Analysis and Co-Simulation of BLDC Motor Drive with Fault Detection by FEA Method

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Abstract—This paper deals with Analysis and Co-Simulation based approach to identify fault detection in Brushless Direct Current (BLDC) motor drive. The Finite Element Method (FEM) is used for the analysis and Pulse Width Modulation (PWM) technique is used to Fed BLDC drive. The analysis and optimization are performed in the ANSYS Maxwell (2D) and RMxprt packages and the power converter circuits are established in the ANSYS Simpler package. The prime objective of this work is to analyse the system with a fault caused by stator short circuit. Hence, the BLDC motor drive is simulated in healthy and faulty conditions separately and the effects of fault on the characteristics of the drive are studied.

Key words: Brushless Direct Current Motor (BLDC), Finite Element Method, ANSYS Maxwell, Simpler, Co-Simulation, Short Circuit Fault

I. INTRODUCTION

BLDC motors are one of the very popular machine used in electric drive systems. They are utilized for many industrial application, for example, consumer appliances, automotive, aerospace, medical, industrial automation equipment and instrumentation. As the name represents, BLDC motors do not utilize brushes for commutation rather, they are electronically commutated. BLDC motors have many merits over brushed DC motors and induction motors. The following are advantages of BLDC motor:

- Good speed versus torque characteristics
- Quick dynamic response
- Efficiency is high
- Operating life is high
- Noiseless operation
- Wide speed ranges

All these advantages makes the brushless direct current motor (BLDC) very efficient drive for being used in many applications. Like all other motors a BLDC motor comprises of stator and rotor. Permanent magnets are mounted on the rotor and the stator is usually made by stacking slotted steel laminations wound with specific number of poles. The stator can also be slot less, it has lower inductance, and slot less motor can run at very high speeds.

However, BLDC motors are susceptible to several types of faults in industrial applications, for example stator short circuit fault, shorted rotor pole inter turn fault, and failure of power diode or switch in the inverter control circuit. In this paper, a very frequent fault, the stator inter turn fault is proposed for the analysis. It may be caused by mechanical, electrical, environmental and partial discharges, which will be enhanced in case of electrical machines fed from inverter. The geometry and dimension of BLDC motor is modelled in the finite element domain. This method gives more precise results than other models. The finite element analysis is applied to study the effect of short circuit fault in the stator winding using ANSYS Maxwell and Simpler [1, 2].

ANSYS Maxwell is the electromagnetic field simulation programming software for engineers who are working under designing and analysing 3-D and 2-D electromagnetic and electromechanical units, motors, actuators, transformers etc. RMxprt is another commercial tool developed by ANSYS which is a format based electrical machine configuration apparatus that gives quick, investigative counts of machine execution in 2-D and 3-D geometry creation for itemized limited component figuring in ANSYS Maxwell. In this project, ANSYS Maxwell software tools are used to create a Brushless Direct Current motor design and to analyse the effects of some specified faulty conditions [3].

This work is composed as takes after: In section II, the proposed FEM is portrayed. While this segment manages the model of the engine in ANSYS/Maxwell, the dynamic model of the BLDC is associated in Maxwell and Simpler. This model with an internal short circuit is illustrated in section III and the simulation results of the proposed model with and without fault conditions are analysed.

II. METHODOLOGY

In this paper, Brushless direct current motor is designed using RMxprt tool based on standard specification and it is analysed using ANSYS Maxwell 2D software. The control circuit for PWM fed BLDC drive is designed using Simpler. The designed motor is analysed for two conditions: one for healthy machine and another by creating a fault in the machine. The specification of BLDC machine considered for design is shown in Table. 1.

The fault is created by short circuiting the stator winding. This causes the adverse effect on the performance of the machine. The various parameters in the machine like magnetic flux distribution, torque, speed, voltage will change in a way that affects the working of the machine. The performance characteristics of the machine under fault and healthy conditions are obtained and compared. Finite Element Method which gives accurate results and comparatively less calculation time for the analysis.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Poles</td>
<td>4</td>
</tr>
<tr>
<td>Output Power</td>
<td>550 W</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>220 V</td>
</tr>
<tr>
<td>Speed</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Rotor inner diameter</td>
<td>40 mm</td>
</tr>
<tr>
<td>Length of Rotor</td>
<td>60 mm</td>
</tr>
<tr>
<td>Stator outer diameter</td>
<td>140 mm</td>
</tr>
<tr>
<td>Stator inner diameter</td>
<td>90 mm</td>
</tr>
<tr>
<td>Length of Stator Core</td>
<td>60 mm</td>
</tr>
</tbody>
</table>

Table 1: Specification of BLDC Motor
A. FEA Model of Brushless Direct Current Motor (ANSYS Maxwell 2D)

The model of the BLDC motor have been designed using ANSYS Maxwell 17.0. This programming solves complex electromagnetic field issues towards utilizing the FEM and it considers the non-linearity conditions for the study. In this work, ANSYS Maxwell is primarily used to design and analyze the BLDC motor. RMxprt is used to create machine model whereby a programming client could gave machine configuration parameters and related majority of the data [4]. In the procedure for imputing those configuration information in the RMxprt, the client need will define the measurements of the stator and rotor of the machine, for example, machine type, number of poles and circuit type. Furthermore, a client need to detail those rated parameters, for example, speed, current and voltage. A client also need to define different parameters of winding such as the slot, wire, conductors, insulation and some other related parameters [6, 7]. There are four steps involved in the finite element analysis:

- Validate the model: Figure 1 illustrates the BLDC model in RMxprt.
- Geometrical model parameters and construction of BLDC in Maxwell 2D as shown in Fig. 2.
- Definition of physical parameters such as regions, materials etc.
- Distribution of flux density under healthy condition as shown in Fig. 3.

