STATOR WINDINGS CURRENTS ANALYSIS OF THE IPM MACHINE UNDER SHORT-CIRCUIT CONDITIONS

Ladislav Knebl
Doctoral Degree Programme (1), FEEC BUT
E-mail: ladislav.knebl@vutbr.cz

Supervised by: Cestmir Ondrusek
E-mail: ondrusek@feec.vutbr.cz

Abstract: The development of the synchronous motors with permanent magnets is, mostly thanks to the legislation pressure to achieve the highest efficiency in electric drives, experiencing raising interest. Since the number of motors used in the industry is growing year by year, it is reasonable to investigate the motor behavior under faulty conditions, such as short-circuit conditions. This paper deals with the stator current analysis of interior permanent magnet synchronous motor under the short-circuit condition, both short-circuit in one phase and symmetrical three-phase short-circuit.

Keywords: short-circuit, interior permanent magnet, Maxwell, Simplorer, finite element analysis

1 INTRODUCTION

The synchronous machines can be divided according to the rotor excitation into non-excited, current-excited and permanent magnet (PM)-excited rotors. In this paper only motor with PM-excited rotor will be investigated. PM-excited synchronous rotors, can be also divided into 2 types: surface-mounted permanent magnet (SMPM) rotor and interior permanent magnet (IPM) rotor. Both types are depicted in Figure 1, where two types of IPM machines are shown namely IPM with V-shaped arrangement and permanent magnet assisted synchronous reluctance machine (PMASR) [1].

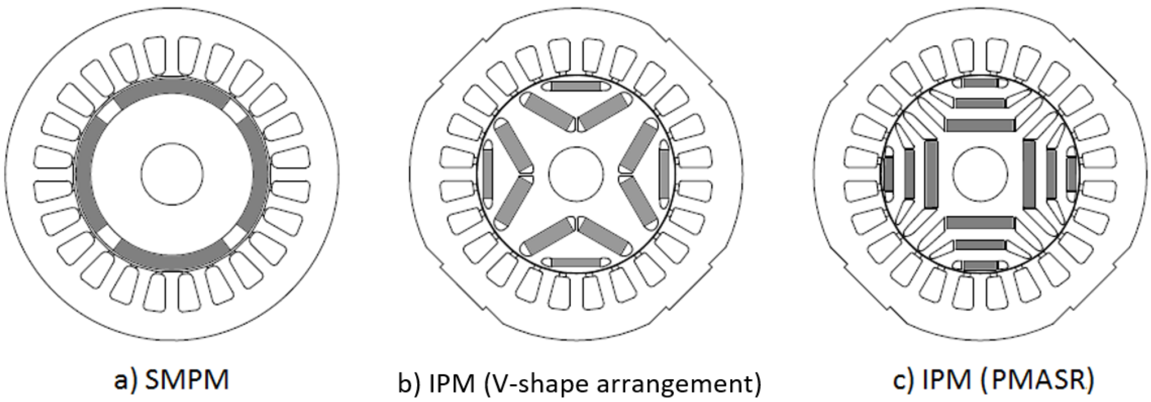

Figure 1: SMPM and IPM synchronous motors comparison (modified from [1]).

Both versions of PM-excited machines have their advantages and disadvantages and mostly depends on the application which type will be used.

2 TESTED MACHINE

Investigated machine will be four-pole three-phase Y-connected IPM machine with permanent magnets in V-shaped arrangement similar to the Figure 1 b). Key parameters of the machine are listed in Table 1 below.

Parameter	Symbol	Value
Rated output torque	T_N	34.4 Nm
Rated line-to-line voltage	U_S	400 V
Nominal power factor	PF	0.87
Rated speed	n	1500 min^{-1}
Stator outer diameter	D_{out}	200 mm
Stack length	L_{stk}	120 mm
Number of slots/poles	Q_s/2p	24/4

Table 1: Key parameters of the tested machine

Ansys software was used for the finite element analysis (FEA) calculations. Ansys is complex engineering simulation software combining various mechanical, thermal and electromagnetic (EM) tools. These tools can be in Ansys combined e.g. motor EM design combined with mechanical analysis. Combination of two electromagnetic tools will be used in this paper i.e. dynamic analysis in Simplorer with FEA analysis in Maxwell 2D. Tested IPM machine geometry and FEA mesh are depicted in Figure 2.

