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Reliability Assessment of Induction Motor Drive using Failure Mode Effects Analysis

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Abstract: *Electric motor drives have seen widespread adoption in many applications. Due to considerable use of electric drives in industrial applications, reliability assessment of drive-motor systems both in design and operating phases is of considerable importance. The reliability factor of the motor drive system plays the vital role in process identity. Any small variations/failure will end up in huge loss. Hence importance is given to failure rate of the fault which can occur in the system, so that suitable precaution can be applied such that motor-drive systems will not cause loss to the user. Failure Mode and Effect Analysis (FMEA) approach is used to identify and list those component failures and combinations of component failures that result in an interruption of operation. The proposed technique is then applied to a practical drive-motor system and the results are presented.*

Keywords: *Reliability assessment, Motor drives reliability, Failure mode and effect analysis (FMEA).*

I. Introduction

Reliability assessment of motor drives is essential, especially in electric transportation applications. Safety is a major concern in such applications, and it is tied directly to reliability. Industrial applications of motor drives require high reliability to maintain the functionality of manufacturing, pumping, cooling, and other processes. Generally reliability of a motor drive can be explored via the emerging field of thermo- electrical analysis. To achieve high reliability levels and fault-tolerant operation, which is important for safety considerations, two main elements should be engineered into the motor drive: i) component redundancy, and ii) fault detection and isolation (FDI) mechanisms.

In this paper a method for reliability assessment of induction motor drive as shown in Fig.1 is presented. Faults can occur in the following six possible subsystems or components:

1) Induction machine
2) Inverter
3) Current sensors
4) Speed encoder
5) Control and estimation platform
6) Connectors and wires.

The control and estimation platform, connectors and wires are assumed to have very low failure rates compared to the rest of the system. This assumption is justified in part since the platform, which is usually a microcontroller or DSP, is very reliable and does not involve high currents, high voltages or mechanical movement. The wires and connectors are static and should have low failure rates, except in high-vibration or corrosive environments, if selected and installed correctly.

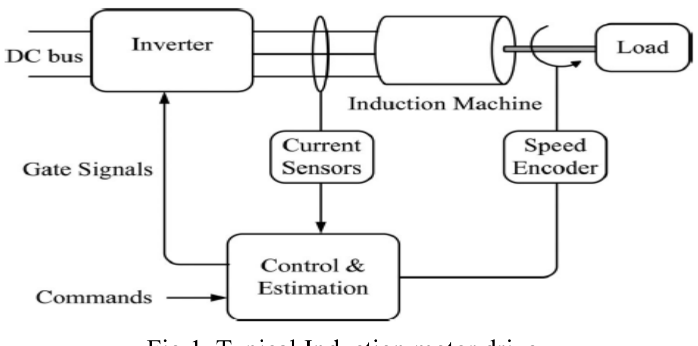


Fig.1. Typical Induction motor drive.

Several reliability modelling techniques are available. These include Reliability block diagrams (RBDs), Fault trees, Markov's models and Failure modes and effects analysis (FMEA). Among these techniques, failure modes and effects analysis (FMEA) modelling is the most powerful. This is because it can capture many important features that RBDs and fault trees cannot.

II. Literature Review

The basic idea for the proposed work was carried out by referring [1] and [2] with implementation carried out by Atmel's ATmega8535 microcontroller. While the literature contains significant work on important aspects of design for reliability and fault tolerance in induction motor drives, comprehensive tools to support systematic analysis and quantitative results have not been discussed. There are many excellent studies that define fault models. The objective of this paper is to create a framework for these models that will support systematic, quantitative analysis of fault impacts and design methods for fault mitigation. Faults include those in the inverter [4], control [5], power supply [6], [7] and motor [8]. Aspects of fault detection and isolation have been analyzed extensively as in [4] and [2]. For example, pattern recognition is used in [9], while a short-time Fourier transform is used to identify faults. Redundancy has been investigated, with extensive work on multiphase motors and split-wound motors. At the control level, fault-tolerant control algorithms for permanent magnet synchronous machines (PMSMs) and induction machines have been presented in [4]. Other strategies for improving the reliability of a system include reliable communication, preventive maintenance, component derating, and component count reduction.

Therefore, much of the available literature is limited to physical faults, e.g., power electronics and machine faults, assumes certain system structures (from a reliability point of view), e.g., series components, and focuses on the development of fault tolerant control algorithms.

III. Fmea

The underlying idea of FMEA [3] has its origin in the US military in the late 1940s. FMEA is a methodology developed to identify potential failure modes in a product or process, to determine the effect of each failure on system operation and to identify and carry out corrective actions.

It may also incorporate some method to rank each failure to its severity and probability of occurrence. FMEA is an inductive failure analysis used in product development, systems engineering, reliability engineering, and operations management for analysis of failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes based on past experience with similar products or processes or based on common failure mechanism logic, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. It serves as a form of design review to erase weakness out of the design or process. It is widely used in development and manufacturing industries in various phases of the product life cycle. Effects analysis refers to studying the consequences of those failures on different system levels. The proposed methodology for reliability modelling covers essential faults in a drive system, including the machine, power electronics, and sensors. Eventually, the result of an FMEA is typically the acceptance of the suggested components, probably recommendations for maintenance tasks or the demand to change certain components.

