Characteristics of 8/6 Switched Reluctance Generator Excited by Suppression Resistor Converter

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This paper describes a consideration of the excitation circuit of a switched reluctance (SR) generator. The SR generator has some features including solid structure and easiness of maintenance. However, the conventional excitation circuit of the SR generator is an asymmetry half bridge converter (AHBC) whose configuration is complicated. In this paper, we examine the operating characteristics of the SR generator excited by a suppression resistor converter (SRC) based on finite-element method (FEM) analysis and experiments.

***Index Terms*—Finite-element method (FEM) analysis, suppression resistor converter, switched reluctance generator.**

I. Introduction

THE switched reluctance (SR) generator has various desirable features which include simple and solid structure, easiness of maintenance, small moment of rotor inertia, and low cost because the SR generator has no rotor windings and no permanent magnet. The solid structure is useful for an ultrahigh speed generator such as a microgas turbine generator [1]–[3]. The simple structure and small moment of inertia suit a low speed multipolar generator for use in wind turbine generators.

However, the SR generator has not been put into practical use because an optimum design of the SR generator has not been established. Furthermore, the excitation of conventional SR generator utilizes an asymmetry half bridge converter (AHBC) whose circuit is somewhat complicated [4], [5]. Some simple excitation circuits have been proposed [6]. However, the quantitative evaluation of the excitation circuits has not been presented sufficiently.

In this paper, we report some considerations on an 8/6 SR generator excited by a suppression resistor converter (SRC) which consists of a half number of switching devices for AHBC [6]. The operating characteristics of the SR generators with suppression resistor converter (SRC) and asymmetry half bridge converter (AHBC) were discussed based on finite-element method (FEM) analysis and experiments.

II. Basic Configuration of SR Generator

Fig. 1 illustrates a basic configuration of the 8/6 and four-phase SR generator used in this paper. The core material is nonoriented silicon steel with a thickness of 0.5 mm. The windings of each phase are connected in series.

Fig. 2 shows the schematic relationship between the winding inductance L of the phase-A and the rotor position angle θ. The torque τ is given by

$$\tau = \frac{1}{2} i^2 \frac{dL}{d\theta}. \tag{1}$$

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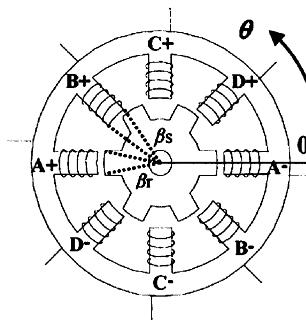

Outer diameter of stator	100mm
Inner diameter of stator	50.2mm
Length of air gap	0.2mm
Stator pole arc βs	20.1°
Rotor pole arc βr	23.5°
Stack length	50mm
Number of windings/pole	52 turns
Core material	50H290

Fig. 1. Core structure of the 8/6 SR generator.

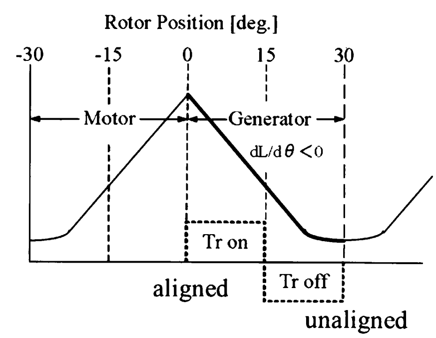

Fig. 2. Inductance versus rotor position curve.

The equation means that the torque is negative in the region of $dL/d\theta < 0$. When the stator windings are excited in the region and the rotor is driven by a proper prime mover, the mechanical rotation energy can be transformed into electric energy.

Fig. 3 shows a conventional excitation circuit of SR generator using an asymmetry half bridge converter. In the figure, $L_{\rm a}$, $L_{\rm b}$, $L_{\rm c}$, and $L_{\rm d}$ show the windings of the phase A, B, C, and D, respectively. The resistor r is each winding resistance. The opposed two transistors turn on and turn off at the same time moment against the appropriate rotor position angle. The stator pole is excited and its winding current increases when the transistors turn on. When the transistors turn off, the currents flow through the external load resistance $R_{\rm L}$ and the generated electric power is supplied to the load resistance.