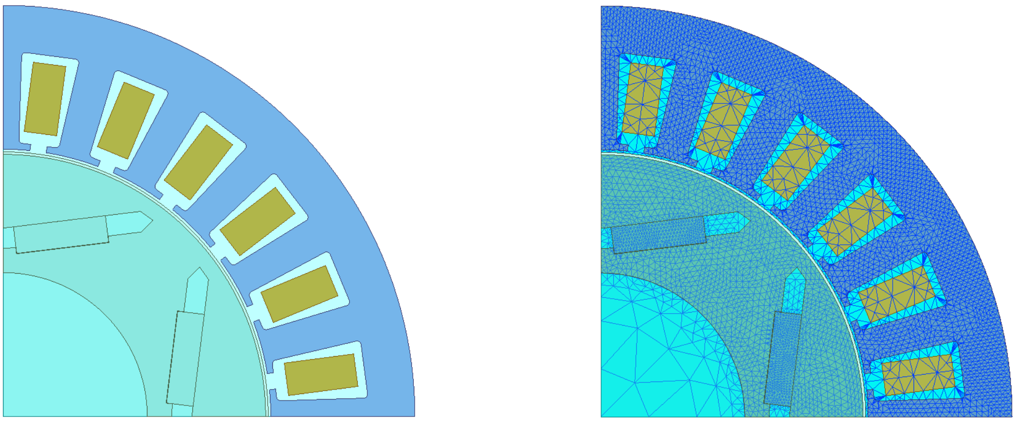

Figure 2: Geometry and mesh of the tested machine.

3 MAXWELL SIMULATIONS

In the Maxwell FEA software the short-circuit in one phase simulations will be calculated. In the one-phase short circuit simulations the model will be fed from the three-phase voltage source. In order to simulate the one-phase short circuit, the number of turns will be lowered. Number of turns in stator windings is 47 and in short-circuit simulation, the number of turns in the first phase will be 35. Torque behavior, stator currents and induced voltage will be investigated. The torque, current and induced voltage behaviors of the machine with no short-circuit are shown in the Figure 3.

The transient current and torque behavior response to the voltage is obvious in all three figures. In approximately 50 ms all three characteristics stabilize and either the maximum values in current and induced voltage or the average value of torque in torque characteristic are not varying. In the machine with defect in the one phase of the stator winding the characteristics are different. The first phase, where the number of turns is lower, has lower resistance and inductance of the coil, thus the current in the defected phase is higher. The characteristics of the defected machine are shown in Figure 4.

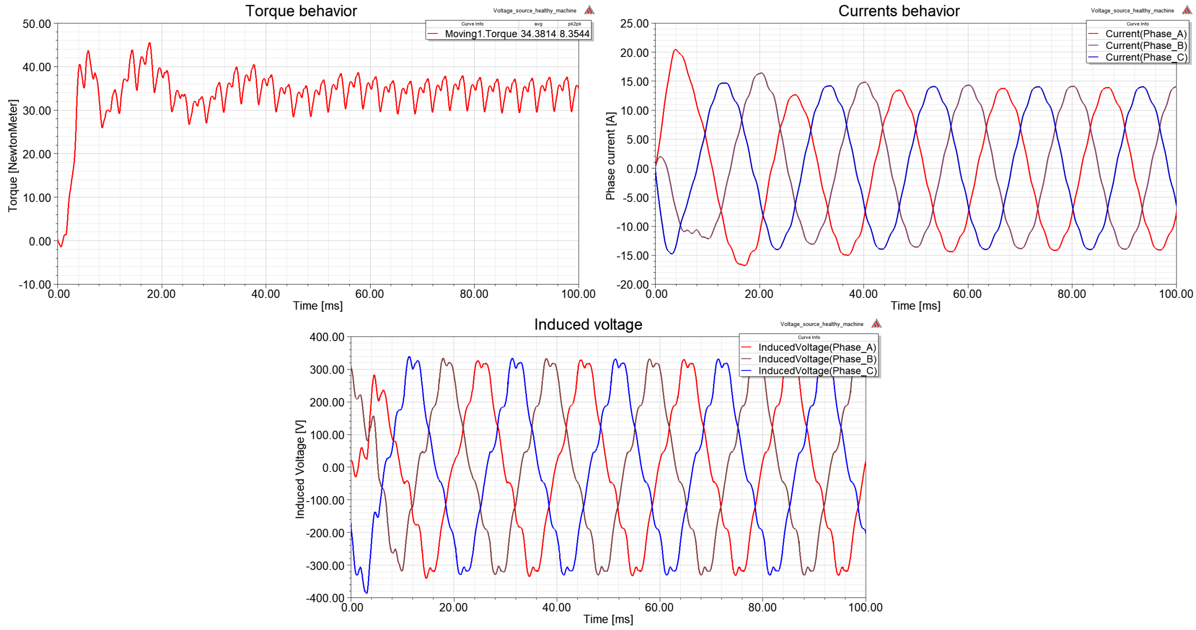

Figure 3: Torque, current and induced voltage of machine with no short-circuit.

