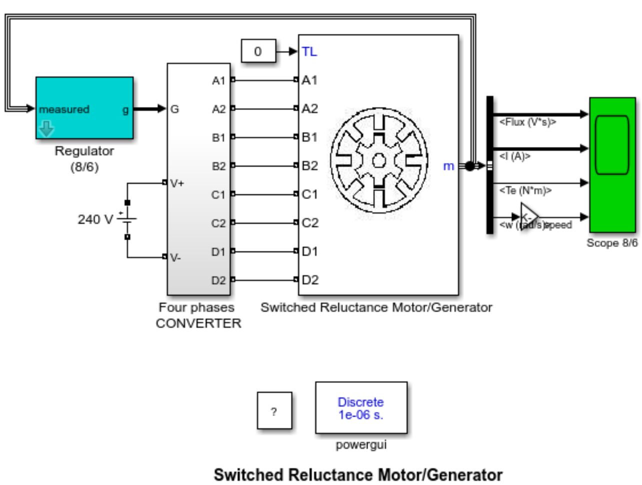

Fig. 5. Simulink Model of Switch Reluctance Machine.

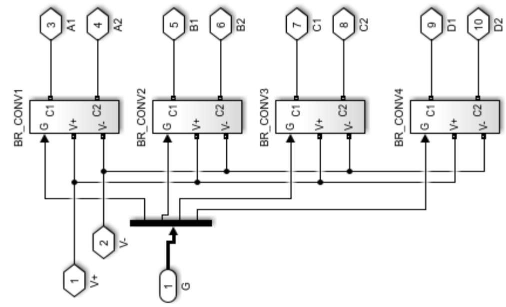

Fig. 6. Four phase converters.

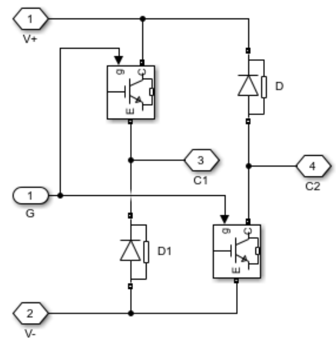

Fig. 7. Bridge converters.

V. SRM PERFORMANCE AS A MOTOR

The motor's inductance is low from rest up to around 3000 revolutions per minute, as well as the current can be adjusted to a reference value. The average torque created in this mode of operation is roughly proportionate to the reference value at hand. We also observe the torque ripple brought on by the hysteresis regulator being switched, in addition to a torque ripple brought on by phase transitions. It is also known as continuous torque operation when used in this manner. The motor's inductance is high for rotational velocities over 3000 rpm. as well as the phase currents are incapable of reaching a reference point imposed by current regulators. When there is no modulation of the power switches, the converter function switches naturally to voltage-fed mode. The d.c supply voltage is continually provided to the phase windings while they are shut during their active periods. As seen on the scope, this leads to waveforms with linearly varying flux. The SRM establishes its "natural" characteristic in voltage-fed mode, where the mean result of the created torque is inversely related to a motor speed. The torque waveforms only show torque ripples caused by phase transitions because the hysteresis regulator also isn't functioning in this situation. Turn-on and turn-off angles, as well as the current waveforms in the motor phases, all have an effect on the average torque and torque ripple in SRM drives. And the motor speed has an impact on these features. Highest torque/ampere ratio, lowest torque ripple, and this throughout the greatest speed range possible are highly desirable in many applications, such as electric car drives. Applying the right pre-calculated turn-on and turn-off angles in relation to the motor current and speed can improve the SRM torque characteristic

