A Study on the Electromagnetic Field Characteristics of Two-Inverter System of Three-Phase Motor Assuming a Failure

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In order to consider the control stability and performance of the motor, it is required to analyze what kind of electromagnetic characteristics it has when the motor is faulty. Therefore, in order to secure the stability of the motor control, an analysis is performed to determine the electromagnetic characteristics of the motor in case of a defect. The number of inverter controllers generally used to control traction motors is one. However, in the case of a failure in the two-inverter system applied for the purpose of reducing the current burden of the controller when controlling the motor, finite element analysis is performed through simulation to analyze the change in the electromagnetic characteristics of the motor. As a result, it was found that there is no problem in the operation of the motor, but the current consumption must be increased due to the increase in torque ripple and phase voltage. At the base speed, it can be seen that the difference in back EMF between channels 1 and 2 is small, but in the field weakening region (high speed region), the torque ripple increases and the difference in back EMF between channels 1 and 2 is extremely large. The key point is that the method proposed in this paper not only reduces the current burden on the inverter during wiring, but also enables operation even when one inverter fails.

Keywords: Current Unbalanced, IPMSM, WFSM, Two-Inverter Control, Traction Motor, Fault Condition.

1. Introduction

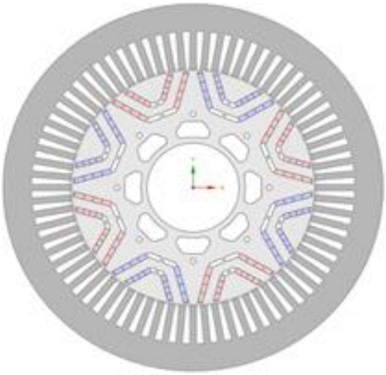
Electric motors, which are mainly designed for electric vehicles, are designed to have high torque and high power density characteristics. This is because the traction motor can be operated in a much wider operation area as the high torque and high power density are provided so that the miniaturization of the motor can be considered. Currently, internal permanent magnet synchronous motors and wound field synchronous motors are mainly used as traction motors. Unlike Surface Permanent Magnet Synchronous Motor, which generates only magnetic torque and requires q-axis current control, both types of motors use d-q-axis current control as a motor that generates magnetic torque and reluctance torque. It is possible to secure a wider operation area than the motors that mainly use other control methods in the constant output section, which is commonly referred to as the weak field region, through the d-q axis current control. However, in order to control the d-q axis current, it is necessary to consider not only the magnitude of the applied current but also the phase angle. Therefore, research on motor design and control techniques for the performance and control stability of the motor is underway. Therefore, in order to consider the control stability and performance of the motor, it is necessary to analyze the electromagnetic characteristics of the motor when it is defective. Thus, in order to secure the control stability of the motor, the analysis is carried out to determine the electromagnetic characteristics of the motor in case of defects. Typical failures that can occur in traction motors include short-circuit and mechanical bearing damage due to the corrosion of the bearing, static and dynamic eccentricity due to the eccentricity of the rotor or shaft of the motor, and synchronous escape due to the occurrence of axial current. The number of inverter controllers generally used for controlling traction motors is one.That being said, the electromagnetic properties of the motor are examined through the application of finite element analysis along with simulation in a two-inverter system, that is utilized to lower the current load on the controller when operating the motor.

Finite Element Analysis

In this paper, if the two-inverter system is used to ensure stability in motor control, it is confirmed through simulation analysis whether one inverter can be operated in case of failure. In addition, in the case of using the Two-Inverter System, which reduces the current burden by increasing the number of inverters, the effect on the output of the motor according to the control command value (size and phase angle) of the current inputted to each inverter is analyzed through simulation. IPMSM, which are mainly used for traction, were selected as the motors analyzed in this paper. This paper is written in the order of the specification of the analysis object, the introduction of the wiring method that separates the channels from the Two-Inverter System, the simulation method assuming that one inverter fails, and the simulation progress.

Analysis Model

A 240kW class 8-pole 72-slot IPMSM model is selected and analyzed. The shape of the motor is shown in Figure 1, and the basic specifications and characteristics are summarized in Table 1. The analytical model stands out because it uses d-q axis current control to produce a wide working range for a motor that has elevated torque needs. Significant current consumption is required, nevertheless, in order to obtain high torque.As a result, to display the linked analysis model, Figure 2 has Channel 1 connected to Inverter 1 and Channel 2 connected to Inverter 2.



