Performances Computation for a Dual-Channel Switched Reluctance Generator Operation Under Single- and Dual-Channel Modes

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Abstract — **This paper presents a dynamic model strategy and performances computation for a 12/8 dual channel switched reluctance generator (DCSRG) considering the effect of mutual coupling between phases of each channel in the DCSRG. Using the proposed dynamic simualtion model, the transient and steady state performances such as generating output dc voltages, phase currents and flux linkages for a DCSRG under single- and dual-channel operation modes are predicted and compared. Finally, the simulation and experimental results are also compared in a 2kW DCSRG systems under different operation modes to verify the proposed modeling and analysis.**

I. Introduction

In the past researches [1-2], the conventional SRM is often used as single channel of three phases or four phases SRM. Recently, a novel 12/8 poles dual-channel reluctance generator (DCSRG) has attracted a great deal of interest in the development of integrated switched reluctance starter/generator for furture aircraft engines and power systems [3] that it is for redundancy/failsafe reasons. Although the structure is very simple, the DCSRG could be considered as two 6/4 SRGs with strong interactions due to the magetically coupling when the dual channels in DCSRG are operated simultaneously. So it is difficult to model and predict performances for the DCSRG.

In this paper, a dynamic model strategy and performances computation for a 12/8 DCSRG including the effect of mutual coupling between phases of each channel are presented. The comparisons of simulation and experimental results such as transient generating, steady state currents and flux linkages under different operation modes are also presented.

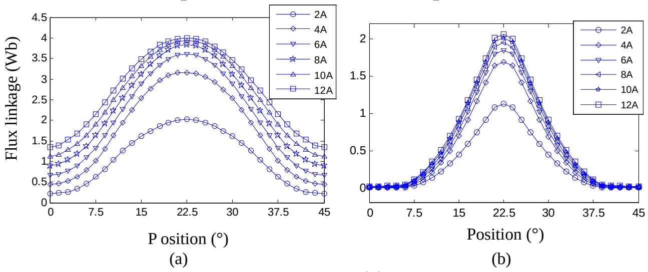


Fig.1 Flux linkage characteristics: (a) self flux linkage in phase $A1$; (b) mutual flux linkage in phase A2 when phase $A1$ is excited

II. Model and Characteristics of DCSRG

A. Dual-Channel Operation Model

When the DCSRG operated as a single channel machine, it is similar to a conventional 6/4 SRG with single-phase excitation. Thus, the the phases voltage equations of DCSRG under single channel operation mode may be expressed as

$$\frac{d\lambda_j}{dt} = u_j - r_{ph} \cdot i_j \tag{1}$$

When the DCSRG are operated under dual channel mode, the dual three phases voltage equations for the DCSRG considering mutual coupling between phases of each channel can be presented as

