Design and Analysis of a Novel Grid-Connected to Rotor Type Doubly Fed Induction Machine

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Abstract — This paper proposes a novel grid-connected to rotor type doubly fed induction machine (DFIM) in which the rotor winding is connected to the grid instead of the stator winding. The stator size and weight of the proposed grid-connected to rotor type DFIM can be reduced because the proposed type can use rotor core more efficiently compared to the stator type DFIM. In order to verify the size and weight reduction of the proposed type, the loading distribution method (LDM) is utilized. As a design result, the stator outer diameter and weight of the proposed type were decreased. The FEM analysis was also performed to verify the design results and to analyze the characteristics of the novel DFIM.

I. INTRODUCTION

Doubly fed induction machines (DFIMs) have been widely used for pumps, fans, flywheel, and wind turbine systems due to variable speed operation, adjustable stator power factor, and small size converter [1]-[3]. The stator winding of a conventional grid-connected to stator type DFIM is directly connected to the power grid while the rotor winding of that is connected to adjustable inverter. To design the conventional grid-connected to stator type DFIM, traditional design methods are utilized such as the D^2L method or the loading distribution method (LDM) and called the shear stress method [4]. The demerits of the design process for a grid-connected to stator type DFIM is its ineffective rotor design which concentrates on the maximizing the inner diameter of the stator to optimize torque production, i.e. D^2L. Because the stator is designed in advance, and the outer diameter of the rotor is essentially determined automatically.

This paper proposes a novel grid-connected to rotor type DFIM wherein the rotor winding is connected to the power grid instead of the stator winding. The stator size and weight of the proposed grid-connected to rotor type DFIM can be reduced because the proposed type can use the rotor core more efficiently compared to the conventional grid-connected to the stator type DFIM which cannot well utilize rotor core as a portion of the flux path. To design the grid-connected to rotor type DFIM, a novel design process is also proposed, which can design rotor portion in advance.

II. DESIGN OF A GRID-CONNECTED TO ROTOR TYPE DFIM

A. Concept of a grid-connected to rotor type DFIM

The stator winding of the conventional grid-connected to rotor type DFIM is directly connected to the grid while the rotor winding is connected to back-to-back AC/DC/AC converters as shown in Fig. 1(a). However, the stator winding and the rotor winding of a proposed grid-connected to rotor type DFIM are connected to converter and grid, respectively, as shown in Fig. 1(b).

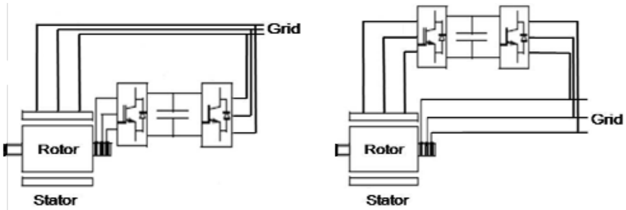
B. Design process using Loading Distribution Method

LDM is a method to design electric machine. The capacity per pole of an electric machine can be described, as in (1) [4]. Therefore, an electric machine can be designed using the electric loading and magnetic loading under a given condition such as the output power, efficiency, and power factor.

$$T_e = \left(\frac{p}{2}\right)(D^2L)K_sB_g\eta\cos\theta \qquad (1)$$

where, T_e is the torque, p is the number of poles, K_s is the rms electric loading (A/m), B_g is the rms magnetic loading (T), η is the efficiency at the gap, and $\cos\theta$ is the power factor at the gap.

The outer diameter of rotor of the conventional grid-connected to stator type DFIM is decided after determination of the stator parameters [4]. Therefore, the rotor size is unnecessarily large and the rotor core around shaft cannot be sufficiently utilized. However, the rotor parameters of the proposed grid-connected to rotor type DFIM can be determined prior to the determination of the stator parameters using the proposed design process as shown in Fig. 2. Therefore, the stator size and weight can be reduced because the rotor can be designed efficiently.