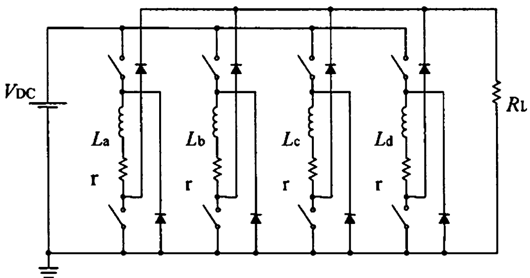

Fig. 3. Circuit configuration of SR generator excited by AHBC.

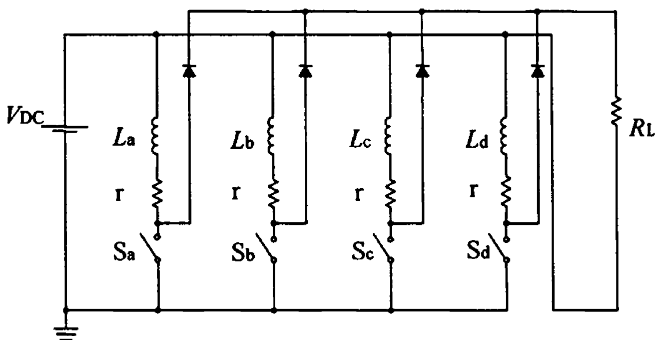

Fig. 4. Circuit configuration of SR generator excited by SRC.

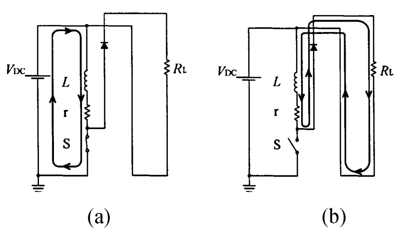

Fig. 5. Operation modes of SRC. (a) Exciting mode. (b) Generating mode.

The circuit of AHBC is somewhat complicated because AHBC needs two transistors and two diodes per phase. In order to reduce the number of the devices, an SRC was proposed.

Fig. 4 illustrates a circuit configuration of the SRC. Fig. 5 shows operation modes of SRC per phase. When the transistor S is on, the dc voltage is supplied to winding and the current flows as shown by the solid loop in Fig. 5(a). When the transistor S is off, the current flows through the freewheeling diode and the external load resistance R_L as shown in Fig. 5(b).

Fig. 6 shows the experimental setup of the AHBC circuit, and Fig. 7 shows that of the SRC circuit. The SRC consists of half number of switching devices for AHBC. The same MOSFET (2SK3132) and power diode (RM25HG) were used for both converters.

Fig. 8 shows a general view of the experimental system of the SR generator. The SR generator is driven by an ac servo motor with a maximum rotation of 4500 r/min. The angle of the rotor is detected by the optical rotary encoder. Gate drive signals of exciting circuits are generated by FPGA.

Fig. 9 shows the typical phase voltage and current waveforms observed in the SR generator with SRC. When the transistor is off, the polarity of the voltage reverses to negative value. This means that the power is supplied to the load resistance. The waveforms of the SR generator with AHBC are almost same.

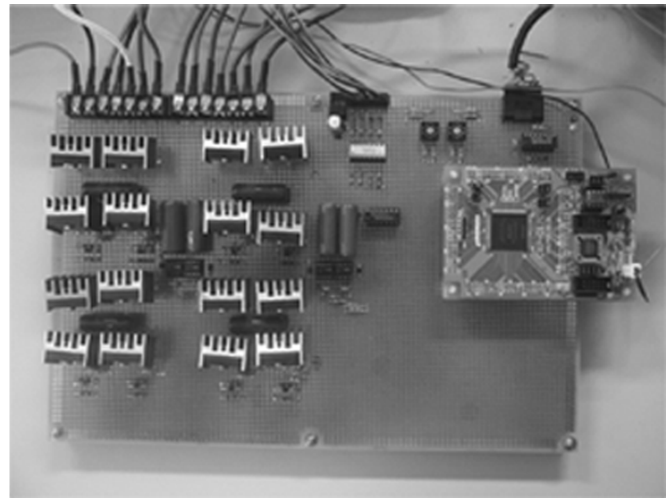

Fig. 6. Experimental setup of the AHBC circuit.

