Modeling and Analysis of Synchronous Machines with Broken Damper Bars

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Abstract — In this paper, synchronous machines with damper winding are modeled based on the winding function approach [1]. The actual winding distribution is used which does not require neglecting the space harmonics. The skew and slot effects are also taken into account. There are m stator windings, one field winding and n rotor bars which are magnetically coupled in the machine equations. The machine equations are derived in natural reference frame in terms of the actual physical rather than transformed or equivalent variables [2]. The effects of number of broken damper bars on the transient time, slip frequency, torque-speed curve and stator current spectrum are presented. The similarity and dissimilarity of damper bar failures in synchronous machines and broken rotor bars in cage induction machines are discussed.

I. Introduction

Failures of damper bars in synchronous machines have not been covered in literature as widely as other faults like eccentricity and inter-turn faults [3-5]. This failure occurs due to the fatigue stress caused by excessive start-stop cycles or speed changes. The proposed model can be easily used to simulate the machine under other faulty conditions such as broken damper bars and end ring, eccentricities and inter-turn faults as well. Unlike the cage of an induction motor, the damper bars are often not equally spaced on the rotor, causing unequal inductances and resistances in the bar circuits. Therefore, a healthy damper winding looks like a symmetrically damaged rotor of an induction machine. This makes the diagnostics more difficult because the well-known broken bar signatures in the stator current spectrum of an induction machine already exist in the current spectrum of a synchronous machine with a healthy damper winding.

II. Simulation Results

As the number of broken damper bars increases, the rotor magnetization decreases and it takes a longer time to reach its final speed. Due to the same effect, when the number of broken bars is increased, at steady state, the rotor lags behind the rotating field by a higher slip.

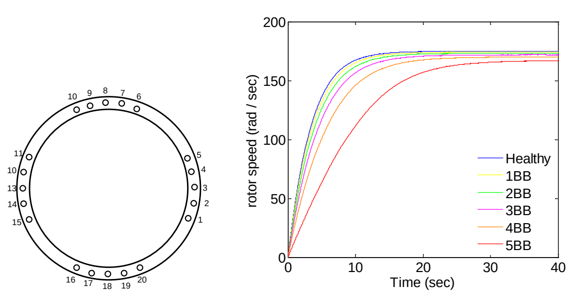

Fig. 1 (left) Damper winding schematic with 5 bars/pole and (right) Rotor speed during startup transient with open field and 10% load, for healthy and 1-5 broken damper bars.

These effects can be observed in figure 1(right) which shows the simulation results of the transient speed at startup with no field excitation for 1 to 5 consecutive broken bars on one pole. Figure 1(left) shows the configuration of the damper winding under study.

Under the same load condition, the amount of slip change depends on the number of broken bars as well as the location of the broken bars. Figure 2(top) shows how the slip changes as the damper bar failures expand from bar#1 to bar #5 for different loads. It can be observed that when the failure expands to the 5th bar, one pole is completely removed and the slip changes significantly. This effect is more severe when the motor is heavily loaded. As shown in this figure, the rate of increase of the slip frequency versus the number of broken bars goes up as the load increases.