(a) Grid-connected to stator type (b) Grid-connected to rotor type

Fig. 1 Schematic diagram of DFIM

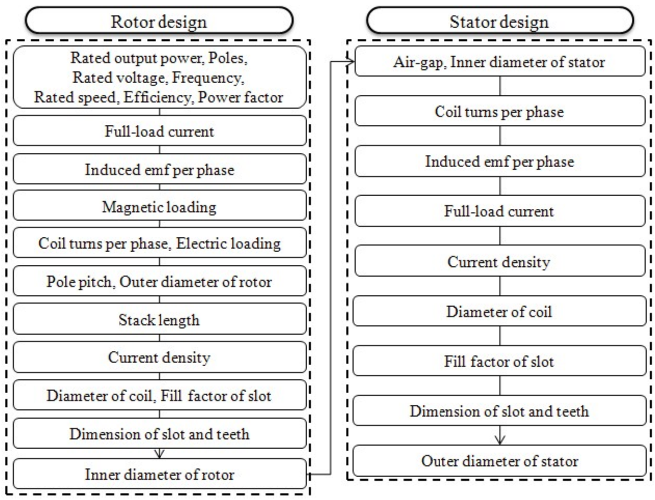


Fig. 2 Design process of a grid-connected to rotor type DFIM using LDM

TABLE I DESIGN RESULTS OF DFIM USING LDM

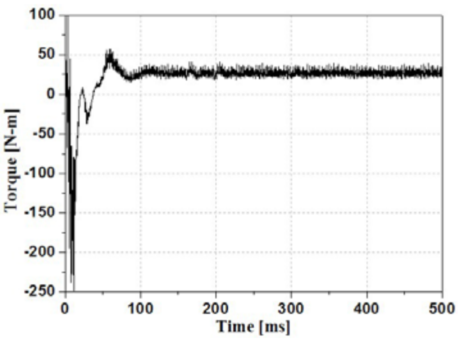
Items		Unit	Grid-connected to stator type	Grid-connected to rotor type
Objective Specifications	Output power	kW	5	
	Rated voltage	V	220	
	Frequency	Hz	60	
	Rated speed	rpm	1,800	
	Efficiency	%	92	
	Power factor	-	0.84	
Stator	Outer diameter	mm	222	197
	Inner diameter	mm	136	136.6
Rotor	Outer diameter	mm	135.4	136
	Inner diameter	mm	75	54
Stack length		mm	116	
Total weight		kg	30.08	25.82

C. Design results

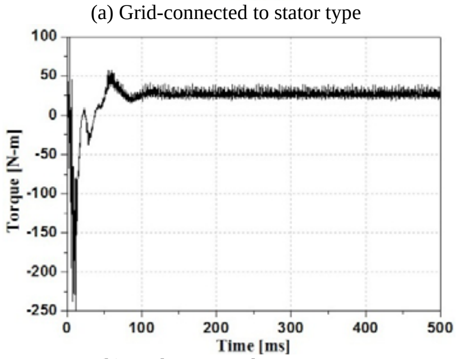
The objective specifications and design results of DFIM using LDM are shown in TABLE I. As a design result, the outer diameter of the stator and weight of the grid-connected to rotor type DFIM can be decreased by 11.3 % and 14.1 %, respectively, compared with the grid-connected to the stator type.

III. CHARACTERISTIC ANALYSIS

To analyze characteristics of the designed DFIMs, the FEM analysis has been utilized. The average torque and the rotor speed of DFIMs are almost identical when the input voltage and frequency to the stator winding are 220 V and 60 Hz, as shown in Fig. 3 and Fig. 4. Therefore, the mechanical output power of DFIMs is also very similar.



(a) Grid-connected to stator type



(b) Grid-connected to rotor type

Fig. 3 Torque characteristics of DFIM using FEM

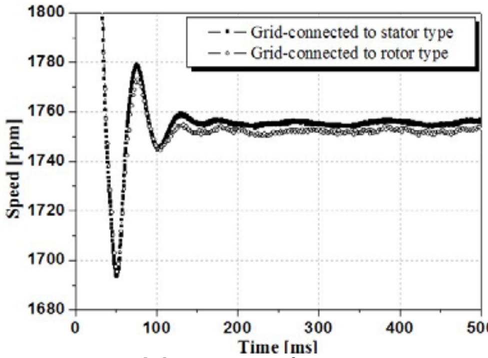


Fig. 4 Speed characteristics of DFIM using FEM

TABLE II ANALYSIS RESULTS OF DFIM USING FEM

Items	Unit	Grid-connected to stator type	Grid-connected to rotor type
Torque	N-m	26.5386	26.5325
Speed	rpm	1755.28	1751.97
Mech. output power	W	4878.13	4867.82
Copper loss	W	286.51	277.39
Core loss	W	109.54	90.11
Total loss	W	396.05	367.50
Elec. input power	W	5274.14	5235.31
Efficiency	%	92.49	92.98

Table II showed that the efficiency of the grid-connected to rotor type DFIM is actually higher 0.5 % than the grid-connected to stator type because of the lower copper loss and core loss.

IV. CONCLUSION

This paper has proposed a concept and a design process for a grid-connected to rotor type DFIM which can reduce the outer diameter and weight compared to conventional designs. In order to compare the conventional grid-connected to stator type and the proposed grid-connected to rotor type, each DFIM was designed using LDM. Design results showed that the outer diameter and weight of the proposed type DFIM were decreased compared with the conventional type. The characteristic analysis using the FEM analysis confirmed the design results. From these results, the proposed grid-connected to rotor type DFIM showed the usefulness of the reduction of the size, weight and material cost compared with the conventional grid-connected to stator type.

V. REFERENCES

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