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Analysis of Converter Circuits for Switched Reluctance Generator in Wind Energy Conversion Systems

E. Annie Elisabeth Jebaseeli, D. Susitra and P. Abirami*

Faculty of Electrical and Electronics Engineering, Sathyabama University, Chennai - 600119, Tamil Nadu, India; anniejebaseeli@gmail.com, susitradhanraj@gmail.com, abiram_80@yahoo.in

Abstract

Wind generation is one of the renewable energy power sources that constitute a remedy for greenhouse gas emission treatments. Conventionally various types of wind energy generators such as Induction Generators or Synchronous Generators have been used as wind Generators. The shortcomings of these conventionally used Generators like complex in structure and limited rotor converter rating have turned research attention to more simple and robust variable speed Generator topologies such as Switched Reluctance Generator (SRG). Investigations have proved that this technology is promising due to the new recent advances in the field of variable speed drives. In this research paper, the operation of split DC Power converter required for SRG with even number of phases is discussed along with the operation modes. Then the converter circuit is simulated and the results are presented to gain knowledge about the characteristics of this converter.

Keywords: Converter, Renewable Sources of Energy, Switched Reluctance Generator, Wind Energy Conversion Systems

1. Introduction

In the last decades, the Switched Reluctance Machine has been used in various applications in industrial and domestic markets. It has good mechanical reliability, high torque – volume ratio, high efficiency and low cost. The machine is most appropriate for high speed operation and harsh environments due to its robust structure that this machine does not contain windings and permanent magnets. In addition both the machine and the power converter are robust. The low inertia of the rotor allows the machine to respond to rapid variations in the load[1]. The SRMachine can act as a SRG when the phase windings are excited during the period of falling inductance[2,3] i.e. by proper synchronization of each phase current with rotor position (after alignment). The SRG is under development for variable speed applications where the inherent characteristic of the SRG makes commercial sense in sourcing aerospace power systems[4,5], starter / alternators for hybrid vehicles, ultra high speed generators such as a micro gas turbine Generator and wind turbine applications[6,7] etc. Recent researches have proved that the SRG is able to efficiently generate electricity by wind power even in a low wind speed[8–11].

In this paper, the equivalent circuit of SRG is dealt in section II and the performance of split DC converter with the simulation circuit is discussed in section III and IV. Finally the simulation results are presented in section V and concluded in section VI.

2. Equivalent Circuit of SRG

Once the stator winding is energized, flux linkage is created relating to the injected current in the stator winding. Neglecting the mutual inductance between the phases in SRM, an elementary equivalent circuit can be derived as shown in Figure 1. Generally the flux linkage varies as a function of rotor position and phase current. Hence the expression for voltage per phase can be written as given in equation 1 as:

$$V = R_s i + \frac{d\lambda(\theta, i)}{dt} \qquad (1)$$

*Author for correspondence

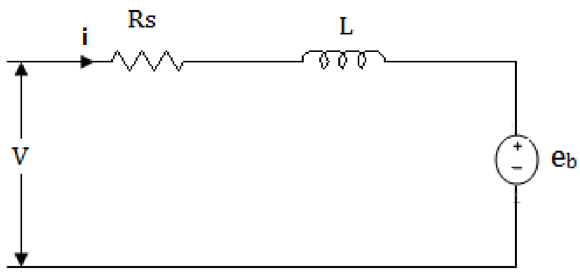

Figure 1. Single phase equivalent circuit of the SRG.

Where vis the voltage across the phase, R_s is the resistance per phase, i is the injected current. Here λ is the flux linkages per phase which is given as:

$$\lambda = L(\theta, i)^{*} I \tag{2}$$

Where L is the inductance of the winding which in turn depends on the rotor position and phase current? Hence the voltage equation can be rewritten as:

$$V = R_s i + \frac{d(L(\theta,i)}{dt} i \tag{3}$$

$$= R_s i + L(\theta, i)\frac{di}{dt} + i\frac{d\theta}{dt}\frac{dL(\theta,i)}{d\theta} \tag{4}$$

$$= R_s i + L(\theta, i)\frac{di}{dt} + \frac{dL(\theta,i)}{d\theta}\omega_m I \tag{5}$$

Where ω_m is the angular velocity. In the above equation, the terms on the right hand side of the equation represent the voltage drop in the resistance, the voltage drop in the inductance and the back emf. Here Back emf is the function of phase current, machine speed and phase inductance profile[12].

Now the equation for back emf can be written as:

$$E_b = \frac{dL(\theta,i)}{d\theta}\omega_m i = K_b \omega_m I \tag{6}$$

Where K_b is the emf constant. Considering the generating mode, the machine is operated during the decreasing inductance making $\frac{dL(\theta,i)}{d\theta}$ as negative. Hence the back emf aids the increase of current[13] during the generating mode.