$$\begin{bmatrix} u_{A1} \\ u_{B1} \\ u_{C1} \\ u_{A2} \\ u_{B2} \\ u_{C2} \end{bmatrix} = r_{ph} \begin{bmatrix} i_{A1} \\ i_{B1} \\ i_{C1} \\ i_{A2} \\ i_{B2} \\ i_{C2} \end{bmatrix} + \begin{bmatrix} \frac{\partial \lambda_{A1}}{\partial \theta} \\ \frac{\partial \lambda_{B1}}{\partial \theta} \\ \frac{\partial \lambda_{C1}}{\partial \theta} \\ \frac{\partial \lambda_{A2}}{\partial \theta} \\ \frac{\partial \lambda_{B2}}{\partial \theta} \\ \frac{\partial \lambda_{C2}}{\partial \theta} \end{bmatrix} \frac{d\theta}{dt} + \begin{bmatrix} \frac{\partial \lambda_{A1A1}}{\partial i_{A1}} & 0 & 0 & \frac{\partial \lambda_{A2A1}}{\partial i_{A2}} & 0 & 0 \\ 0 & \frac{\partial \lambda_{B1B1}}{\partial i_{B1}} & 0 & 0 & \frac{\partial \lambda_{B2B1}}{\partial i_{B2}} & 0 \\ 0 & 0 & \frac{\partial \lambda_{C1C1}}{\partial i_{C1}} & 0 & 0 & \frac{\partial \lambda_{C2C1}}{\partial i_{C2}} \\ \frac{\partial \lambda_{A1A2}}{\partial i_{A1}} & 0 & 0 & \frac{\partial \lambda_{A2A2}}{\partial i_{A2}} & 0 & 0 \\ 0 & \frac{\partial \lambda_{B1B2}}{\partial i_{B1}} & 0 & 0 & \frac{\partial \lambda_{B2B2}}{\partial i_{B2}} & 0 \\ 0 & 0 & \frac{\partial \lambda_{C1C2}}{\partial i_{C1}} & 0 & 0 & \frac{\partial \lambda_{C2C2}}{\partial i_{C2}} \end{bmatrix} \cdot \begin{bmatrix} \frac{di_{A1}}{dt} \\ \frac{di_{B1}}{dt} \\ \frac{di_{C1}}{dt} \\ \frac{di_{A2}}{dt} \\ \frac{di_{B2}}{dt} \\ \frac{di_{C2}}{dt} \end{bmatrix} \tag{2}$$

B. Computation of Self and Mutual Flux by FEA

The flux patterns under single and dual-channel excitation models are computed by finite element analysis (FEA). And the self and mutual flux linkages in each phase are also computed by FEA for various rotor positions, in which only one phase (phase A1) is excited with various current levels, which is shown in Fig.1.

It may be seen in Fig.1 that when phase $A1$ at 0º<θ<7.5º and 37.5º<θ<45º, the mutual flux linkage of phase $A2$ are almost zero, but when 7.5º<θ<37.5º, the self flux linkage and the mutual flux linkage rapidly increased. At the aligned position (θ=22.5º), the self flux linkage in phase $A1$ and the mutual flux linkage in phase $A2$ are both at maximum.

IV. Performances Computation of DCSRG

A. Simulation Model

The detailed simulation block diagram of phase-$A1$ considering mutual coupling between phases $A1$ and $A2$ under dual channel operation mode is given in Fig.2. The other phases such as phases $B1$ and $B2$, and phases $C1$ and $C2$ simulation block diagrams are similar to Fig.2.

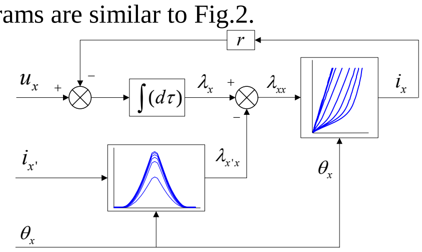


Fig.2 Simulation block diagram of phase-$A1$ considering mutual coupling between phases $A1$ and $A2$ (x represents A1 and x' represents A2)

B. Comparison of Performances under Single Channel Operation and Dual channel Operation Modes

1) Generating performance under closed-loop control

This section shows the comparison of the simulated dynamic performances during generating operation, such as the dc bus voltage and phase current, when the DCSRG was operated under single and dual-channel modes with closed-loop control. It can be seen from the simulation results that at the beginning of generating in closed-loop control, the dc bus voltage of the machine under dual channel operation mode raised faster than that under single channel operation mode.

2) Steady state performances

This section show the comparison of simulated steady state results of three phases in one channel at the same dc bus voltage and speed conditions when the DCSRG was operating under single- and dual-channel mode. It can be also found that before the phases are switched off, the phase current under single channel operation mode increased more rapidly than that under dual channel operation mode.

V. Experimental Verification

A. Single Channel Operation Mode

The block diagram of experimental DCSRG system setup is shown in Fig.3. In this setup, the DCSRG are driven by two independent sets of power electronic circuits with dual control channels. Fig.4 shows the steady state waveforms of dc bus voltage, gating pulse, and phase A1 current simulated by the proposed model of DCSRG and measured in the laboratory when the machine operates under single channel generating mode.