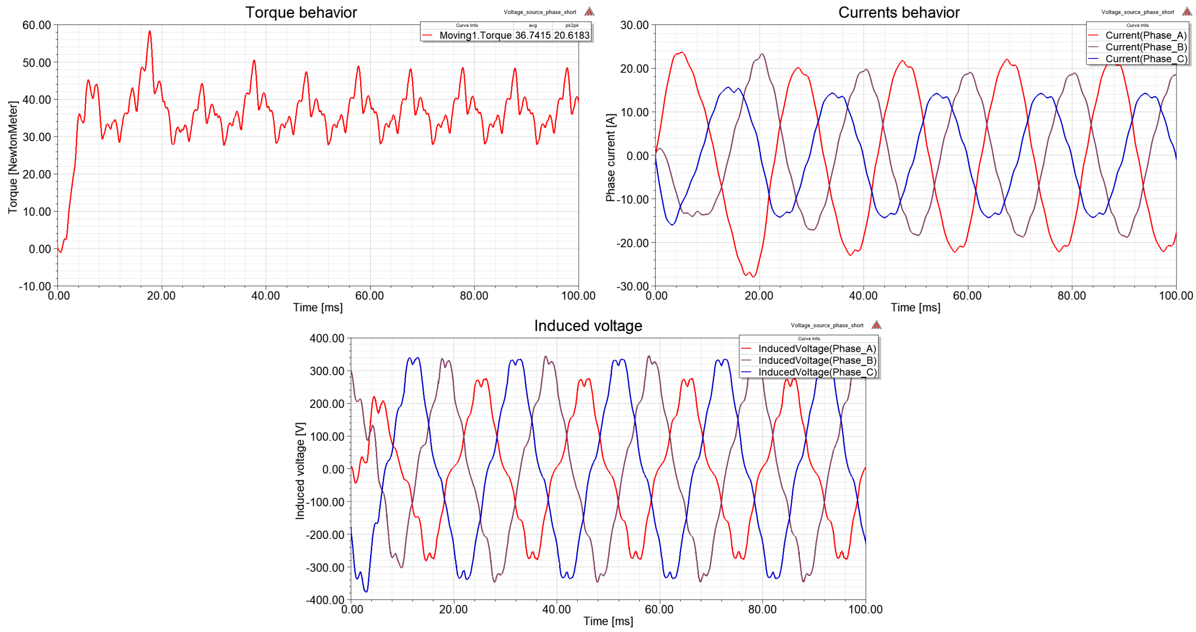

Figure 4: Torque, current and induced voltage of the machine with defected phase and 35 turns in the first phase.

The average torque in torque characteristics has increased by 6 % and the torque ripple has increased from 8.4 % to 20.6 %. The increased current in one phase lead to decreased current in other phases, which had to lead to the peaks in the torque characteristics. Maximum value of the induced voltage in the coil with lower number of turns has lowered by 15.4 % from 325 V to 275 V. Thus the presence of short-circuit in winding can be discovered from the stator currents, from the peaks in the torque characteristic and also from the lowered voltage.

4 SIMPLORER SIMULATION

Firstly the power inverter was designed in the Simplorer software, the inverter model is shown on Figure 5. Sine waves and triangle wave were compared in the state blocks and then the signals (either 1 or 0) were sent to the transistor. The reference sinusoidal waves with the carrier triangle signal are shown in the Figure 6.

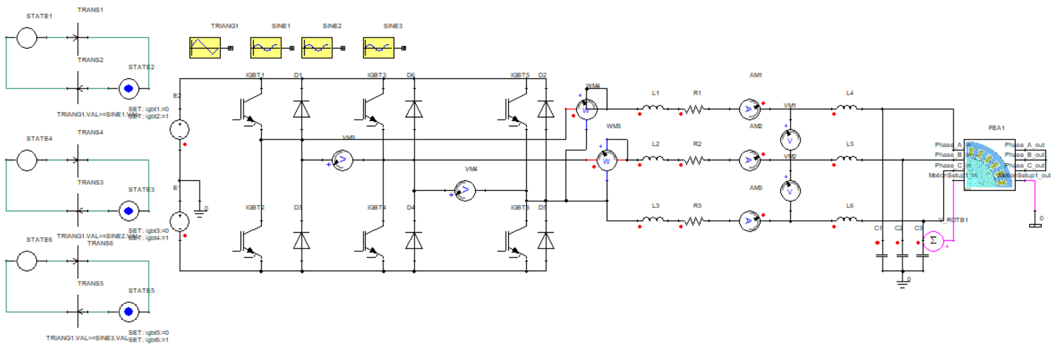

Figure 5: Power inverter modeled in the Simplorer.