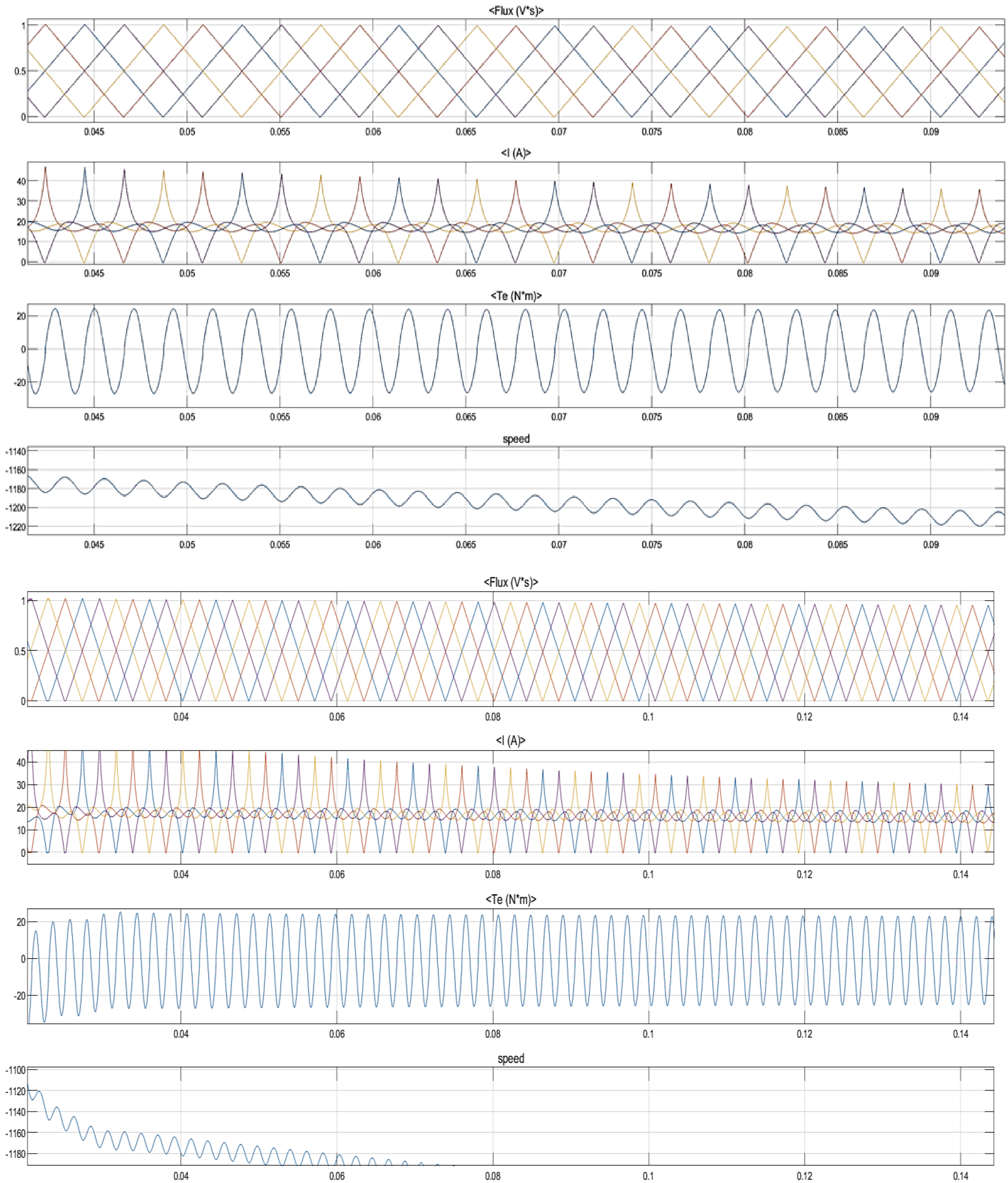

Fig. 8. From Top to Bottom (Flux, Speed, Current and Torque output characteristics of Switch Reluctance Motor).

