A Dynamic Cosimulation Approach for a Switched Reluctance Starter/Generator Using Maxwell SPICE and Simplorer

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Abstract —**The switched reluctance machine (SRM) has attracted a great deal of interest in the development of an integrated starter/generator (ISG) for aircraft or electric vehicle engines and power systems due to the low cost and high reliability. This paper presents a cosimulation approach for a switched reluctance starter/generator (SRS/G) system assisted by Maxwell SPICE and Simplorer. The nonlinear magnetization characteristics of flux linkage and torque of the machine have been considered and computed by finite element analysis (FEA). From FEA static results, a dynamic equivalent mgnetic circuit model of SRS/G is introduced into Simplorer using Maxwell SPICE rules which is considered the indirect field-circuit coupling. The control strategies for the SRS/G operating in the motoring and generating states are presented. The simulation and experimental results for a 6/4 SRS/G system are also presented and compared to demonstrate the validity of the simulation method.**

I. INTRODUCTION

Recently, the switched reluctance machine (SRM) has attracted a great deal of interest in the development of an integrated switched reluctance starter/generator (SRS/G) for future aircraft or electric vehicle engines and powe systems. The development of the integrated SRS/G will result in an aircraft or electric vehicle with improved performance and lower weight. However, the phase winding flux linkage or inductance and torque of SRM are the functions of rotor position and phase current, which makes the SRM to be a nonlinear system.

In this paper, a dynamic cosimulation approach which combines the Maxwell SPICE with Simplorer program is used to predict the dynamic performances for a 6/4 SRS/G system. The machine topology and control principle are introduced. By using the dynamic indirect field-circuit coupling model, the dynamic electromagnetic performances of SRS/G system are predicted and compared with measured data to verify the proposed cosimulation approach.

II. MAXWELL SPICE WITH SIMPLORER MODEL OF SRS/G

Maxwell SPICE is a modified version of Berkeley SPICE and is included in the Maxwell equivalent circuit model generator package. By using the FEA method, the export circuit equivalent (ECE) tool of Maxwell 2D is used to generate Maxwell SPICE equivalent circuit of SRM from Maxwell 2D solutions. A 2D parametric static magnetism solution can export detailed FEA data based analysis with Maxwell 2D. Multidimensional look up tables embedded into the SPICE model represent the nonlinear behavior of the system. Then, the equivalent circuit model generated from Maxwell2D could be imported into a Simplorer environment. Fig.1 shows the indirect field-equvilent circuit model of SRS/G in Simplorer for the study of the dynamic performances, the ECELink1 is the SRM field-equivalent circuit coupling model that generated from Maxwell SPICE. In order to make the SRS/G operates smoothly and steady, the commutating current sequences are needed to be installed. The position dependent control of the switches is modeled based on state machines.

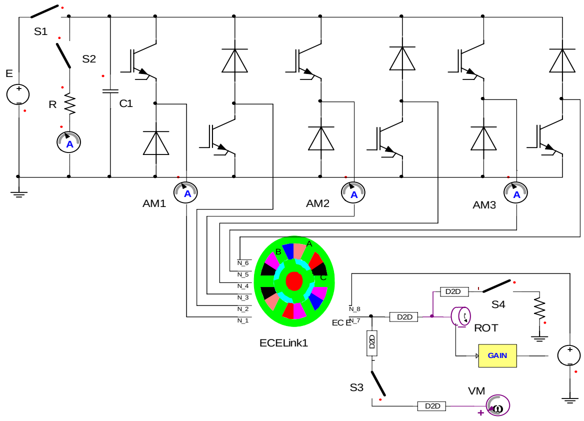

Fig.1 The indirect field-circuit model of SRS/G system in Simplorer

III. SYSTEM CONTROL STRATEGIES

In order to get excellent performance for the integrated SRS/G in the dynamic operation, the various different kinds of control strategies need to be adopted. Therefore, the speed PID control with varied parameters and chopped current control (CCC) are used when SRS/G operates in the motoring state. When the SRS/G system reaches the request speed of electric power generation state, the voltage feedback control needs to adjust the voltage stabilize in the demanding amplitude. At the same time, in order to make the generator reach higher power efficiency when it operates at different speed, the turn-on and turn-off angles require optimization. Therefore, the voltage feedback PID control with varied parameters, the angle position control (APC) and current control are used in the generating state.

IV. PEFORMANCE PREDICTION AND VERIFICATION

In this section, we use the proposed modeling method to predict the dynamic perfomances of the SRM operating as a starter/generator. The steady state machine variable waveforms and several characteristic curves predicted by the model are compared with the actual measured data.

A. Start-up Performance

Fig.2 shows the simulated dynamic phase current, voltage and flux linkage of motor phase *A*, total torque and speed at the starting-up mode.

B. Generating performance

At the generating mode, the simulated dynamic dc-bus output voltage, phase current, phase flux linkage and bus current are plotted in Fig.3.

