Non-invasive generator diagnosis: A model-based idea evaluation

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Abstract

Non-invasive diagnosis of machines like generators and motors is a technology worthwhile pursuing given its several advantages. Invasive diagnostic sensors could interfere in the operation of the machine and also call for stoppage of the machine for repair and inspection of the sensors. In this research work, the feasibility of using multiple external magnetic flux sensors to diagnose and identify generator defects has been explored. A multiphysics model of the generator solving relevant electromagnetic equations was developed using the COMSOL finite element (F.E.) multiphysics software. The model was used as a tool to study the feasibility of measuring and analyzing the external magnetic flux to detect, identify specific defects and to determine location of the defects.

Introduction

The idea of non-invasive sensing using external magnetic flux to diagnose machine defects has been investigated by several researchers. Tehrani et al. [1], published a review paper on numerous aspects like flux measurement sensors available, diagnosis schemes adopted by other researchers, etc. Irhouma et al [2] performed experiments employing multiple external flux sensors on a motor to demonstrate diagnosis of stator faults. Relevant to the current paper, Santos et al. [3] measured the external magnetic flux and detected rotor turn fault or short circuit in a motor. The fault signal increased with the severity of the defect or percentage of short circuit turns. The studies mentioned here are encouraging and indicate that it is technically feasible to use the external magnetic flux to detect defects within rotary machines. However, a gap in most studies, is examining the possibility of identifying specific defects and of pinpointing the location of a specific defect.

This paper describes a multiphysics or electromagnetic model developed to simulate a 8 pole 50 Hz generator of outer diameter 2.640 m [4], using the COMSOL multiphysics code. The purpose of the model is to study the feasibility of multiple external magnetic flux sensors to detect, identify and if possible locate specific defects. For example a stator short circuit fault and static rotor eccentricity fault are similar to each other, in terms of inducing eccentricity in the electromagnetic fields. This calls for a method to distinguish one fault from the other and if possible to determine the location of the fault. Several defects were simulated using the model and at the end characteristics of the transient magnetic flux profies specific to the defects were identified.

Keywords

Generator, non invasive, multiple sensors, diagnosis, multiphysics model

Simulation Model

The multiphysics model of the generator was developed using the rotating machinery module in COMSOL. Fig 1A shows the schematic and figure 1B shows the meshing or discretization scheme.
The rotor was prescribed a rotational frequency, fr, of 12.5 Hz since line frequency, 50 Hz = fr × number of poles/2. The rotor coils was prescribed a total current of 25000 A DC. The stator was fixed and the external air space was also modeled.
Following are the equations solved by the code:
The ampere's law:
$\nabla \times \mathrm{H} = \mathrm{J}$ where H or magnetic field strength = B/μ, B is the magnetic flux density and μ is the magnetic permeability.
$B = \nabla \times A$ since B is the curl of the current, A.
$J = \delta E$ where E is the electric field in the coils and δ is the electric conductivity of the copper wires.
A triangular meshing scheme was used and the critical zones were well resolved for properly capturing the physics. The model simulated closed circuit conditions, and a resistance inductance circuit was connected to the stator coils (figure 1C).

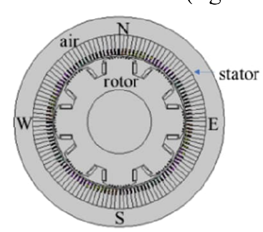

Fig 1A

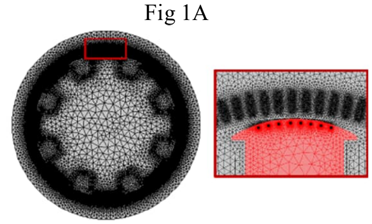

Fig 1B

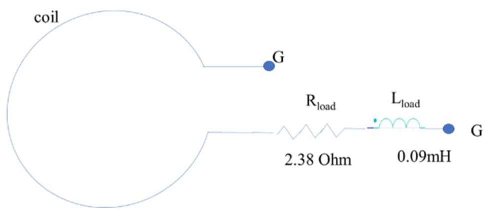

Fig 1C

Fig. 1A: Schematic of generator simulation, Fig. 1B: Meshing or discretization of domain, Fig. 1C: External RL load circuit.