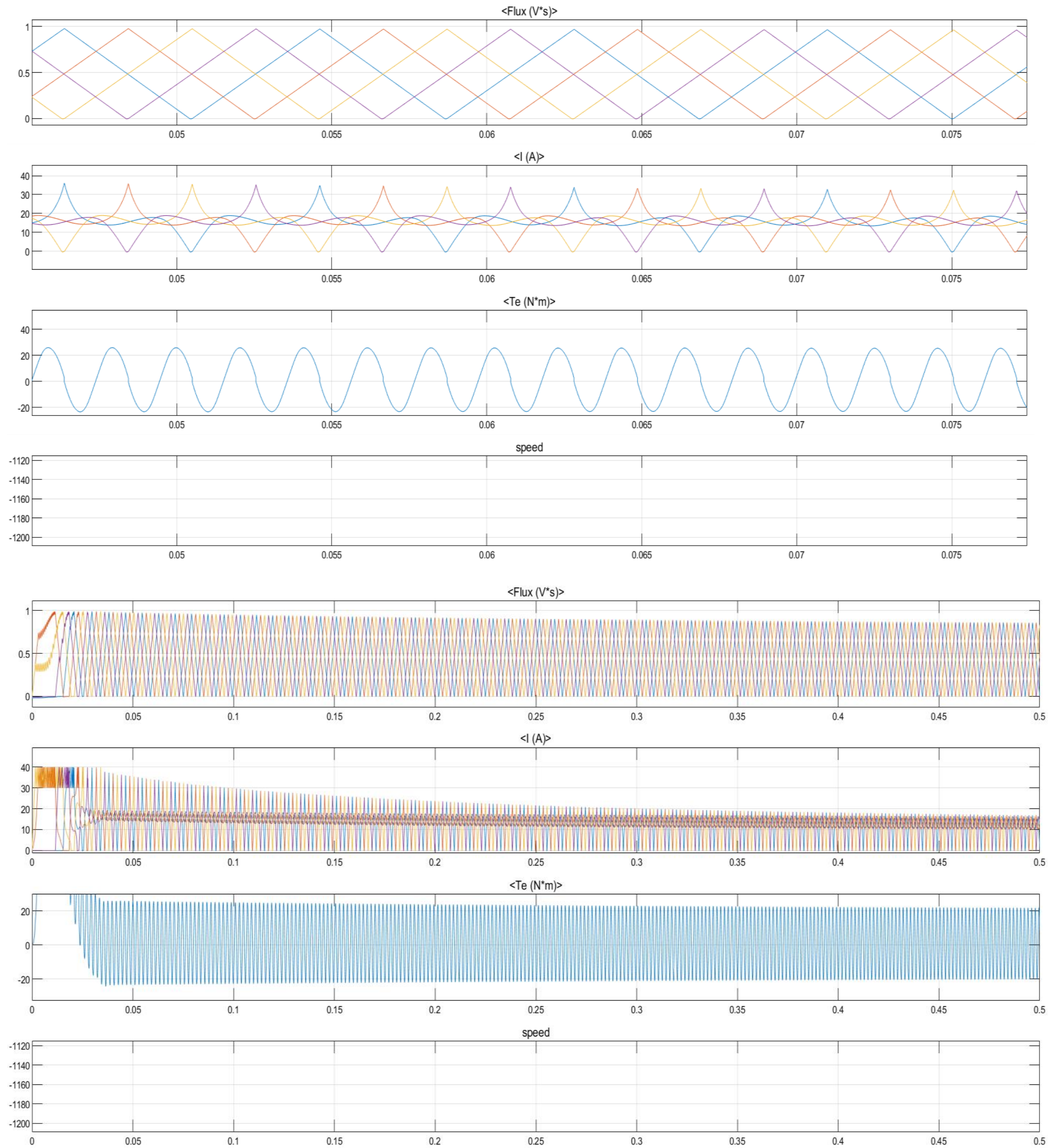

Fig. 9. From Top-Bottom (Flux, Speed, Current and Torque output characteristics of Switch Reluctance Generator).

The output graphs of switch reluctance machine operating in motoring mode and generating mode are shown in figure 8, 9.

A. SRM output Flux

Existing control methods used in SR motors are often based on look-up tables of the torque and flux characteristics that are derived from magnetic finite element analysis (FEA).

B. SRM Output Current

In this there are three currents a (red), b (yellow) and c (blue). In this graph the starting current is high for each phase, but it got stable after some time, and it's happened because of the torque rippling. At t = 0.02 the input current starts to stable

C. SRM Output Torque

Due to current changes the torque ripple in SRM is significant from one phase to the next. The turn-on and turn-off angles of the converter are mostly to blame for torque ripples, a distinctive feature of SRM.

D. SRG Output Current

In this there are three currents a (red), b (yellow) and c (blue). In this graph the starting current is high for each phase, but it got.

E. SRG Output Flux

In this starting flux is normal at starting no ripples founds but after some duration the flux becomes zero for some time then again flux created.

F. SRG Output Torque

Switch reluctance generator produces negatives torque which is not a very suitable condition for load connected to it.

VI. CONCLUSION

Switched Reluctance Machines (SRM) are becoming more and more common among different electrical machines, due to their excellent performance, simple and magnet-free design, winding-free rotor, and wide range of industrial interest applications.

SRM with a small control variation can be operated as a motor as well as a generator. The only difference between generating and motoring mode is the operating/switching angle. The same machine functions as a motor when it is operated under low inductance conditions, and as a generator when higher inductance is chosen for its operation or switching.

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