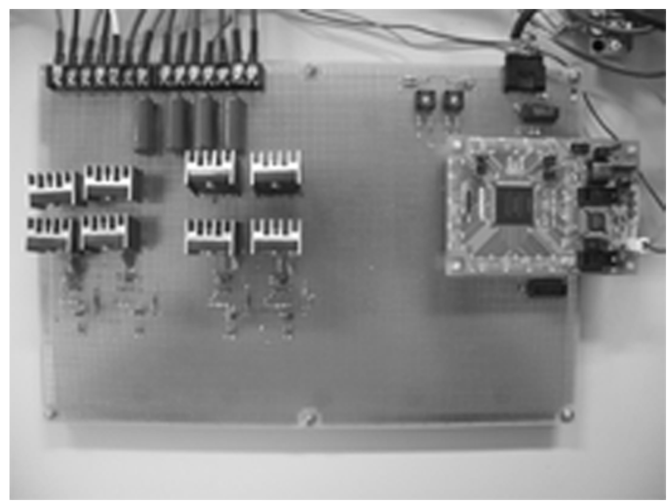

Fig. 7. Experimental setup of the SRC circuit.

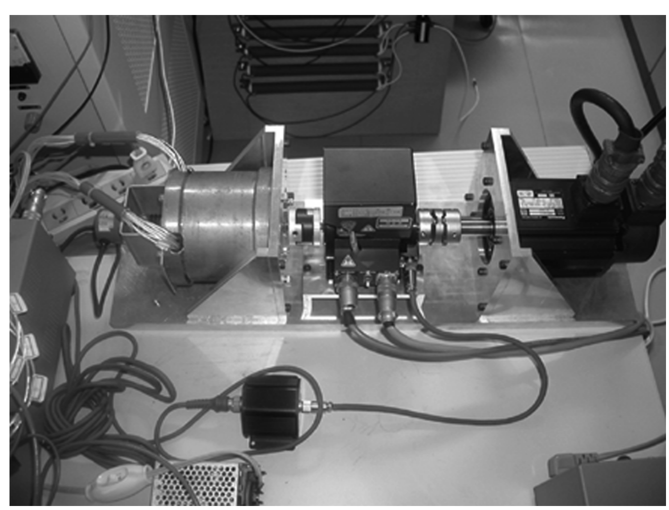

Fig. 8. Experimental system.

III. Characteristics of Trial SR Generator

Fig. 10 shows the calculated relationships between the power generation characteristics and the exciting dc voltage.

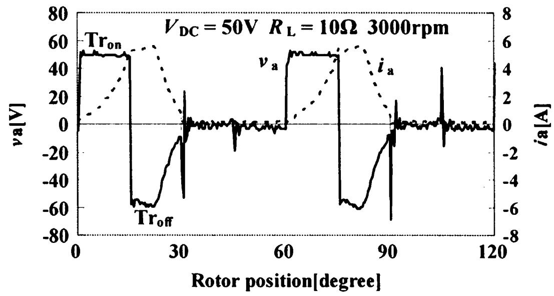

Fig. 9. Observed waveforms of voltage and current of Phase-A when the dc voltage is 50 V, load resistance is 10 Ω, and the rotational speed is 3000 r/min.

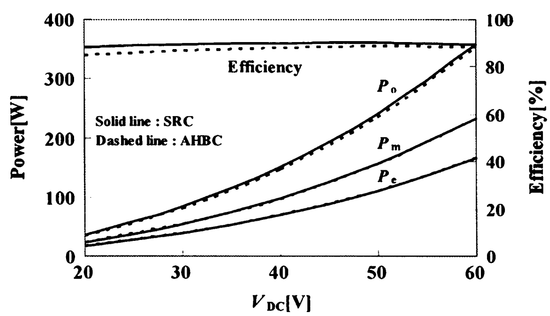

Fig. 10. Calculated relationships between the exciting voltage and output when the load resistance is 10 Ω and the rotational speed is 3000 r/min.