An FMEA is conducted with the following steps:

- List all the components
- identify functional failures and failure modes
- determine component functions identify functional failures and failure modes
- describe the effects of these failure modes
- identify the consequences for each failure mode
- determine recommended actions

The results of an FMEA are usually documented in tabular format as shown in Table 1.

Table 1: FMEA worksheet

Potential Failure Mode	Potential Effect of Failure	Severity	Class	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Current Design Controls Prevention	Current Design Controls Detection	Detection	R. P. N.

Risk Priority Number (RPN) plays an important part in the choice of an action against failure modes. After ranking the severity, occurrence and detect ability, the RPN can be easily calculated by multiplying these three numbers:

$$RPN = S \times O \times D \quad (1)$$

The practice of prioritizing work on the basis of RPN has no theoretical basis. This has to be done for the entire process and/or design. Once this is done it is easy to determine the areas of greatest concern. The failure modes that have the highest RPN should be given the highest priority for corrective action. This means it is not always the failure modes with the highest severity numbers that should be treated first. There could be less severe failures, but which occur more often and are less detectable. After these values are allocated, recommended actions with targets, responsibility and dates of implementation are noted. These actions can include specific inspection, testing or quality procedures, redesign (such as selection of new components), adding more redundancy and limiting environmental stresses or operating range. Once the actions have been implemented in the design/process, the new RPN should be checked to confirm the improvements. These tests are often put in graphs for easy visualization. Whenever a design or a process changes, an FMEA should be updated.

IV. Methodology

The reliability modelling methodology for a motor drive proceeds in simple steps. The first step is to define the essential system components or subsystems. These are the elements that can fail frequently and can affect system operation. Whether the whole system would later fail or not is part of the observations. After these components are determined, possible fault modes are analyzed, e.g., OC or SC faults in an IGBT–diode module. The fault modes can be expanded into a long list, but basic or common faults should be considered. The motor drive will be operating under certain conditions with desired performance desired performance characteristics.

These conditions and operational characteristics are used to set performance bounds. For example, the torque on the motor shaft set by the pedal in an electric vehicle should be bounded within certain limits, and once it exceeds these limits, over speeding or sudden braking could occur.

After the first level of faults is injected and critical variables are recorded, these variables are compared to the performance bounds. If any variable exceeds its allowed bounds, the system is considered in a “failure” state; otherwise, it has survived.

V. Experiments And Model Validation

An induction machine, inverter, and control were implemented experimentally to validate the model is shown in Fig. 2. To protect the experimental setup without significantly affecting the model, two factors were considered. The first factor is to avoid injecting faults that could cause severe failures or trigger the protection circuitry as predicted from simulations. The second factor is to use a tight external closed-loop torque control in experiments to avoid sudden overload conditions on the dynamometer and the motor shaft. Fig. 3 and Fig. 4 show the experimental result for fault among several that were tested. The faults shown are speed encoder omission, current sensor constant, and an OC fault. Results show that the model is valid and generally behaves as expected from experiments. Note that the model is almost perfect under faults which are the main goal of the modelling process.

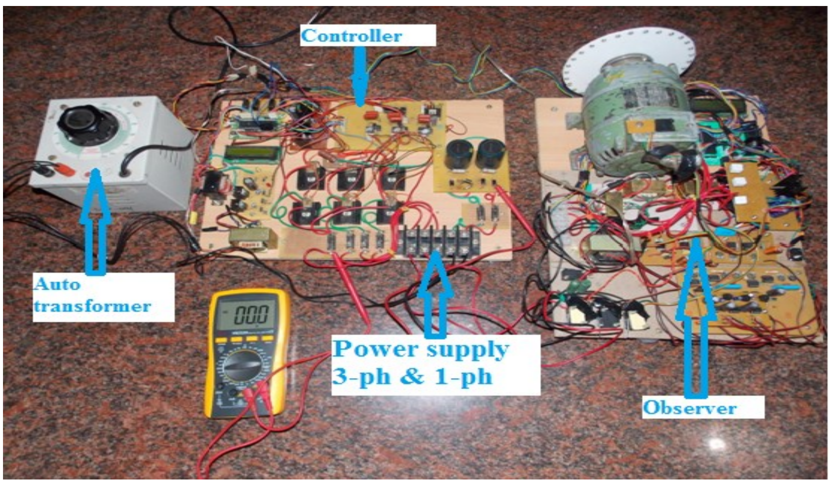


Fig. 2. Overall system setup for experimental testing.

