Structural Design Methodology of BLDC Motor Considering Response Time of Phase Current

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Background

The Brushless DC (BLDC) motor is getting more widely used in home appliances, vehicle and industry for its easy control method and low cost. For proper control of the BLDC motor, it is designed to have trapezoidal back-EMF waveform. Although, in low speed or low phase current, the instantaneous switching in phase current do not affect the performance of the motor, but as the rotating speed of BLDC motor rises, it is getting difficult for the phase current to response the instantaneous switching of the square wave. An the distortion of phase current affects the performance of the BLDC motor, such as torque ripple and efficiency.

Objectives

- Comparative analysis between two BLDC motor which designed in different design concept.
- Consider structural method of design BLDC motor which has instantaneous switching in phase current.

Conclusion

- Comparative analysis between initial design model which designed through traditional design process and improved model which designed considering response time of phase current has been conducted
- Initial Design BLDC model which designed through traditional design process shows higher current density and consequently lower efficiency in voltage source analysis compared with that of ideal current source analysis because of sudden rise in phase current whose component can not well contribute to output torque.
- Redesign is conducted to improve the performance of motor through changing pole / slot combination, magnet thickness.
- Improved design BLDC model shows identical performance both in ideal current source and six-step voltage source analysis because sudden rise in phase current is reduced.

