Thesis Abstract

Induction machines are widely applied in industries and essential parts of industrial systems. They are found in various applications for marine propulsions, aerospace actuators, and traction in electric vehicles/hybrid electric vehicles. Despite their rugged construction, they are subjected to fault due to aging, severe operating conditions, and harsh environments. Industrial surveys have shown that stator winding accounts for a significant portion of faults in electrical machines. Stator winding inter-turn short is the primary root of stator winding fault and can spread out and lead to catastrophic damages. Diagnosis and prognosis of this kind of fault have become an important topic, which is potential to increase the availability and reliability of electrical machines and the associated systems, reduce maintenance cost, and support maintenance decision making.

Diagnosis is the process of detecting fault occurrence, isolating the true fault from other ambiguous factors, and estimating the severity information. Prognosis is the process of predicting the fault progression and estimate the remaining useful life before the machine must be stopped. Therefore, early fault detection is critical for an effective and timely prognosis. However, there is little research proposed to address this problem, and the current approach has the drawback of requiring prior information in implementation. Fault severity estimation/measurement is another essential part of diagnosis process. While the fault is represented by two electrical parameters, viz. fault loop resistance and percentage of shorted turns, the early fault severity estimation of these direct electrical fault parameters has achieved limited success. Regarding prognosis, most of the research on inter-turn short fault is focused on fault detection, and is lacked of work on prognosis. There is little research on prognosis, of which there is no work using the direct electrical fault parameters. This thesis aims to develop a model-based framework using the electrical fault parameters and propose the associated techniques to address the aforementioned challenges of diagnosis and prognosis of stator winding inter-turn short fault.

The challenge of incipient fault detection is on the influence of the ambiguous factors, such as inherent asymmetry, voltage imbalance, and load variation, causing the same effects in the diagnostic indicators as the fault does or masking the fault occurrence. Model-based technique is the key approach to address this challenge. Its strength lies in the ability to incorporate the electrical fault parameters in the model and hence the analysis of fault effects. Two generic methods are proposed. The first is a decomposition method in which the effect of fault is decomposed from that of the ambiguous factors, so that a fault-dependent quantity, sensitive to only fault severity level, can be generated. The second method is a multiple-indicators approach, based on the multi-physics in nature of electrical machines, in which certain supplementary indicators are concurrently used.

The necessity for prognosis is the availability of certain fault-related quantities. The electrical fault parameters are direct severity quantities, but they are unknown and unmeasurable. In this thesis, an estimation process is proposed to identify these parameters, linking the diagnosis and prognosis process. The filtered-based approach, using particle filter, is applied to estimate the fault parameters. Particle filter is chosen since it can be applied to a general nonlinear system under non-Gaussian noise. Also, a significant advantage of particle filter-based approach is that the statistical quantities of the particles can be employed to quantify the performance of remaining useful life estimation results. In order to identify the degradation models, both static and nonlinear dynamic functions are assumed, and standard data modelling method can be applied.

The theoretical development is supported by experimental results, where various fault severity levels and different loads and voltage imbalance conditions are taken into account to validate the incipient fault detection, electrical fault parameter estimation, and degradation model identification and remaining useful life prediction. The proposed framework and associated techniques are generic in nature and can be diversified to include other faults/ machines.