3. Split DC Converter

The switched reluctance motor cannot be fed from the direct AC or DC supply. In order to control the current through the phase windings in response to the feedback obtained from the rotot position sensor, a converter circuit is required. The selection of suitable converter and control scheme for a specific application depends on the performance requirements, configuration of SRM and cost etc. There are various configurations of converters used in SRM drives. One of the converter suitable for the operation of 8 / 6 SRM is the split DC supply converter since it has even number of phases[14]. Figure 2 represents the circuit diagram of a split DC supply converter.

This converter consists of two capacitors C_1 and $C_2$for splitting the given input DC supply. In order to energize or deenergise the phase windings, four MOSFETS are used along with the phase windings. The main advantage of this converter is it has only one switch per phase and four diodes are used for regenerative action. The Phase windings A, B, C and D are connected with the switches and diodes in such a way to provide the freewheeling and regeneration action. Due to this, the capability of regenerating the stored energy is increased in this converter. Also two phases are energized simultaneously to increase the torque production in order to minimize the torque ripple.

3.1 Modes of Operation

3.1.1 Mode 1

Figure 3 shows the operation of the split dc converter in energizing mode namely mode1.When the switch S1 is

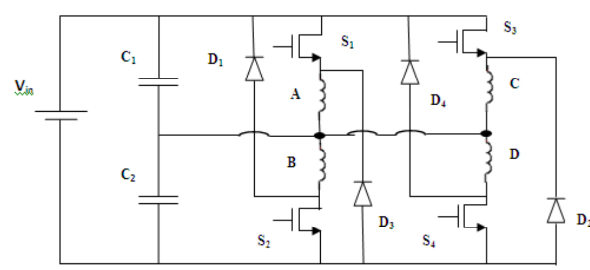

Figure 2. Split DC Converter.

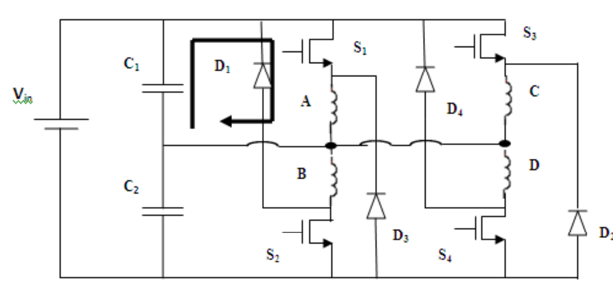

Figure 3. Split DC converter with s1 on.

on, Coil A gets magnetized and the path for the circulating current is through S1, Coil A and C1. So the coil gets energized in this mode.

3.1.2 Mode 2

Figure 4 shows the mode 2 operation of the split dc converter. When the Switch S1 is turned off, energy stored in the coil A gets demagnetized through C2, D3 and coil A. During this time the capacitor C2 gets charged until it attains half of the input voltage value (i.e., Vin/2).

4. Simulation Circuit

Figure 5 shows the simulation circuit of split dc converter. The input is a DC voltage of 72 volts. Also it consists of the split capacitors, each gets charged to half of the input supply voltage (i.e., Vin/2). The four MOSFETs are used as switches to control the flow of current through the winding. The coils A, B, C and D are connected to obtain the freewheeling and regeneration actions of the system. The pulse generators are used to give input pulses to the MOSFETs. The voltmeters and ammeters are used to measure the voltage and current flowing through each coil.

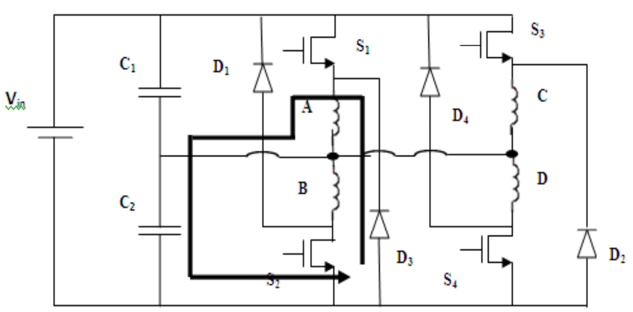

Figure 4. Split DC Converter with s1 off.

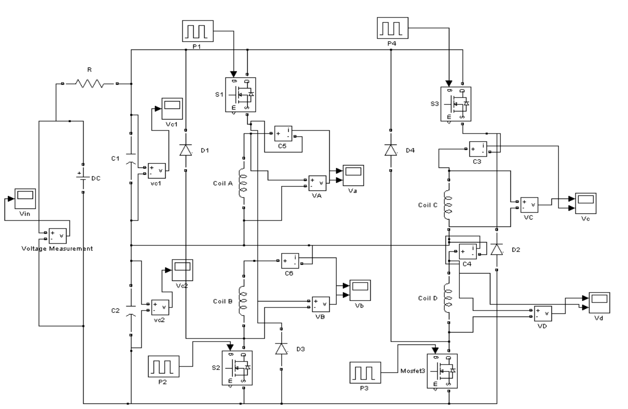

Figure 5. Simulation circuit of split DC converter.

