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Analysis of Characteristics of Permanent Magnet Synchronous Machines with Novel Topology of Fractional-Slot Concentrated Winding

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Linwei Hu, Kai Yang*, Songjun Sun, Wenyi Yu, Yuanbo Ding

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronics Engineering, Huazhong University of Science and Technology, China

Paper Overview

➢ *Fractional-Slot Concentrated Winding(FSCW)*

- A type of winding topology which is featured for its short end winding, high torque density, lower copper loss and so on, but it is also characterized by a large content of space MMF harmonics which cause undesirable results.

➢ *Slot Phase Diagram*

- A table that is decided only by the slot and pole numbers of the machine. It is like turning the spokes of the star of slot map into slot numbers in the slot phase diagram. And it is the fundamental basis to design winding system which help to design a new topology of FSCW

➢ *Slot Vectors Superposition Method*

- The MMF produced by one coil side can be expressed as the sum of v pole-pair sine waves(v=1,2…∞), which is the fundamental basis for slot vectors superposition method. For v pole-pair spatial MMF harmonics, we firstly get the sum of the MMF produced by one Phase with phasor method, then we can calculated the winding factor for the total v pole-pair harmonic.

Slot Phase Diagram

➢*Slot Phase Diagram for 10-pole,12-slot combination*

Table.1 Slot phase diagram of Spp=2/5 combinations for conventional FSCW

		Spp=2/5; 10-pole, 12-slot;Three phase; 360 degree											
		Phase A		-C		Phase B		-A		Phase C		-B	
phase	12	1	2	3	4	5	6	7	8	9	10	11	12
Slot number		1	6	11	4	9	2	7	12	5	10	3	8
		-7	-12	-5	-10	-3	-8	-1	-6	-11	-4	-9	-2
		8	1	6	11	4	9	2	7	12	5	10	3
		-2	-7	-12	-5	-10	-3	-8	-1	-6	-11	-4	-9

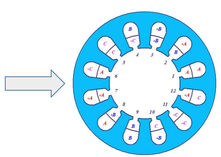
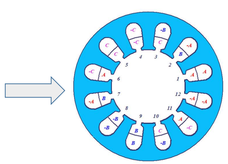


Table.2 Slot phase diagram of Spp=2/5 combinations for proposed FSCW

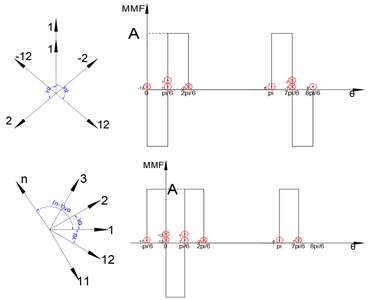
		Spp=2/5; 10-pole, 12-slot; Three phase; 360 degree											
		Phase A		-C		Phase B		-A		Phase C		-B	
phase	12	1	2	3	4	5	6	7	8	9	10	11	12
Slot number		1	6	11	4	9	2	7	12	5	10	3	8
		-7	-12	-5	-10	-3	-8	-1	-6	-11	-4	-9	-2
		8	1	6	11	4	9	2	7	12	5	10	3
		-2	-7	-12	-5	-10	-3	-8	-1	-6	-11	-4	-9



Two different FSCW topologies for 10-pole, 12-slot combination

- For design of three-Phase winding system, each axis of one Phase share the spatial angle difference of 120deg.
- For double layer winding, two same slot numbers(ignore the sign) will be chosen to make up the winding.

Slot Vectors Superposition Method



$$k_{wv} = \frac{2+(-2\cos v\alpha)}{4}$$, v is odd.

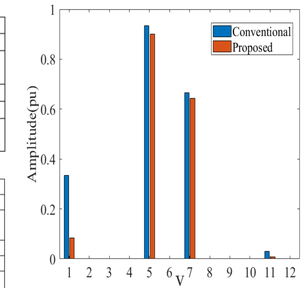
$$k_{wv} = \frac{\sqrt{Im^2 + Re^2}}{8}$$, v is odd

Table.3 Winding factors for conventional FSCW

v	1	2	3	4	5	6
k_{wv}	0.067	0	0.500	0	0.933	1.000
Rotating Direction	BWD	-	-	-	FWD	-
v	7	8	9	10	11	12
k_{wv}	0.933	0	0.500	0	0.067	0
Rotating Direction	BWD	-	-	-	FWD	-

Table.4 Winding factors for proposed FSCW

v	1	2	3	4	5	6
k_{wv}	0.017	0	0.354	0	0.901	0.500
Rotating Direction	BWD	-	-	-	FWD	-
v	7	8	9	10	11	12
k_{wv}	0.901	0	0.354	0	0.017	0
Rotating Direction	BWD	-	-	-	FWD	-



2D FEA Method

A 7.5 KW PMSM is taken for finite element analysis and two different winding arrangements are applied for the machine.

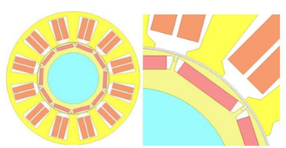
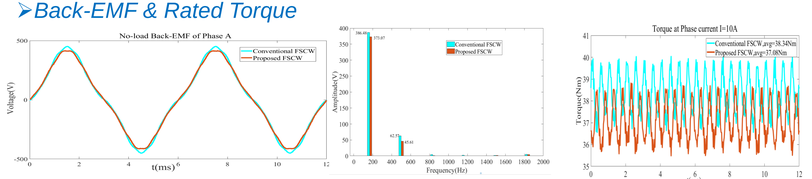


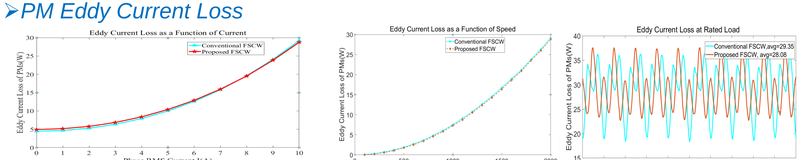
Table.5 PMSM parameters

Rated power	7.5kw	Rated speed	2000rpm
Stator outer diameter	239mm	Stator inner diameter	130mm
Rotor outer diameter	128mm	PM type	N35
PM height	6mm	PM width	30mm

➢*Back-EMF & Rated Torque*



➢*PM Eddy Current Loss*



COUCLUSION

- Slot phase diagram is proposed to design winding system and a new FSCW topology is obtained by this way.
- Slot vectors superposition method along with complex number method is applied to calculate the winding factors for each MMF harmonic.
- 2D FEA is applied to verify the performance of the PMSM.