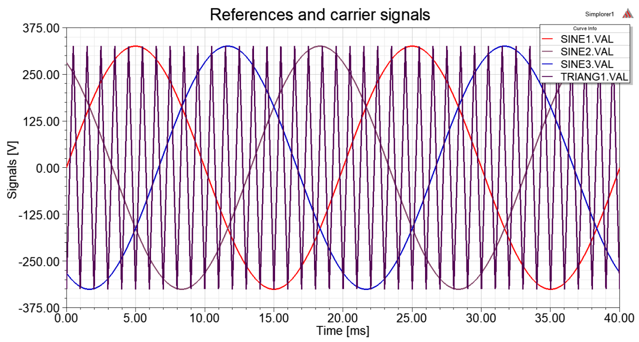

Figure 6: Power inverter modeled in the Simplorer.

Advanced product coupling needs to be allowed in Maxwell 2D settings in order to simulate dynamic simulations. The simplorer provide the voltage source for the FEA model stator winding [2]. In the simplorer only the three-phase symmetrical short-circuit condition will be analyzed. The motor is working at the nominal speed 1500 min^{-1} and the speed is forced via V_ROTB1 component. The short-circuit bridge is located between the power inverter and the IPM motor as depicted in the Figure 7 and the short-circuit is triggered by the voltage source at the 150 ms, the simulation length was chosen to be 400 ms. This simulation is demonstrating e.g the defected insulation in the cable, connecting the power inverter with the motor. The results of the three-phase symmetrical short-circuit simulation are shown on Figure 8.

The simplification in the simulation is obvious from the figures. When the circuit is short-circuited by the triggered switches, the current instantly increase and changes the way of flowing, which is in the picture depicted by the opposite phase of the current. The current is flowing from the motor, which is now behaving like a generator, to the short-circuited part of the circuit and the speed of the rotor is constant. This might be caused by the mechanical load with high moment of inertia.

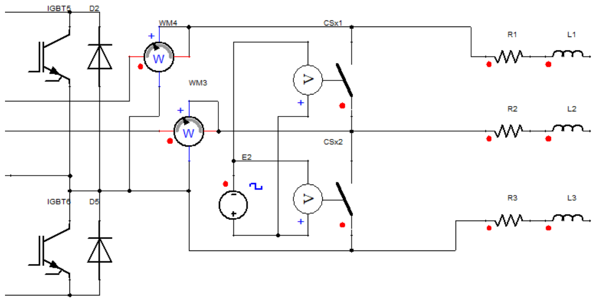

Figure 7: Short-circuit placement in Simplorer

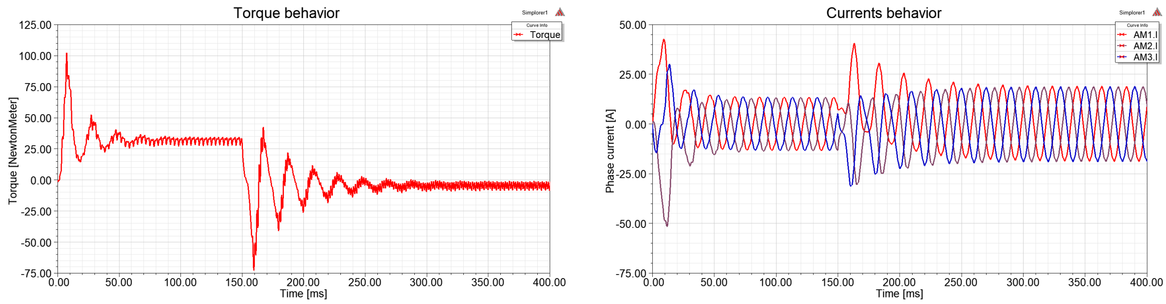

Figure 8: Torque and current behaviors of the machine with symmetrical three-phase short-circuit.

5 CONCLUSION

Short-circuits were simulated and results are presented in the paper. The presence of the short-circuited winding can be determined from the stator current measurement, but also from the measurement of the developed torque of the machine. From the results is obvious, that the short-circuit between 12 turns, creates torque peaks in characteristics and that might cause damage to the machine. In the symmetrical three-phase short-circuit simulation results is obvious that the current changed the way of and the current maximal value has increased. The current is limited by motor windings resistances and reactances and the developed torque became, after the transient response to the short-circuit, stable at 5 Nm.

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