Fig. 2 shows the geometrical 2D model of the BLDC and the distribution flux density of the model is shown in Fig. 3.

Fig. 1: BLDC model in RMxprt

Fig. 2: BLDC model in Maxwell 2D.

Fig. 3: Distribution of Flux density

B. SPWM Inverter (ANSYS - Simplorer)

In this section, the design of PWM inverter control circuit fed by BLDC motor using the Simplorer software is discussed. The inverter circuit consists of six IGBT switches with antiparallel diodes as shown in Fig. 4. The purpose of selecting IGBT as a switch is due to its high power rating and switching frequency compared to other switches such as MOSFET, BJT etc. The main advantage of Simplorer is that, it is possible to co-simulate with Maxwell 2D/3D [4].

Fig. 4: Three phase PWM Inverter circuit.

The switching of IGBTs done through the pulses. Here, SPWM technique is used to generate pulses. These pulses or control signals are generated by comparing Sine wave and triangular wave. The reference waveforms are implemented using time functions. The Sine Wave is selected in the Time Functions library. To generate PWM pulses, the sine wave is compared with the triangular wave and the magnitude of the sine wave, in this case, is taken as 350V with 50 Hz frequency and triangular wave with a magnitude of 400V with 1 kHz frequency. Fig. 5 and Fig. 6 shows the PWM comparison signals and PWM output.

Fig. 5: PWM Comparison Signals.

Fig. 6: PWM Output
C. Simulation model in Simulor

The coupling between Maxwell and Simulor is effectively created in the Simulor project. The Maxwell component coupling link allows to import the FEA electric machine model to the Simulor for co-simulation [5] as shown in Fig. 7. In order to realize the co-simulation, user can follow the following steps: open Simulor Circuit → Sub Circuit → Maxwell Component → Add Transient Co-simulation. Then, the Maxwell Component motor model is reported in the Simulor schematic. Fig. 7 shows the simulated system model for the study of inverter fed BLDC motor [8, 9]. In the systematic model, Motor Speed is given (rated speed 1500 rpm) by $V_{ROT}$ module.

![Simulor Circuit Model](image)

Fig. 7. Simulated system model for a BLDC Drive

The validity of the proposed model and co-simulation are verified. Ansoft/Maxwell 2D based on finite element analysis method is used to calculate BLDC’s electromagnetic relationship to realize motors performance.

III. BLDC MODEL WITH STATOR WINDING SHORT-CIRCUIT FAULT

In this section, the model of the broken machine is set up by Co-Simulation of ANSYS Maxwell and Simulor. It was checked by the consequences of the solid machine.

A. BLDC Short-Circuit Fault

In this section the stator winding short circuit fault is analyzed and the parameters are listed in the Table 2. The short circuit in stator winding is created by decreasing the number of turns in a phase of coil [3]. Here, stator winding faults created in phase-A, the number of turns chosen is 20 but in all other phases, the number of turns are 25.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Turns</th>
<th>In Slot</th>
<th>Out Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil 1 A</td>
<td>20</td>
<td>1T</td>
<td>8B</td>
</tr>
<tr>
<td>Coil 2 A</td>
<td>25</td>
<td>2T</td>
<td>7B</td>
</tr>
<tr>
<td>Coil 3 C</td>
<td>25</td>
<td>3T</td>
<td>9B</td>
</tr>
<tr>
<td>Coil 4 C</td>
<td>25</td>
<td>4T</td>
<td>9B</td>
</tr>
<tr>
<td>Coil 5 B</td>
<td>25</td>
<td>6T</td>
<td>10B</td>
</tr>
<tr>
<td>Coil 6 B</td>
<td>25</td>
<td>6T</td>
<td>11B</td>
</tr>
</tbody>
</table>

Table 2: Turns in Each Coil of Phases under Faulty Condition.

B. Simulation Results

Fig. 8 shows the FEM outline of BLDC motor using ANSYS Maxwell and Simulor. The programme is executed in Simulor and the results are obtained. Fig. 8 and Fig. 9 shows the stator current and electromagnetic torque wave forms under sound and faulty conditions.

![FEM Outline of BLDC Motor](image)

Fig. 8: Performances of healthy machine obtained by Simulor. (a) The stator currents and (b) The electromagnetic torque.

Comparing the performance of the motor under healthy condition and faulty condition as shown in Figure 8 and Figure 9, it is observed that the short circuit in the stator winding of a BLDC motor effects on stator currents and the torque. In fact, the short circuit increases the amplitude of the current in the short circuited phase and magnitude of current increases to higher level. The magnitude of the stator current is increased by 5A comparing to normal condition. This increased current may damage the winding and it affects the performance of the motor.

![Stator Current and Electromagnetic Torque](image)

Fig. 9: Performance of the faulty condition machine obtained by Simulor with 20% short circuit fault. (a) The stator currents and (b) The electromagnetic torque.)
IV. CONCLUSIONS

This paper proposed Analysis and Co-Simulation of BLDC motor drive with fault detection using finite element method and to study the performance degradation of machine under fault. The proposed methodology made use of efficient computational resource ANSYS Maxwell and the solution obtained by this technique is found more efficient. Design of the motor is successfully done using RMxprt tool and then converted to 2D model in ANSYS. The fault is created by decreasing the number of turns in one coil of phase-A, which leads to short circuit in the stator winding, using Maxwell and Simplorer tools. The performance characteristics of machine under healthy and faulty conditions are verified. Also, the flux distribution has been shown under healthy and faulty condition. It can be concluded that the key benefit of RMxprt is its ability to automatically set up a complete Maxwell project (2D/3D) including geometry, materials and boundary conditions.

REFERENCES