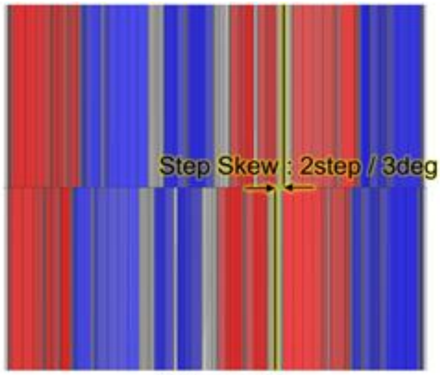


Fig. 1: Motor Shape of Analysis Model

Table 1: Basic Specifications

Parameter	Value	Units
Output Power	240	kW
Speed (Base / Max)	1,600 / 8,500	rpm
Poles / Slots	8 / 72	–
Stator Outer Diameter (SOD)	350	Φ
Rotor Outer Diameter (ROD)	224	Φ
Stack Length (L_{stk})	201	mm
Skew Step	2 (100.5mm per 1step)	step
Skew Angle	3.5	degree
Parallel number of windings	4	–
Reels number of windings	28	reels

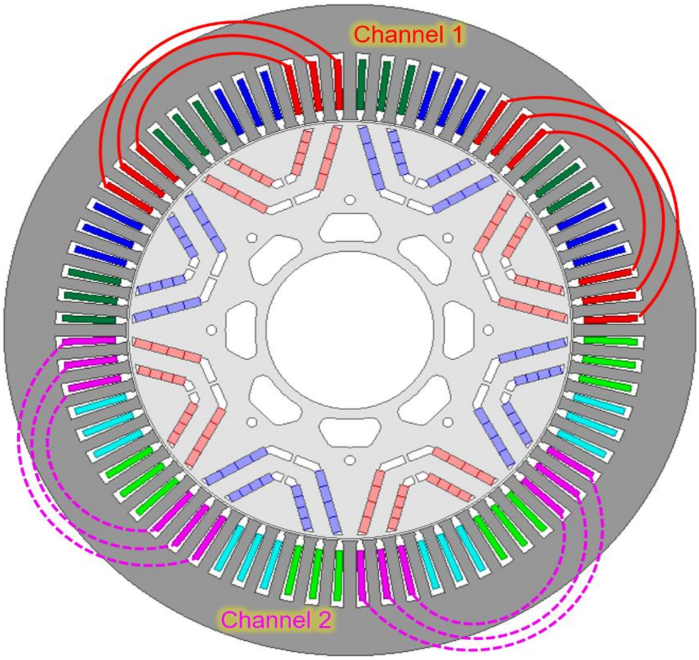


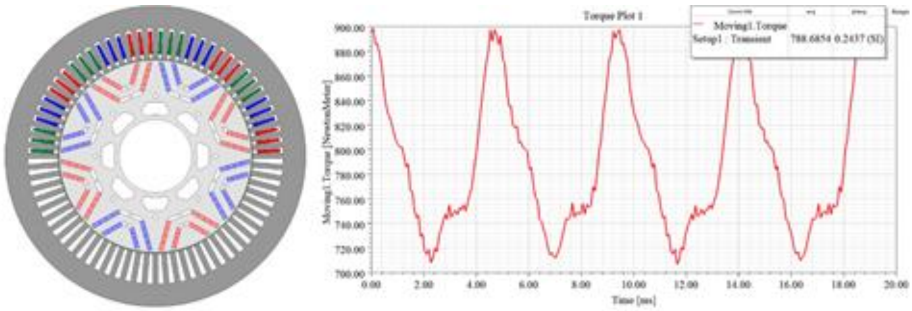
Fig. 2: 2D-FEM Shape of Analysis Model Wired by Channel

Analysis Method

As mentioned above, one inverter is generally used for controlling an existing drive motor. However, in this paper, it is mentioned that the control method using two inverters is considered to reduce the current consumption of the inverter because the traction motor requiring high output high torque requires high current. Therefore, in order to branch and connect the channel to each inverter even when the winding is connected to the motor, the Channel 1 of the winding is connected to the Inverter 1 and the Channel 2 of the winding is connected to the Inverter 2. In this way, the simulation is conducted assuming that one inverter fails after the connection, and the operation of the motor is analyzed even when one inverter fails. Assuming that there is a difference between the magnitude and phase angle of the current applied to each channel, and a difference between the magnitude and phase angle, the analysis is performed.

Analysis Process

First, in order to assume that one inverter fails, Channel 1 is normally wired, and Channel 2 is not wired and the simulation proceeds. Figure 3 shows the Analysis Model and torque of Channel 1 normally connected and Channel 2 unconnected.