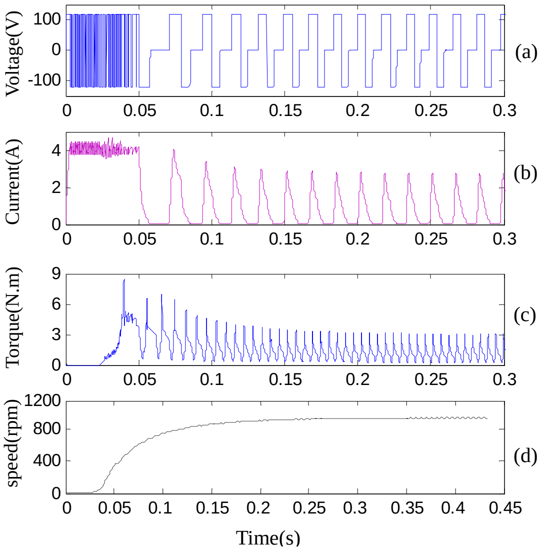

Fig.2 Simulate waveforms at start-up: (a) phase voltage, (b) phase current, (c) total torque , (e) speed

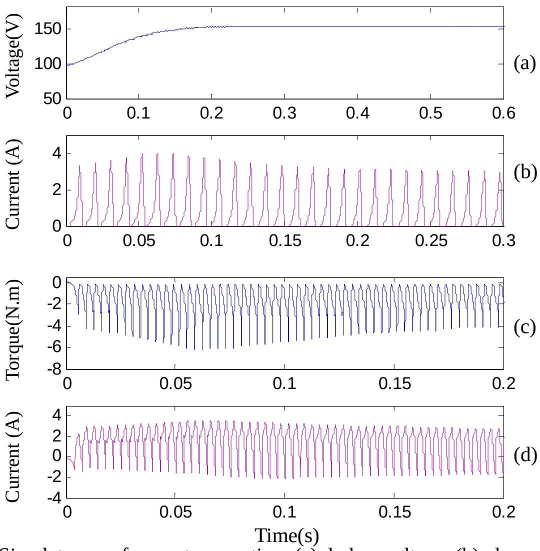

Fig.3 Simulate waveforms at generating: (a) dc-bus voltage, (b) phase current, (c) total torque, (d) bus current

C. Steady State Performances and Verification

The validity of the proposed simulation method has then been tested. Fig.4 shows a comparison of measured current and simulated phase current and total torque when the machine was operated at the starting-up mode. Fig.5 shows a comparison of measured current and simulated phase current when the machine was operated at the generating mode.

Fig.6 shows the comparison of simulated results using this proposed modeling method and measured torque-speed characteristic at the motoring state. The average torque is closely predicted but is slightly overestimated by the measuremt. The maximum deviation between the simulated and measured curves is lower than 10%. These comparisons reveal that the simulated and measured values are in good agreement.

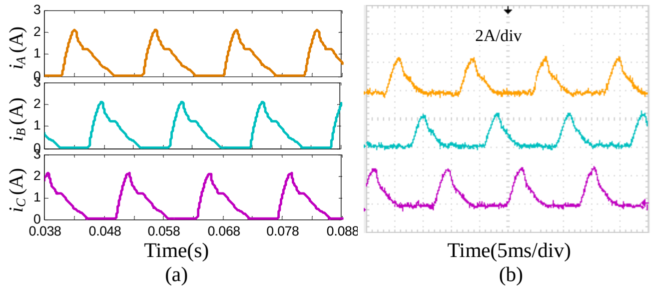

Fig.4 Simulated and measured phase current at motoring mode with 550rpm and 110V: (a) simulated, (b) meaured

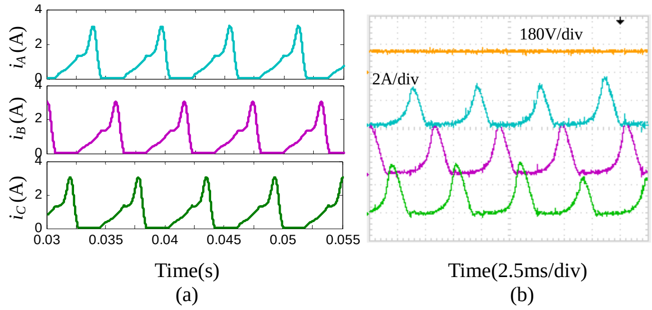

Fig.5 Simulated and measured phase current at motoring mode with 1300rpm and 160V: (a) simulated, (b) meaured

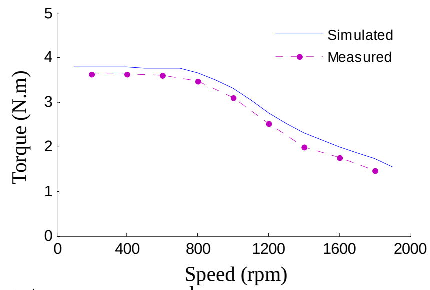

Fig.6 Average torque versus speed

V. CONCLUSION

This paper has presented a dynamic cosimulation approach which considered the indirect field-equivalent circuit coupling for SRS/G system assisted by Maxwell SPICE with Simplorer. Based on the proposed model, the simulation results and experimental results for a 6/4 SRS/G system was presented. All the simulation results of dynamic performance such as steady state phase current and torque-speed characteristics computed by the proposed model are very similar with the experiment tests, which verified the novel simulation method.

ACKNOWLEDGMENT

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REFERENCES

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