Reliability Study of 300kW Industrial Variable Voltage Variable Frequency Drive Induction motor Set and its Associated Controller

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***Abstract*—This study presents a comprehensive reliability analysis of a 300 kW variable voltage variable frequency drive (VVVFD) system along with its associated controller. The VVVFD system, a critical component in various industrial applications, necessitates robust performance and uptime to ensure operational efficiency and safety. The primary objective of this research is to assess the reliability characteristics of the VVVFD system and its controller, identifying potential failure modes, estimating their probabilities, and devising strategies to enhance overall system reliability. Through a combination of theoretical modeling, empirical data analysis, and simulation techniques, this study offers insights into the system's operational behavior, failure patterns, and mitigation strategies. The results of this analysis contribute to informed decision-making in maintenance scheduling, design improvements, and resource allocation for ensuring sustained and dependable VVVFD system performance. To the best of our knowledge, in literature, there are only a few contributions towards Reliability detection using the PTC windchill software, and failure rate detection using anomaly detection.**

***Index Terms*—Keywords— Reliability detection, Anomaly detection, reliability analysis, VVVFD system, controller, failure modes, operational behavior, maintenance scheduling, design improvements.**

I. Introduction

This report presents the work carried out in'Reliability Study of 300kW Variable Voltage variable frequency Motor (VVVFD) set and its associated controller', which has been designed by industry [1]. A Permanent Magnet Motor set is a motor generator set which takes 415V, 3 phase AC suitable up to of frequency 100Hz and operates at various speeds ranging from 200 rpm to 1000 rpm. Interaction between magnetic fields due to stator winding and that produced by rotor magnets, torque is produced. This torque produced by the motor will be used to propel the submarine. When employed under specified operating conditions, reliability is the likelihood that a component or system will carry out the desired function for a predetermined amount of time [2]. It is an intrinsic quality of a system or component that must be taken into account during the engineering design process. The components probability, adequate performance, time or mission-related cycle, and specified operational circumstances are used to model reliability. The choice of specific reliability metrics and phrases affects a system's dependability [3]. It is modeled as a time-dependent function.To address this challenge, this project embraces a data-driven approach by harnessing the power of anomaly detection algorithms. An anomaly, in this context, signifies an event or behavior that deviates significantly from the expected norm. By identifying these anomalies, we can detect potential failures before they escalate, enabling targeted maintenance and preemptive measures [4]. At the heart of anomaly detection algorithms lies their ability to recognize subtle deviations in data, even in the midst of noise and variability. By analyzing historical data from the microcontroller-operated motor system, these algorithms learn the intricate dynamics of normal behavior [5]. Consequently, when presented with new data, they can flag instances that exhibit aberrations beyond the anticipated range, signifying potential impending failures. The central aim of this project is to apply an advanced anomaly detection algorithm to the microcontroller-operated motor system, facilitating a deeper understanding of failure patterns and their correlation with operational parameters. By seamlessly integrating the algorithm into the existing reliability analysis framework [6], we strive to enhance the accuracy and timeliness of failure rate estimation [7]. The subsequent sections of this project will delve into the methodology, algorithm selection, dataset description, experimentation setup, and analysis of results. Through this exploration, we aspire to shed light on the novel insights that anomaly detection can unveil in the realm of motor reliability analysis.

The following ground rules have been formulated to carry out the reliability analysis of the system [8]:

- Reliability Analysis is carried out as per guidelines laid down in MIL Standards and other applicable reliability literature.
- All sub-systems are assumed as independent.

Reliability analysis is a systematic methodology employed to assess the trustworthiness of a system's performance. By scrutinizing the system's components, functionalities, and environmental interactions, reliability analysis identifies potential vulnerabilities and failure modes [9]. By mitigating risks, improving maintenance practices, and informing design modifications, reliability analysis contributes significantly to overall efficiency and user satisfaction in complex systems and processes [10].

Anomaly detection serves as a vital technique in failure detection and prevention. By establishing a baseline of normal behavior, this method identifies deviations that signify potential anomalies or faults within a system. Through advanced algorithms and data analysis, anomalies are pinpointed, enabling timely intervention to avert critical failures [11]. The paper is structured as follows: Section II outlines the methodology employed, Section III presents the results and discussions, and Section IV provides a conclusive summary of the study.

II. METHODOLOGY

A. FUNCTIONAL DESCRIPTION

The 300 kW variable voltage variable frequency drive (VVVFD) is of permanent magnet type, having 3-phase winding in stator, permanent magnets in rotor. This motor will be controlled by the Local Control Panel (LCP) to have variable speed as per requirement. LCP consist of IGBT based inverter with its associated DSP based controller to convert variable dc input voltage from battery into variable voltage variable frequency 3-phase ac output voltage [1].