Theory

Operating Principle of Δ-winding BLDC Motor

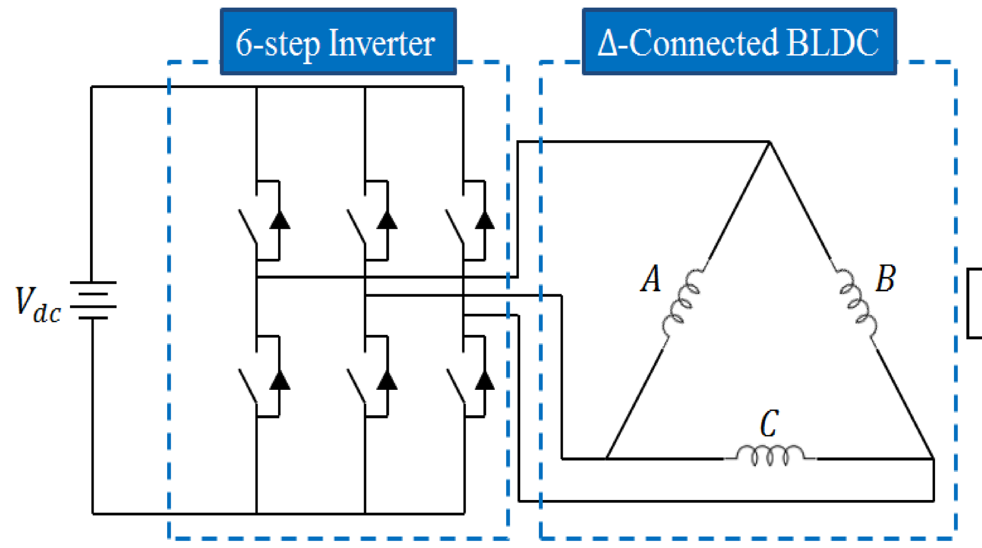


Fig. 1 Equivalent Circuit of Δ-winding BLDC motor

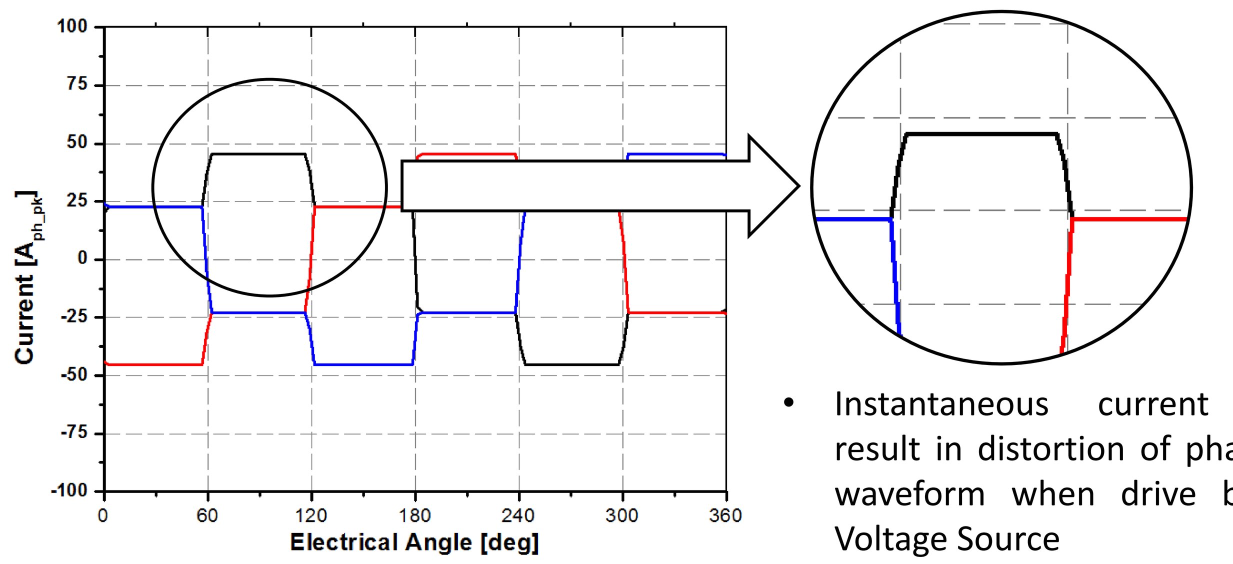


Fig. 2 Phase Current of Δ-winding BLDC motor with Ideal Current Source

- Instantaneous current switching result in distortion of phase current waveform when drive by Six-step Voltage Source
- Design considering response time of phase current is necessary

Design of ECF BLDC Motor

Traditional Design Process

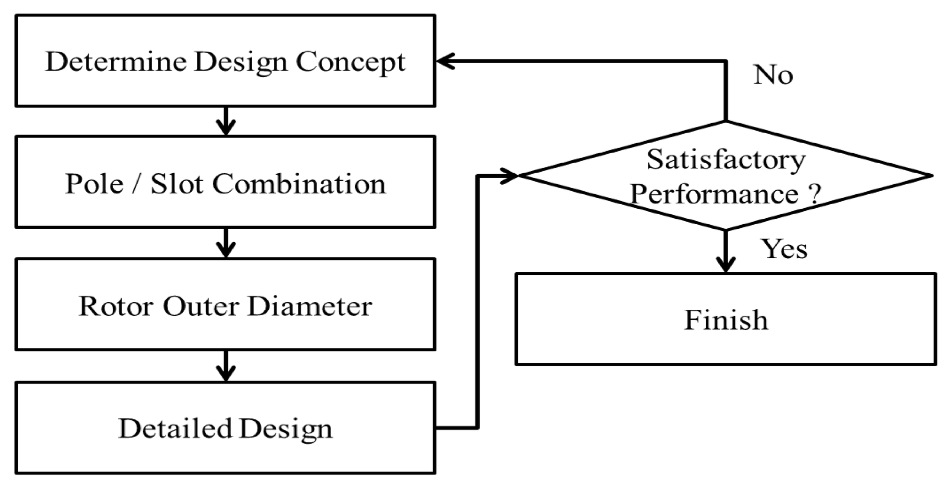


Fig. 3 Traditional Design Process

- Traditional Design Process does not consider response time of phase current
- Consequently result in high torque ripple and low efficiency etc.

Item	Performance & Specification
Rated Power [W]	510
Operating Point	1.6 Nm @ 3,100rpm
Operating Voltage [Vdc]	13
Max. Current [Adc]	50
Operating Temperature [℃]	-30 ~ 100
Stack Length [mm]	Under 15
Outer Diameter	140
Winding Pattern	Δ - winding

Results

Initial Design Model (Traditional Method)