Simulation Results

Baseline or healthy generator: The model was run in the transient mode with a time-step of 1e-4 s and after completion of the run, the results were postprocessed to obtain results relevant to generator functionality. Figure 2A and 2B below show the current and voltage waveforms across the stator phases. Figure 2C shows the magnetic flux density distribution across the domain as well as in the external air space, something of interest to this study. The results below correspond to a healthy or non-defective generator.

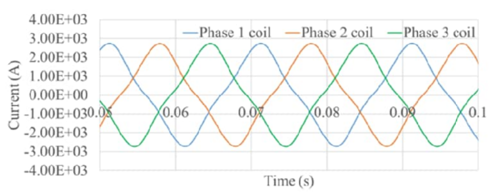

Fig 2A

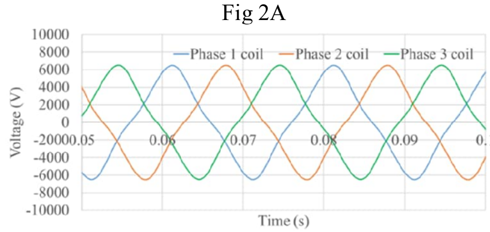

Fig 2B

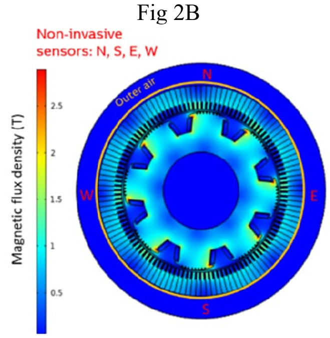

Fig 2C

Fig 2A: Current vs time on stator coils, Fig 2B: Voltage vs time on stator coils, Fig 2C: Magnetic flux density distribution computed by the model.

N, E, S, W marked in figure 2C are points on the generator casing and represent location of the non-invasive magnetic sensors to measure the external or leakaged magnetic flux. During the simulations, the leaked magnetic flux was computed at these points as a function of time.

Defects in generator: In this section, results of simulating defects encountered in generators, using the model are depicted. The leakage flux transient profiles computed at the external sensor locations (N, E, S, W), were studied to determine whether a given defect imposes a unique characteristic in the profiles, enabling its detection.

A challenge in identification of defects is to distinguish mechanical defects from each other like rotor static eccentricity from dynamic eccentricity. In static eccentricity (Fig 3A) the rotor and stator geometric centers are separated relative to each other by a fixed distance (ε = 2.5, 5, 7 mm in our study). However, the rotor rotates about its own geometric center (0,0). In dynamic eccentricity (Fig 3B) the rotor and the stator are not only shifted with respect to each other's centers, but the rotor also revolves around the geometric center of the stator (0, ε).

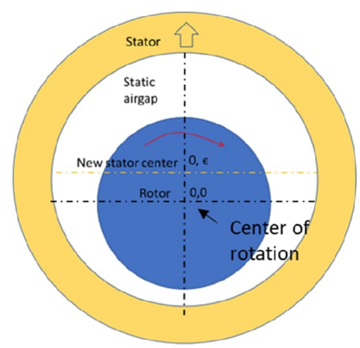

Fig 3A

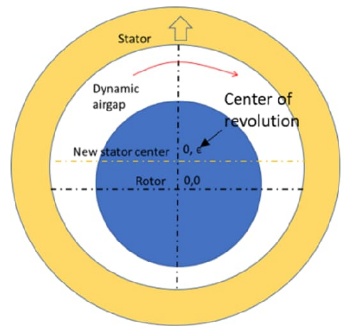

Fig 3B

Fig 3A: Rotor static eccentricity. 3B: Rotor dynamic eccentricity. Eccentricities are exaggerated for convenience of understanding.

Figure 4A shows the flux profiles computed under the baseline or healthy conditions at the N, E, S and W locations. It is seen that the profiles are similar to each other. The amplitude of each profile is roughly 1.5e-4 T.