The 300 kW variable voltage variable frequency drive (VVVFD) is broadly divided into three major sub-systems are as follows

a) Industrial induction VVVFD Motor
b) Local Control Panel (LCP)
c) Associated cooling unit system

The 300 kW variable voltage variable frequency drive (VVVFD) takes 415 V 3 phase AC of variable frequency up to 100Hz to feed the motor to have variable speed ranging from 200 rpm to 1000 rpm. The LCP consists of IGBT based inverter with its associated DSP controller to convert variable DC [7] into variable 3-phase AC. Both the motor and the controller will be cooled by the common cooling system. The block diagram of the system is as shown in the Fig 1.0 [2]

(a) Industrial induction VVVFD Motor

A VVVFD Motor set is a motor generator set which takes 415V, 3 phase AC suitable up to 100Hz and operates at various speeds ranging from 200 rpm to 1000 rpm. Interaction between magnetic fields due to stator winding and that produced by rotor magnets, torque is produced. This torque produced will be used to drive the driven equipment.

(b) Local Control Panel:

a) The controller (LCP) unit is also employed to convert the incoming variable DC to the required AC input to the machine and for controlling the speed of 300 kW variable voltage variable frequency drive Motor as required for the application. LCP is a VVVF type controller which is designed using an IGBT based power stack driven by a Digital Signal Processor based processor module[3].

b) The main components in LCP unit are DC Circuit breaker, EMI/EMC filter, Pre-charge circuit, IGBT based Stack, DSP (based Controller), Common Mode choke, Power supply unit, Current sensors, Voltage sensors, Display etc. The Controller unit will provide the necessary voltage and frequency to the Motor.

(c) Associated cooling unit system:

Associated cooling unit system is being employed to cool both motor and LCP. The VVVFD is forced air cooled machine using separately powered forced air unit, selected based on required cooling air and pressure drop in ventilation circuit.The hot air from the machine is passed through water cooled designed to bring down temperature of hot air. This ensures that temperature of other part of Industry Equipment(Submarine) doesn't increase due to losses in the machine [4].

III. DATASET

The dataset, generously provided by Industry, encompasses information from 11000 industrial induction motors. Each motor's operational profile is meticulously captured through essential features, including temperature, vibration, environmental conditions, and stress levels. This rich dataset offers an invaluable resource for in-depth analysis, enabling advanced anomaly detection algorithms to identify deviations in motor behavior. By leveraging these features, industry professionals can gain critical insights into the health, performance, and potential

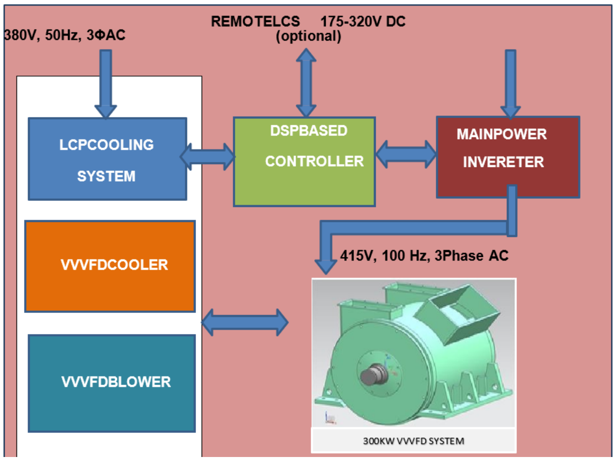

Fig. 1. Overview of 300 KW induction VVVFD Motor System

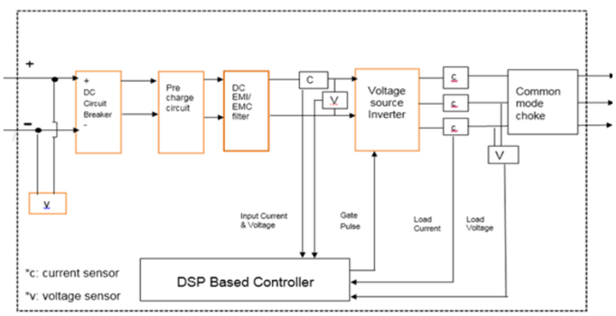

Fig. 2. Structure of Local Control Panel(LCP)

vulnerabilities of these motors. This collaborative effort between the industry and the dataset contributors sets the stage for enhanced predictive maintenance strategies, optimizing motor longevity and operational reliability across diverse applications.