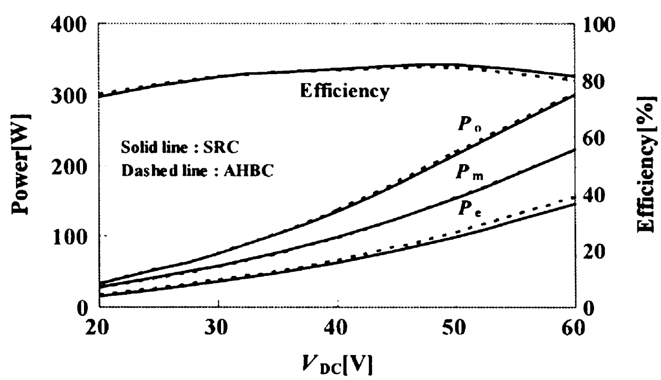

Fig. 11. Measured relationships between the exciting voltage and output when the load resistance is 10 Ω and the rotational speed is 3000 r/min.

Here, we utilize a general purpose FEM analysis program "Maxwell-2D" for the magnetic field analysis. The rotational speed is 3000 r/min and the load resistance is 10 Ω. The solid curves show the calculated values obtained in the SR generator with SRC and the dashed curves show that with AHBC. In the figure, P_m, P_e, and P_o are the mechanical input power, the electric excitation power, and output power, respectively. The efficiency is calculated by the following equation:

$$\eta = \frac{P_o}{P_e + P_m} \times 100 \quad [\%]. \tag{2}$$

Fig. 11 shows the measured relationships between the power generation characteristics and the exciting dc voltage. The rotational speed and the load resistance are same as in Fig. 10. Figs. 10 and 11 reveal that the calculated results agree well with

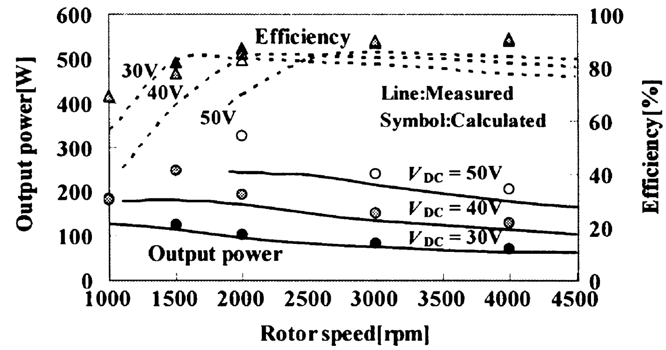

Fig. 12. Variations of the output power and efficiency with the rotational speed for various value of the dc voltage.

the experimental ones except for some differences arise from neglecting the iron loss and mechanical loss in the calculations. It found that the operating characteristics are almost same in SRC and AHBC circuit.

Fig. 12 shows the variations of the output power and efficiency with the rotational speed for various values of the dc excitation voltage. The solid curves show the output power and the dashed curves the efficiency. The symbols show the calculated values. The figure reveals that the efficiency of the trial 8/6 SR generator is about 80% in the wide region of the rotational speed. The calculated output power agrees well with the experimental ones.

IV. Conclusion

The operating characteristics of the SR generator with SRC and AHBC were discussed based on the FEM analysis and experiments. The power generation characteristics of the SR generator with SRC are almost same as with AHBC. The SRC circuit has half of the power devices as AHBC and has common ground of gate circuits for the power transistors. This means that the circuit configuration of the SRC is more simple, reliable, and low cost including the gate circuit. The trial 8/6 SR generator has a good efficiency of about 80% over a wide range of the rotational speed. It is expected that the application of the SR generator to a high-speed generator such as the microgas turbine. Furthermore, a multipolar SR generator is also interesting for the low-speed generator such as the wind turbine generator.

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