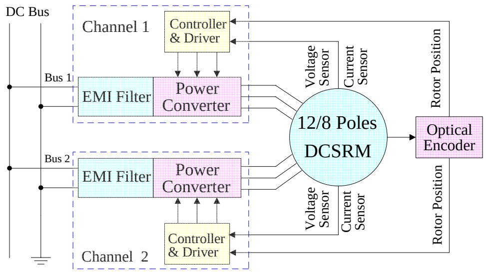
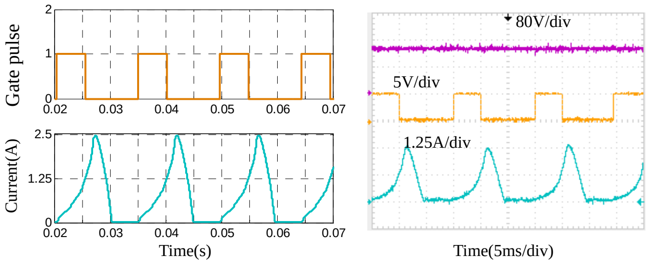


Fig.3 Block diagram of the experimental setup

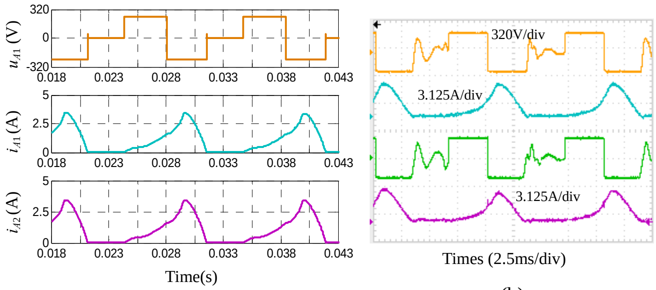


(a) (b)

Fig.4 Simulation and measured three phases current waveforms under single channel generating mode at 500rpm: (a) Simulated and (b) measured.

B. Dual Channel Operation Mode

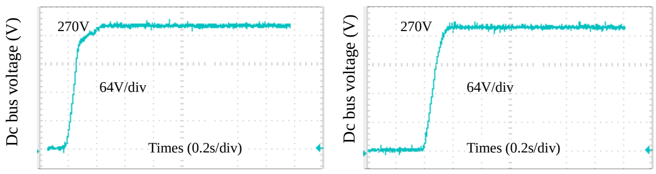
Fig.5 shows the steady state waveforms of phases *A*1 and *A*2 simulated by the proposed model of DCSRG and measured in the laboratory when the machine operates under dual channel generating mode.



(a) (b)

Fig.5 Simulation and measured results under dual-channel generating mode at 720rpm: (a) Simulated and (b) measured.

Fig.6 shows the output dc-bus voltage at generating under single and dual-channel modes based on voltage closed loop control. It can bee seen that the out put dc voltages are up from 5V to commanded voltage of 270V during 0.33s and 0.21s by using closed loop control under single and dual-channel mode, respecitvely.



(a) (b)

Fig.6 Measured dc-bus output voltage at transient generating under different operation modes: (a) single channel mode, (b) dual channel mode

There are good agreement between the simulated waveforms and the experimental results when the DCSRG operates under dual channel mode, which verified the proposed DCSRG modeling method with considering the mutual coupling for each channels.

VI. Conclusion

This paper has presented a dynamic model strategy and performances computation for a 12/8 DCSRG including the mutual coupling between each channel. By using this proposed DCSRG model, the dynamic performances such as generating output dc voltage, phase currents, and flux linkages are predicted and compared under different operation modes. Simulation and experimental results were compared in DCSRG systems under single channel operation mode and dual channel operation mode to validate the efficiency and accuracy of the proposed modeling method.

Acknowledgment

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