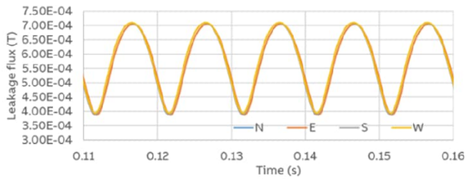

Fig 4A

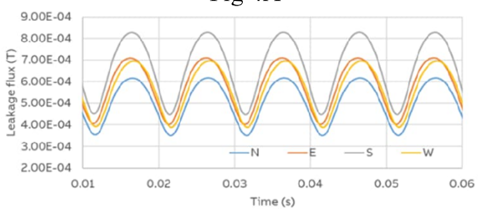

Fig 4B

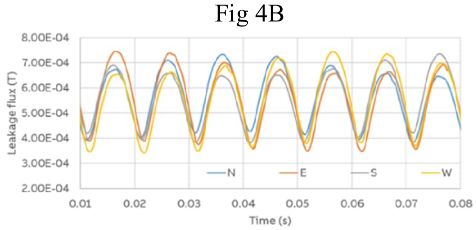

Fig 4C

Fig 4A: Leakage flux computed at N, E, S, W under healthy condition; 4B: Rotor static eccentricity condition and 4C: Rotor dynamic eccentricity condition.

Figure 4B, shows profiles under static eccentricity condition (ε = 2.5 mm) of the rotor. The figure reveals unequal amplitudes at each selected point. However the average amplitude is almost the same as that computed in the baseline case (1.5e-4 T). The profile at point S shows the highest amplitude since the rotor was shifted towards S and away from N. It is also to be noted that point S always shows the highest amplitude. Hence using multiple sensors it is also possible to identify the location of a particular defect. Figure 4B shows leakage flux profiles under rotor dynamic eccentricity condition (explained in fig 3B above). Here the average flux amplitude is also the same as in the baseline case at any instant of time. However, the highest amplitude is experienced by all points N, E, S and W turn by turn. This is because at one instant the rotor may be closest to one external point and at some other instant it may be closest to another point. The observations from figures 4A, B and C, suggest that using multiple sensors, it is not only possible to detect a defective mechanical condition of the rotor/stator assembly, but it is also possible to distinguish one defect from the other.

Besides the identification of specific mechanical defects, differentiating electrical faults from mechanical faults is also crucial in machine diagnosis. Stator interturn shorting is a common fault in generators and also motors. The fault is identical to the rotor static eccentricity fault, since in both cases there is a magnetic field disruption on a single side. The generator model was used to simulate cases of stator interturn short circuit faults (Fig 5A). To simulate the effect, a few coil groups were selected for deactivation. Figure 5B shows magnetic leakage flux profiles at the N, E, S and W external points corresponding to the defect.

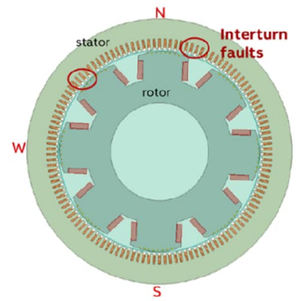

Fig 5A

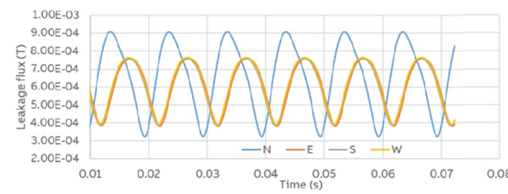

Fig 5B

Fig 5A: Inter turn stator short circuiting [4]; Fig 5B: Leakage flux external points computed under stator shorting condition.

It is seen that the profile amplitude at N is clearly different than that at the other points, E, S and W. In other words the average amplitude is no longer equal to that in the baseline case (1.5e-4 T shown in figure 4A). This is unlike the case with rotor static eccentricity (Fig 4B) where the average amplitude is equal to that in the baseline case (both equal to 1.5e-4 T). Hence we see that using multiple magnetic flux sensor it is possible to distinguish electrical faults from similar mechanical faults.

Conclusions

The multiphysics model of the generator developed in this study proved to be a useful tool in studying how specific defects manifest themselves in magnetic flux profiles. The idea of using multiple external magnetic flux sensors to detect, identify and locate specific defects seems promising. This is evident from the unique signatures imposed by individual defects on the magnetic flux transient profiles. The study establishes a stepping stone for extensive future studies, both computational and experimental, in the field of non-invasive generator defect diagnosis.

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