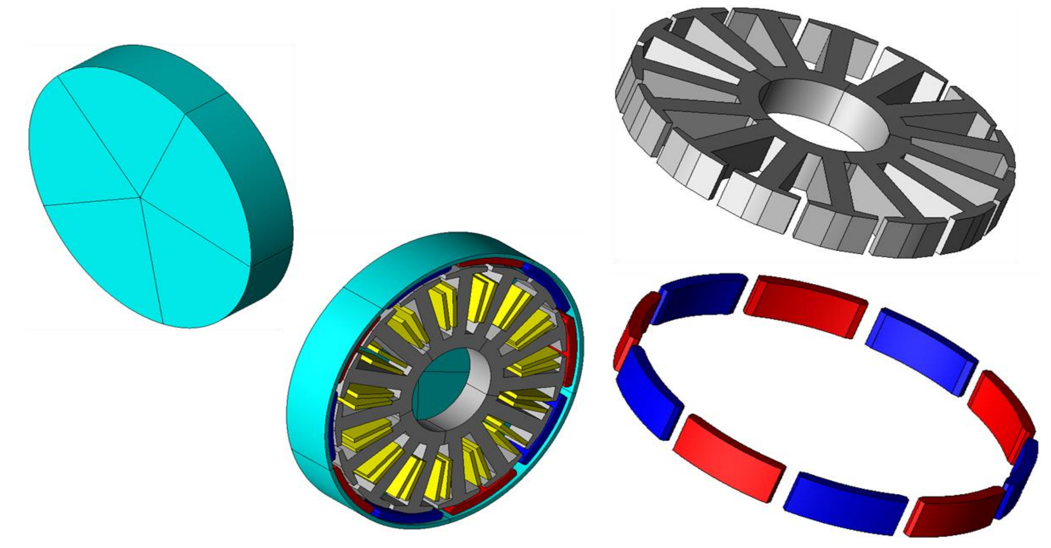


Fig. 4 Initial Design Model

Item	Current Source	Voltage Source
Current Density [A/mm2]	8.7	10.8
Phase Current [Aph_rms]	47.0	58.3
Average Torque [Nm]	1.58	1.58
Torque Ripple[%]	7.8	40.3
Efficiency [%]	68.2	65.6

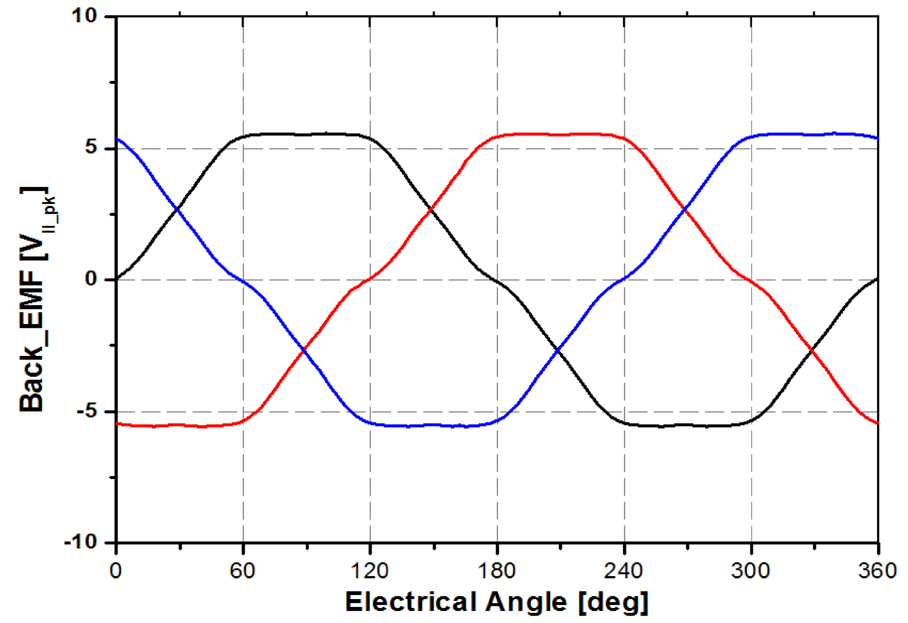


Fig. 5 No-load Back-EMF Waveform

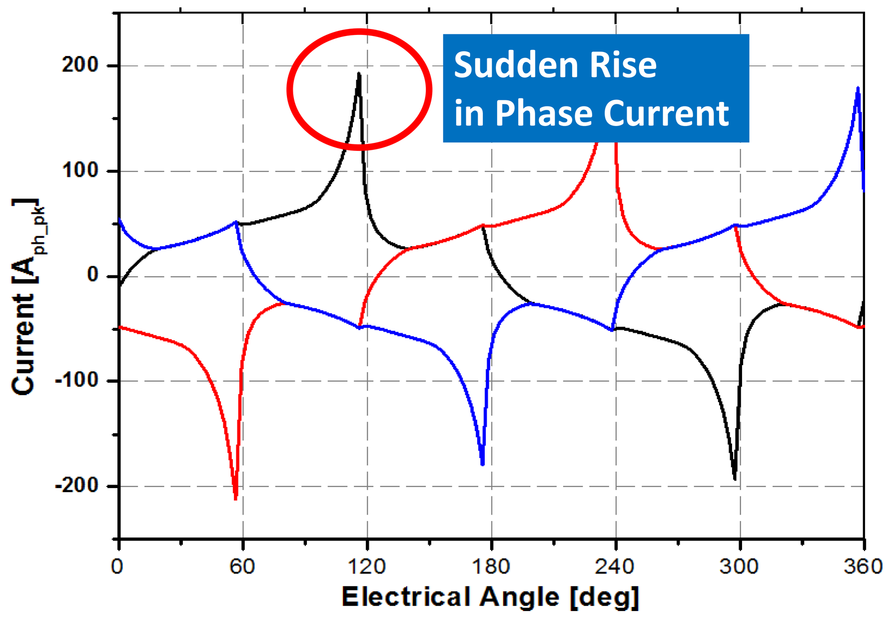


Fig. 6 Phase Current Waveform

- Theoretically the BLDC motor shows same output torque in both ideal current source and six-step voltage source, but the designed model shows different output torque in different input sources, because of the saturation characteristics of magnetic material, the sudden rising current does not contribute to the output torque entirely.
- So the motor which has step waveform current source like BLDC motor, it has to be design to have low time constant

