DIAGNOSTICS OF FAULTS IN ROTATING ELECTRIC MACHINERY USING WIRELESS SENSORS

ABSTRACT

In critical applications utilizing rotating electrical machines, condition-monitoring systems (CMS) are deployed to prevent unexpected breakdown and schedule maintenance. The conventional CMS for rotating electrical machines are predominantly based on externally available signals, while the internal signals, especially on the rotor, remain relatively unexplored. To access these internal signals, wireless sensors offer an effective solution in terms of cost and ease of deployment. This opens up an opportunity to explore invasive condition monitoring systems for electrical machines. This thesis presents the development of a wireless sensor based CMS to diagnose multiple electrical faults in a brushless synchronous generator (BLSG). BLSGs are widely used for electrical power generation in marine, aerospace and industrial applications.

A feasibility study is conducted to evaluate the applicability for utilizing wireless RF as communication means inside an electrical machine. Based on the study it is concluded that the wireless link quality metrics do not show any deterioration inside the machine and in fact, are enhanced compared to indoor environment. With the confidence from the experimental feasibility study, a rotor mounted wireless sensing system is developed for a 14 KVA BLSG test bed. The test rig is capable of emulating stator armature faults, rotor field winding faults and rotating rectifier diode faults and simultaneously measuring rotor electrical signals during machine operation.

To identify the characteristic electrical fault signatures under stator armature inter-turn, rotor field inter-turn and rectifier diode faults, a phase domain model of a salient pole BLSG is developed. Modified-Winding Function Approach is utilized to compute the inductances of the main generator and exciter generator. The developed model is able to come close to replicating the actual machine behavior during healthy state and progression of the faults. Based on the model, it is found that the current state of art indicators may not be suitable for reliable diagnosis of multiple faults. A new set of fault indicators based on rotor based electrical signatures is proposed and its effectiveness for fault diagnosis under multiple fault conditions is presented with experimental validation.

A comparison of the conventional fault signatures based on stator terminal signals and external casing vibration with the invasive electrical signals from rotor mounted wireless sensors is presented. To enable this comparison under different fault conditions, a normalized fault severity metric is introduced. From the investigation, the rotor based electrical signal measurements obtained through a wireless sensor is found to be more effective in tracking the evolution of a fault. A hybrid fault diagnosis scheme, based on the fusion of conventional and invasive fault signatures is presented. Based on this study, it is found that the overall diagnostic performance is improved compared to the schemes that only rely on either non-invasive or invasive fault signatures.

The present work is focused on identifying fault signatures based on internal electrical signals. An investigation into other key physical quantities such as thermal, magnetic and mechanical needs to be carried out. The selection of measurements (noninvasive and invasive) required for reliable diagnosis can be formulated as an optimization problem. This will help in identifying the minimum set of measurements required to achieve high diagnostic accuracy. The fault severity metrics proposed in this thesis captures the resultant effect of the fault on the machine. Estimating the physical fault severity will aid in the better assessment of the machine's condition and in prognosis, for calculating the remaining useful life.

LIST OF PUBLICATIONS

Journal Articles:

P. S. Kumar, L. Xie, B. H. Soong, and M. Y. Lee, “Feasibility for utilizing IEEE 802.15.4 Compliant radios inside rotating electrical machines for wireless condition monitoring applications,” IEEE Sensors Journal, vol. PP, no. 99, p. 1, 2018. [Early Access]

Conference Articles:

P. S. Kumar, L. Xie, M.S.M. Halick, and V. Vaiyapuri, “Online Stator End Winding Thermography using Infrared Sensor Array,” in the 43rd Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2018. [Presented; to be published in IEEExplore]

P. S. Kumar, L. Xie, K. Thiha, B.-H. Soong, V. Vaiyapuri, and S. Nadarajan, “Rotor mounted wireless sensors for condition monitoring of brushless synchronous generator,” in Industrial Electronics Society, IECON 2017-43rd Annual Conference of the IEEE. IEEE, 2017, pp. 3221–3226.

P. S. Kumar, L. Xie, and B. H. Soong, “Feasibility of wireless RF communication inside rotating electrical machines for condition monitoring applications,” in Proc. 19th Int. Conf. Electrical Machines and Systems (ICEMS), Nov. 2016, pp. 1–6.

P. S. Kumar, Y. Chen, M. Y. Lee, S. Nadarajan, and L. Xie, “Modified winding function approach to stator fault modelling of synchronous generator,” in Proc. 12th IEEE Int. Conf. Control and Automation (ICCA), Jun. 2016, pp. 161–166.