(a) 2D-FEM Model in case of Channel 2 Failure (b) Motor Torque at Channel 2 Failure

Fig. 3: 2D-FEM Model and Torque at Channel2 Failure

The torque represents the result of the analysis at the Base Speed of 1,600 rpm, and 788.69 Nm, which is about 43.82% of the steady-state torque of 1800 Nm, was derived. Theoretically, 900 Nm, which is 50% of the existing torque, was expected, but the torque ripple and phase voltage increase caused the torque to decrease. Nevertheless, it can be shown that even in the case that Channel 2, or Inverter 2, fails, there is no problem with running the motor provided the wiring is completed using the present method. The characteristic comparison table, assuming both Channel 2 failure and normal conditions, is displayed in Table 2.

Table 2: Keywords in every network map cluster

Parameter	Normal Condition	Fault Condition	Units
Input Current	793		Arms
Current Angle	55		degree
Torque	1,801.33	788.69	Nm
Torque ripple	5.74	24.37	%
Voltage (Phase / Line to Line)	190.01 / 324.19	213.05 / 288.46	Vrms

In the previous analysis, in order to verify that actual operation is possible when one of the two channels fails, the analysis was conducted only at Base Speed, which is the maximum load point that requires the highest torque and maximum current consumption. Next, analysis is performed assuming a state in which the magnitude and phase of the current are unbalanced, and the magnitude and phase angle of the current are differently applied to Channel 1 and Channel 2 to proceed. Case 1 increases the current magnitude of Channel 1 by 10Arms to analyze the current unbalanced state, and Case 2 increases the current angle of Channel 1 by 5deg to analyze the current phase unbalanced state. Case 3 is examined by using every condition that came before it to examine the situation when the phase angle and magnitude are both out of balance. It is the same as the wiring method in Figure 2, and analyzes Cases 1, 2, and 3 in Base and Max Speed. Figure 4 shows the analysis results, comparing torque, torque ripple, and the difference in counter electromotive force between Channel 1 and 2.

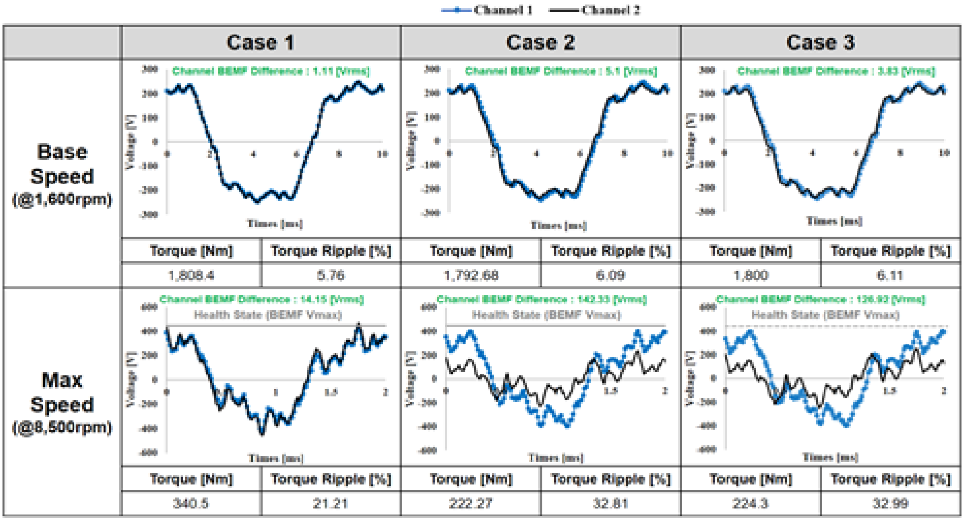


Fig. 4: Analysis results of Fault Condition Case Study

2. CONCLUSION

In this paper, analysis was conducted assuming the failure of the motor and inverter through simulation. A wiring method that makes it easy to operate the motor with one inverter to reduce the current burden and operate the motor even in case of failure is presented. In addition, through the progress of Cases 1, 2, and 3, it can be seen that the difference in Back EMF between Channels 1 and 2 is small at the base speed, which is the maximum load point, but the torque ripple increases in the field weakening region (high-speed region) requiring d-q axis control. It was found that the difference in counter electromotive force between Channels 1 and 2 was extremely large. This may be a natural result because the analysis was performed assuming a failure, but the key point is that the method proposed in this paper not only reduces the current burden on the inverter during wiring but also enables operation even when one inverter fails. Additional research will be carried out, and WFSM, which is widely used as a driving motor in the industry, and the hairpin winding method instead of the round copper method will be applied to determine whether wiring is possible with the same principle and to conduct research on what countermeasures are needed assuming a failure.

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