Improved Design Model

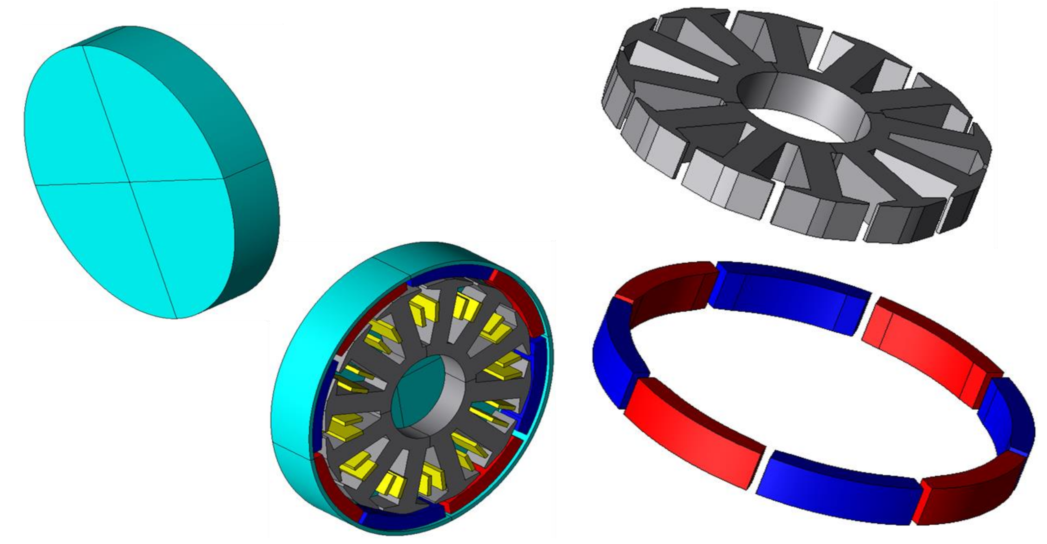
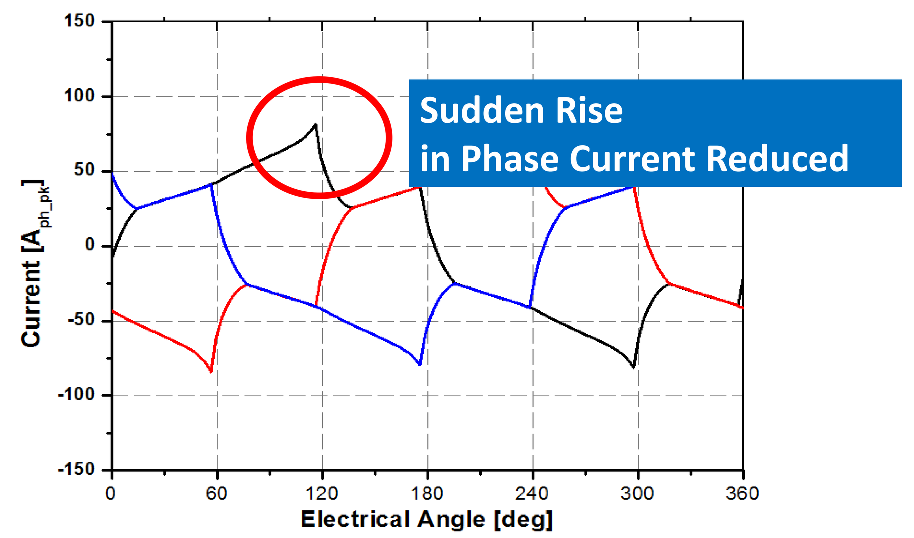


Fig. 7 Improved Design Model

Item	Current Source	Voltage Source
Current Density [A/mm2]	9.86	9.96
Phase Current [Aph_rms]	43.3	43.7
Average Torque [Nm]	1.58	1.58
Torque Ripple[%]	7.9	39.7
Efficiency [%]	68.8	75.0



- To decrease time constant of the motor, the improved model is designed to have thicker magnet and teeth width compared with initial model
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- The reduction in switching frequency leads to reduction of coreloss because the coreloss is proportional to n-th degree of switching frequency

Presented at the Applied Superconductivity Conference , 2012 Oct. 7 – 12, Portland, Oregon; Session: Nb-based Wires and Tapes II; Program I.D. number: 2MPQ-10