Failure Modes of the Electric Motors

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The reliability assessment of electric machines plays a very critical role in today's engineering world. The reliability assessment requires a good understanding of electric motors and their root causes. Electric machines mostly fail due to mechanical problems and bearing damage is the main source of this. The bearings can be damaged by mechanical, electrical, and thermal stresses. Among all stresses, the researcher should give special attention to the electrical one, which is bearing current and shaft voltage.

bearing current shaft voltage capacitance

1. Introduction

Despite the fact that the bearing current problem in electrical machines has been well-known for almost a century [1], it is still a relevant focus for ongoing research. Failures brought on by bearing currents result in significant mechanical damage to electrical machines, which causes expensive maintenance and operational costs [2]. Magnetic asymmetry and electrostatic discharge are the main causes of bearing currents at that time. The magnetic asymmetry is caused by the inability to produce a motor with absolute accuracy, due to such issues as rotor eccentricities and asymmetrical windings [3].

With the emergence of inverter-fed electric machines and their increasing popularity, a third cause of bearing failure appeared. The new source is a high-frequency common mode voltage (CMV) that will produce a high-frequency common mode current [4][5]. The problem can possibly become worse with pulse width modulated (PWM) drives that employ extremely fast switching components such as silicon carbide (SiC) or gallium nitride (GaN) switches to minimize converter losses [6][7][8]. The generated high-frequency common mode current due to PWM flows through the winding of the machine and then to the stator of the machine. A circulating flux will then be produced in the frame, leading to a high-frequency inductive circulating bearing current [9][10]. Moreover, there are additional types of bearing currents, such as electric discharge machining (EDM) bearing currents or high-frequency capacitively bearing current [11][12]. EDM current is generated when the voltage across one of the bearings exceeds a threshold and a breakdown happens [13]. A more detailed explanation of these currents is given later in their paper. Several proposed solutions for mitigating bearing failures were proposed in the literature, including the development of ultralow inductance switching power cells [14], the installation of electrical field emission (EMI) filters [15][16][17], the use of electrically-insulated bearings and shaft grounding brushes [18], and modified PWM techniques [19][20][21].

Numerous studies have been conducted to better understand the fundamental processes of bearing currents and the appropriate mitigation measures [22][23][24][25][26][27][28][29][30]. The shaft voltage sources and their generating methods were thoroughly described in [22]. Moreover, strategies for regulating and/or eliminating these sources were examined so that users might have a better understanding of how these voltages and currents are formed. The testing for detecting shaft voltage sources, as well as their potential circuits, were also described in [22]. The authors of [23] presented a number of practical strategies for reducing bearing currents such as the selection of a carrier frequency between 1.5 kHz and 3 kHz, insulated bearings, shaft ground brushes, a common mode filter, and using a special cable to reduce common mode current. The work in [23] lacks theoretical and mathematical analysis. The authors of [24] offer an in-depth overview of bearing currents, focusing on practical and simple approaches for mitigating bearing current in conventional PWM inverter drives, such as inverter output filters and insulated bearings, without considering mitigation methods that require hardware and/or motor modifications. The effectiveness and losses of several proposed mitigation strategies for bearing currents, EMI, and motor terminal overvoltage are assessed and compared in [25] using laboratory measurements and user-friendly application assessments. The modelling of an induction motor under a bearing fault state was reviewed in [26]. It was proven that model-based techniques are more advantageous than experiment-based techniques in bearing fault detection. The authors of [27] reviewed and evaluated EMI modelling methodologies for various function units in a variable-frequency drive system, such as induction motors, motor bearings, and rectifier-inverters, in terms of the applicable frequency range, model parameterization, and model correctness. The frequency of the EMI phenomena is in the range of several to tens of MHz, which is greater than the frequency of the bearing currents; therefore these models, which were built primarily for EMI analysis, have limited checks on the bearing currents. A comprehensive study of all aspects of the shaft voltage and bearing current phenomena was presented in [28], along with a review of bearing failure approaches with a focus on electric vehicles (EV) and hybrid EV motors. The work in [29] introduced a summary of the methods for assessing the state of bearings as well as low- and high-frequency inverter-generated shaft voltages. The bearing current modelling and mitigation methods for electrical machines with variable-frequency drives were reviewed in [30]. However, the bearing current mitigation method using multiphase systems was not introduced in the previous review papers about this topic. The literature also lacks a thorough analysis of this subject that covers every aspect in depth.