Figure 6 shows the input voltage to the split DC converter. The voltage applied is of 72V.

5. Simulation Results

Figure 6 shows the input voltage for the split converter whose magnitude is 72V. Figure 7 shows the voltage across the capacitor 1 (C1) which is charged to a value equal to half of the input voltage when the switches are turned on. Figure 8 shows the voltage across the capacitor 2 (C2) which is also charged to a value equal to half of the input voltage.

Figure 9 shows the output voltage and current across the Coil A. The voltage across the coil is observed as 36V. From this it can be inferred that the input applied voltage is divided across the coils connected in the circuit. Since the power required is reduced, this results in saving of power.

Figure 10 shows the voltage across MOSFET and Diode. From this it is observed that during the ON time of

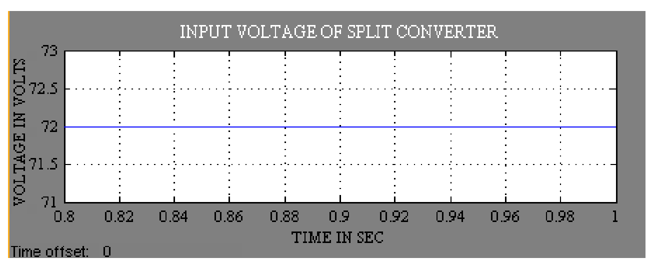

Figure 6. Input Voltage of split DC converter.

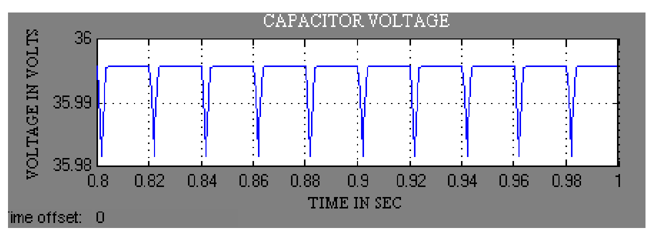

Figure 7. Voltage across the capacitor C1.

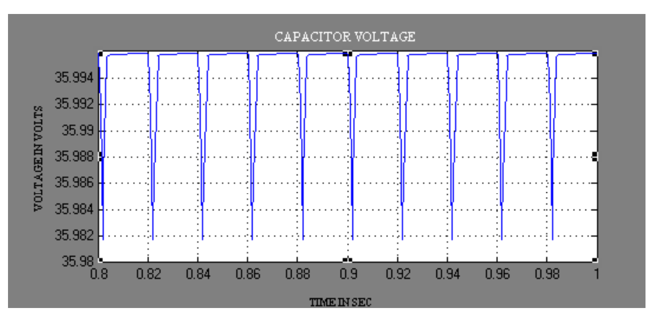

Figure 8. Voltage across the capacitor C2.

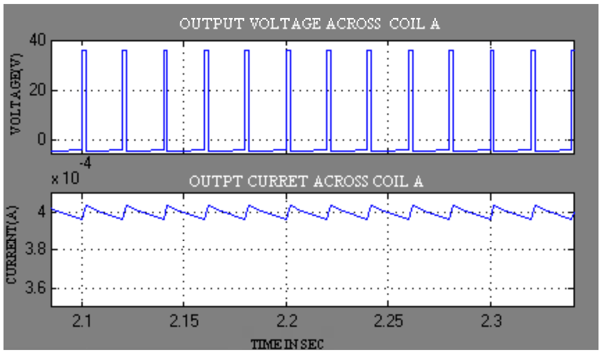

Figure 9. Output voltage and current across Coil A.

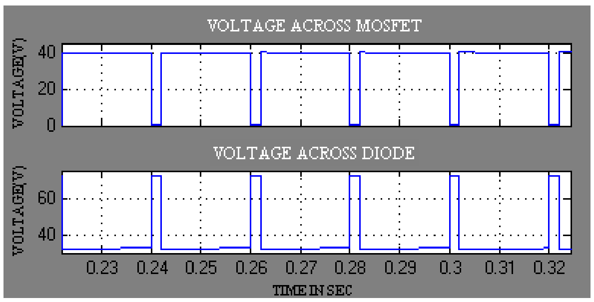

Figure 10. Voltage across MOSFET and Diode.

MOSFET, the diode is in off position. Thus the **MOSFET** and diode combination in this converter activates the freewheeling and regeneration modes. Since the voltage across the switch is nearly equal to $V_{dc}/2$, the voltage stress on the switch is reduced[15].

6. Conclusion

The split DC converter which has been used in fractional horse power applications with even number of phases is discussed and simulated. Since this converter requires only one power switch and diode per phase, this feature makes the drive more economical and compact. Hence it is recommended for low cost applications. Also the phases of winding are independent which results in uninterrupted operation of drive even in the case of fault in any one of the winding. This makes the SRM drives superior than other ac motor drives.

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