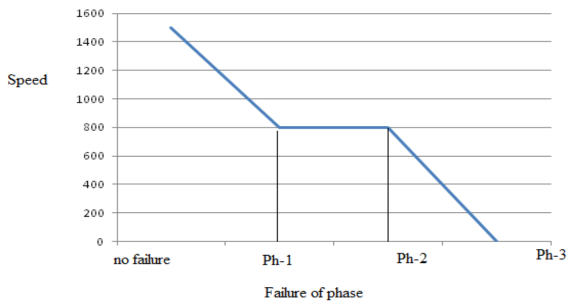


Fig. 3. Speed characteristic under phase failure

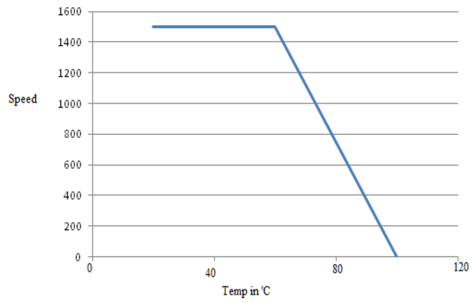


Fig. 4. Speed vs. Temperature plot.

The main purpose of this work is to increase the reliability of induction motor drive system by considering faults. Here reliable operation boundary is designed with the help of FMEA technique, is shown in Fig. 5.

http://www.qimacros.com/lean-six-sigma-articles/fmea/

Potential Failure Mode and Effects Analysis (Design FMEA)

System:	Name/number of system
Subsystem	Name/number of subsystem
Component	Name/number of component
Model:	model years/programs
Core Team:	Team members
Design Responsibility:	Reliable
Key Date:	15-07-2008

Item/Function Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Class	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Current Design Controls Prevention	Current Design Controls Detection	Detection	R. P. N. *
Speed sensor	Sensor is disconnected	Motor will collaps or shaft thrown out	10	Critical	Dangers speed/Broken rotor bar	7	reduce motor speed/ switch off the supply	Visual monitoring	10	700
Supply	1- phase failure	Production/Hr is less	9	Critical	Phase to ground	8	reduce current	CT	6	432
Supply	2- phase failure	Potentiol safty hazard[Operater can injured	10	Critical	no rotation of motor	7	Switch off the supply	CT	6	420
Motor	Temp. rise in motor	over load	10	Critical	winding failure	8	Switch off the supply	Thermistor	3	240
Inverter	Power electronic device	connection failure	2	normal	problem in estimation	3	check for connectivity	nil	5	30

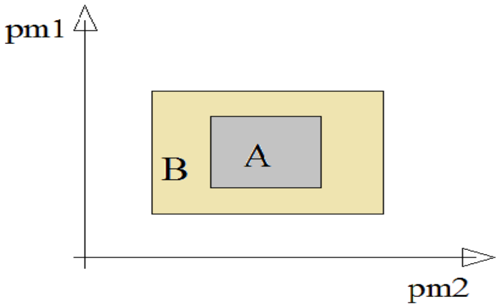
*Risk Priority Number (R.P.N)

Fig. 5. FMEA technique to assess reliable boundary.

System performance criteria are essential in determining whether performance is acceptable. After every fault, system performance is evaluated based on performance measures. These metrics can be functional, such as state overshoot or settling time, or non functional, such as the total energy consumption or cost. In a motor drive, these measures should consider the safety of the operator, e.g., passengers in an electric vehicle, and safety of the motor drive itself.

A general depiction of two performance measures pm1 and pm2 is shown in Fig. 6 and Fig. 7. The rectangle labelled **A** shows the actual performance of the system, while the rectangle labelled **B** shows the acceptable bounds on each performance measures. If **A** is enclosed by **B**, then the system performance is acceptable otherwise, the system has failed.

For each system configuration arising from different faults, performance measures are analyzed. Even though these measures are useful in determining whether each possible system configuration has failed or not, it is necessary to define an aggregated reliability measure using a FMEA model. In an induction motor drive, performance measures include the machine speed and torque, stator current peak, and settling time of all of these and bounds are set based on desired operational limits.



*(pm) Performance measures

Fig. 6. System survivals within performance bounds.

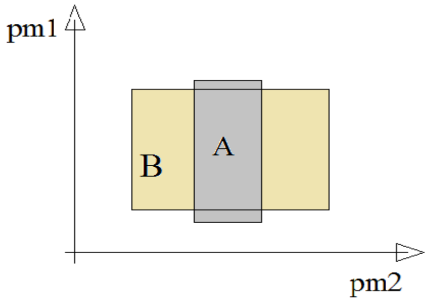


Fig. 7. System failures outside performance bounds.

VI. Conclusion

The proposed methodology for reliability modelling covers essential faults in a drive system, including the machine, power electronics, and sensors. The methodology leads to a FMEA reliability model of an induction motor drive and can be extended to other drives or to more faults in other components. A model was validated in experiments and used for the complete procedure Simplifications were proposed based on dominant fault modes, which were found to be faults in the speed encoder and on a high–low failure-rate approach by calculating RPN.

Further research could apply this methodology to other drive topologies, more components in any topology (e.g., link capacitors, gate drives, etc.), design of fault tolerance, and actual field failure rates. Even though FMEA models use a fixed failure rate, which might not be accurate since failure rates generally vary with time, the proposed methodology serves the purpose of a comprehensive, straightforward, and versatile reliability modelling procedure.

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