2. Failure Modes of the Electric Motors

The evaluation of motor failure mechanisms can be carried out in a variety of ways. According to motor failure root-cause studies, there are generally three main failure mechanisms. The most crucial failure mode is electrical-related failure, which is brought on by problems with motor winding insulation, winding short circuits, overloading, and other problems [31]. The degradation of insulating material is frequently due to winding temperature limits being exceeded. Coils can be damaged by a winding current that is too high due to an overloading problem. The second type of failure is magnetic failure, which often happens when a permanent magnet (PM) becomes thermally demagnetized. A PM may be thermally demagnetized for a variety of reasons, including high motor operation temperatures, shock, vibration, and strong magnetic fields produced by the stator windings. The mechanical failure of a motor’s structure and components is the third failure mode. Bearing failures are typically seen in this failure scenario. Broken or loosened rotor bars are another frequent failure mode. Most mechanical breakdowns are often the consequence of slow processes such as mechanical wear and the gradual deterioration of the material characteristics. The damaged parts keep showing recognizable symptoms throughout the process until they totally fail. This is not the same as the majority of electronic component failures, which occur abruptly and without notice. Despite the reliability and ease of construction of induction machines (IMs), studies have indicated that the yearly motor failure rate is roughly estimated at 3–5% per year, and in severe circumstances up to 12% [32]. The cost of the downtime in a production caused by a motor failure might be substantial or even exceed the cost of a new motor. Under some circumstances, a motor failure might stop the entire production of the factory.

In order to address motor failure modes according to main causes of failure, IEEE presented a thorough study in three parts [33][34][35] based on data collected from 1141 motors that were larger than 200 hp and no more than fifteen years in operation. The first part of this research gave overall findings based on motor type categories. The second part integrated several categories and addressed the issues that were raised in the first part. The third part of the survey findings was intended to address new inquiries and comments as well as to give more detailed assessments of topics that had not been previously covered. The Electric Power Research Institute (EPRI) has carried out a similar examination into motor failure modes [36]. Although EPRI concentrated only on faulty motor components, it gave comparable results with IEEE. Venkataraman et al. [32] combined the results of these two studies, as shown in **Table 1**. **Table 1** shows that bearing failures and failures related to the stator insulation are the most frequent causes of motor failures. Mechanical breakdowns can be caused by high vibration. In addition, many malfunctions are caused, directly or indirectly, by excessive operating temperatures.

Table 1. Summary of IEEE and EPRI studies [31][32].

Failure Mode	IEEE Study		EPRI Study		Average (%)
	Failure Contribution	(%)	Failure Component	(%)	
Mechanical failure	High vibration	15.5	Sleeve bearings	16	
	Poor lubrication	15.2	Antifriction bearings	8	
	-	-	Trust bearings	5	
	-	-	Rotor shaft	2	
	-	-	Rotor core	1	
	Total	30.7	Total	32	31.35
Electrical failure	Normal deterioration	26.4	Stator ground insulation	23	
	Persistent overload	4.2	Turn insulation	4	
	-	-	Bracing	3	
	-	-	Cage	5	

Failure Mode	IEEE Study Failure Contribution	(%)	EPRI Study Failure Component	(%)	Average (%)
	-	-	Core	1	
	Total	30.6	Total	36	33.3
Environmental and other reasons	High ambient temperature	3	Bearing seals	6	
	Abnormal moisture	5.8	Oil leakage	3	
	Abnormal voltage	1.5	Frame	1	
	Abnormal frequency	0.6	Wedge	1	
	Abrasive chemicals	4.2	-	-	
	Poor ventilation cooling	3.9	-	-	
	Other reasons	19.7	Other components	21	
	Total	38.70	Total	32.00	35.35

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