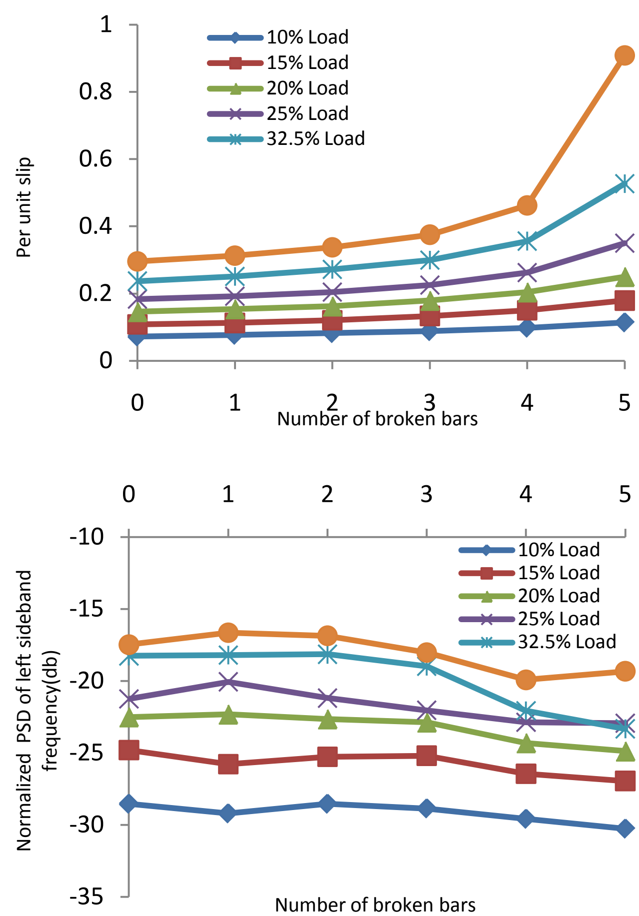

Fig. 2 Effect of number of broken bars and load on (top) per unit slip frequency and (bottom) normalized PSD of the left sideband frequency.

For detection of broken rotor bars in induction motors, investigation of the left sideband component of the stator current spectrum, (1-2s) f, has been frequently suggested in the literature. This component exists in the stator current spectrum of an induction machine when there is a rotor asymmetry and its amplitude increases with more severe rotor faults. A synchronous machine with a damper winding and open field operates like an induction machine with an incomplete cage and some missing bars between the poles (figure 1(left)). Therefore, even in the case of a healthy damper winding, the left sideband exists. Figure 2(bottom) shows the variation of the normalized PSD of the left sideband component for the healthy and 1-5 broken damper bars, with different loads. It can be observed that even in a healthy damper the left sideband component is significant and it increases with load. Under some load conditions (like 10% and 15% load in this case), it might be even more significant than the faulty cases. Compared with the per unit slip variation in Fig. 2. (top), the behavior of the left sideband component is relatively hard to predict and is not directly correlated to the degree of the fault. It will be analytically shown in the full paper that the amplitude of this component is a nonlinear function of slip which in turn depends on the load, number and the location of the broken bars. It also depends on the damper winding dimension.

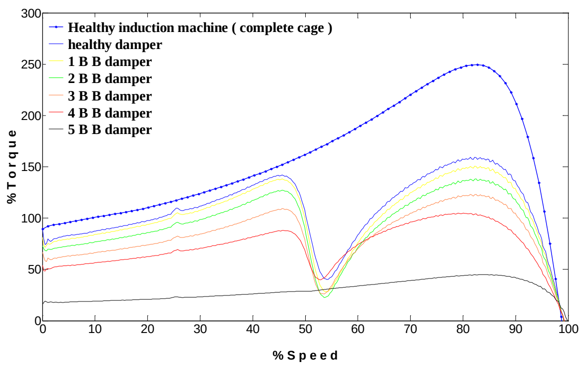

Fig. 3 Effect of number of consecutive broken damper bars on the torque speed curve as well as the torque speed curve of a complete cage in an induction machine with the same parameters.

The effect of damper bar failures on the torque speed curve of the synchronous machine with open field is demonstrated in figure 3. The torque speed curve of the same machine with a complete cage, which is an induction machine with the same parameters and but with 9 bars per pole, is also included in the same figure for comparison. In fact a healthy damper in figure 3 is like the cage of an induction machine with 4 symmetrically broken bars per pole.

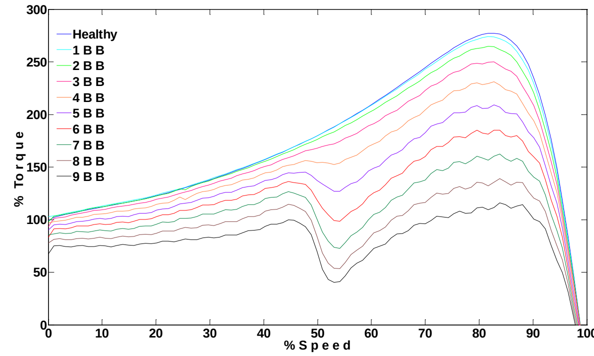

Fig. 4 Effect of number of consecutive broken rotor bars on torque speed curve in the induction machine

The torque speed curves of the same induction machine (complete cage) are presented in figure 4 for 1 to 9 consecutive broken rotor bar conditions. It can be observed that for more severe faults the dip become stronger and the speed at the dip decreases.

In the case of synchronous machine with faulted damper winding (figure 3) this effect is more severe because of the asymmetric structure of the damper. These dips are affected by harmonics due to the rotor faults and will be explained in details in the full paper.

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