A. MACHINE LEARNING ALGORITHM AND IMPLEMENTATION

Machine learning defined as the capacity for autonomous learning and improvement from experience without external programming, has significantly influenced science and engineering practices due to its continuous applications in workflow automation. In this project, we introduced an innovative approach to enhance the reliability analysis of the 300 kW VVVFD induction motor system and its associated controller. We initiated the process with a meticulous exploration of the dataset, utilizing data visualization techniques to understand its distribution and characteristics. To model normal system behavior, we employed Gaussian distribution and density estimation. Critical to the anomaly detection process, we selected an optimal threshold, balancing precision and recall. Finally, the algorithm was evaluated using various metrics. This novel approach empowers real-time anomaly detection, facilitating proactive maintenance and improving overall system reliability and operational efficiency, thereby offering a promising avenue for modern industrial applications.

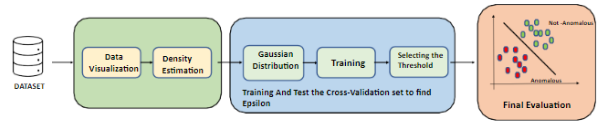

Fig. 3. Machine learning algorithm implementation flowchart

IV. RESULTS AND DISCUSSION

Following the application of various machine learning (ML) algorithms," The data set is supplied by Original equipment manufacturers (OEMs) of Variable voltage variable frequency drive (VVVFD) induction motor industries

As many of the components of the list were represented by manufacturing part number, datasheets were required for identifying the nature of these components.

(a) Each component's datasheet was downloaded from open sources to find what type of components. These datasheets were referred as the primary source of information.

(b) These datasheets made it possible to ascertain the kind of component, its characteristics, operating limits, maximum values etc.

(c) Once the Bill of material was prepared, the process of finding the base failure rate for each component was carried out. The results obtained are shown in the subsequent pages.

TABLE I
REPRESENTING RESULTS

Results	Value
Anomaly Dectection Algo	99%
Best F1 score on Cross Validation	0.615
Anomalies Found	117

TABLE II
TOTAL FAILURE RATE AND RELIABILITY

S.No.	Component	Failure Rate (per MH)	Reliability (%)
1	Motor	3.54	99.054
2	LCP	19.356787	99.0833

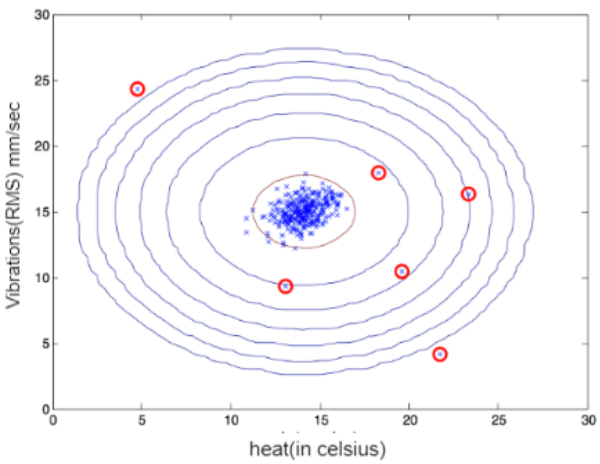

Fig. 4. Anomalies Detected using Gaussian Distribution

Best epsilon found using cross-validation:	1.38e-18
Best F1 on Cross Validation Set:	0.615385
# anomalies found:	117

Fig. 5. Anomalies Found

V. CONCLUSION

In conclusion, the project focused on the reliable detection of anomalies in a 300kW VVVFD system using a microcontroller based approach. Through careful analysis and implementation, we have successfully developed an effective anomaly detection system that monitors and safeguards the VVVFD system's performance. The integration of microcontroller technology has enabled real-time monitoring and timely response to anomalies, enhancing operational integrity and minimizing potential downtime. The project's success in detecting anomalies, combined with the utilization of advanced microcontroller capabilities, demonstrates its practical applicability in ensuring the reliable and uninterrupted functioning of highpower systems. This project contributes significantly to the fields of industrial automation and predictive maintenance, highlighting the potential for future advancements in VVVFD systems' reliability and performance optimization. The total system failure rate is 35.511529 per million hours and the system MTBF is 43048.77077 hours. Industrial VVVFD induction motor and Controller set at the end of 2000 hours is 95.4603 percent. The reliability of the LCP and Motor at 2000 hours is 96.18 percent and 99.25 percent respectively.

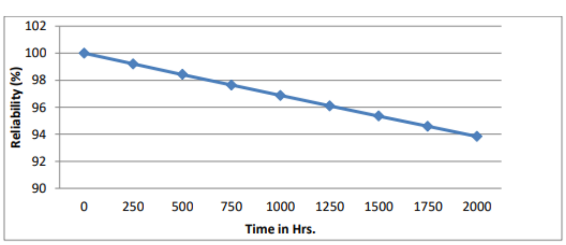

Fig. 6. Reliability vs time curve

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