Development of Inter-Turn Short Circuits Sensor for Field Winding of Synchronous Generator

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ABSTRACT – An effective method of detecting inter-turn short circuits on round rotor windings is described. Shorted-turns can have significant effects on a generator and its performance. A method of detecting inter-turn short circuits on rotor windings is described. The approach used is to measure the rate of change of the air-gap flux density wave when the rotor is at operating speed and excitation is applied to the field winding. The inter-turn short circuits sensor for synchronous generator's field winding has been developed. The sensor, installed in the generator air-gap, senses the slot leakage flux of field winding and produces a voltage waveform proportional to the rate of change of the flux. For identification of reliability for sensor, a inter-turn short circuits test was performed at the West-Inchon combined cycle power plant on gas turbine generator and steam turbine generator. This sensor will be used as a detecting of shorted-turn for field winding of synchronous generator. The purpose of this paper is to describe the design and operation of a sensitive inter-turn short circuits detector. In this paper, development of inter-turn short circuits sensor for field winding of synchronous generator and application in a field.

1. INTRODUCTION

The rotor winding of large utility generators may develop inter-turn short circuits, which can increase in severity over a period of time. Rotor shorts produce damage to the main wall and inter-turn insulation at the site of the short due to overheating, and thermal unbalance due to unsymmetrical heating around the rotor. This cause of increased vibration may be difficult to distinguish from that due to other causes such as ventilation blockages and end winding packing misalignment, as well as potentially disastrous mechanical problems such as crack development[1].

The use of shorted-turns sensor has proven effective in the detection of generator rotor winding shorted turns and has helped to improve the quality of predictive maintenance decisions concerning when or if rotor rework should be performed[2].

Analysis of air-gap flux probe data can pinpoint the number and location (pole and coil) of inter-turn short circuits without having to take the generator on-line[3].

2. INTER-TURN SHORT CIRCUITS IN THE FIELD WINDING OF SYNCHRONOUS GENERATOR

Inter-turn short circuits can have significant effects on a generator and its performance. If the percentage of total turns shorted out is small, the generator may be able to run at rated load for years without further problems. Larger shorted turn percentages, however, can cause operating conditions that may limit unit loads. If the problems become severs, forced outages may occur. condition that may result in running a rotor with shorted turns include:

- Rotor unbalance that varies with field current changes(A rise of operating temperature)
- Rotor vibration due to unbalanced magnetic force
- Higher field current than previously experienced at a specific load
- Higher operating temperatures due to higher field current

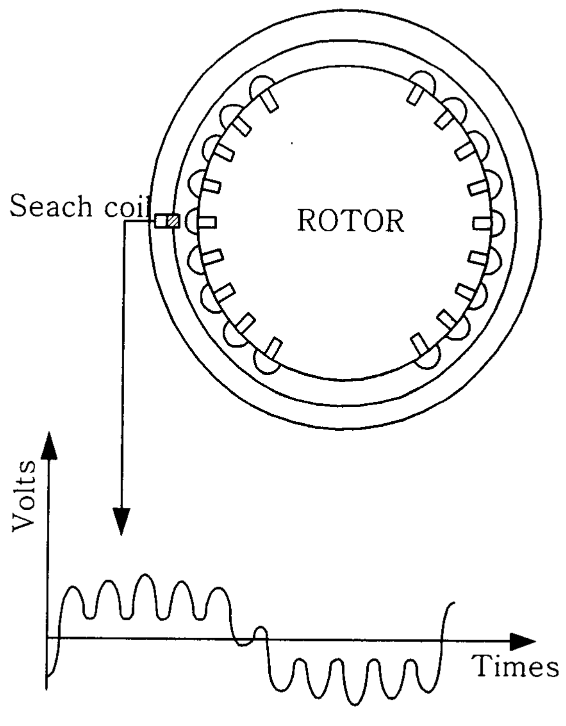

Fig. 1 Flux probe test.

2.1 Structure and insulator of generator rotor

The contents of one of the axial slots in rotor is indicated in Fig. 2. The winding in the slot consists of approximately 7 ~ 18 copper strips, separated from each other and the rotor body by insulation.
Typically, turns insulation material is a glass/eppoxy material, a glass/polyester material, nomex, less then on millimeter thick. The thick of turns insulation material is approximately 0.3 ~ 0.5 millimeter.

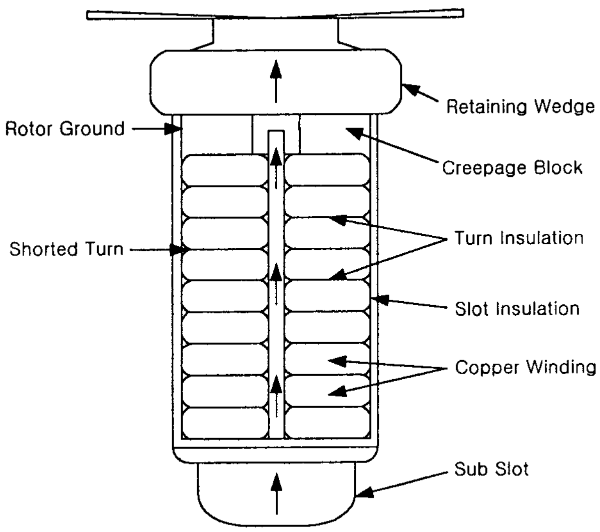

Fig. 2 A cross sectional of field winding.

2.2 Causes of inter-turn short circuits

The two main causes of inter-turn short circuits in rotors are conducting debris, which has been attributed to copper 'dusting' and pick-up, and localised degradation of insulation due to overheating. In the first copper particles are produced by abrasion between half conductors ('dusting') when on barring gear, or by friction between conductor and main wall insulation at normal running speed. Both mechanisms for producing debris may be present, but 'dusting' has been the main cause in those rotors with half conductors. inter-turn short circuits and earth faults located over the body length of rotors have been attributed to this mechanism.

Localised and rapid degradation of insulation can be the result of shorts due to conducting debris, as explained later, but overheating of insulation because of inadequate ventilation can also cause shorts if there is space to allow adjacent turns to come together by distortion. These are more likely to occur in the end winding region.

2.3 Failed insulation

Inter-turn short circuits are usually the result of failed insulation between individual windings in a rotor. Insulation failure can be a result of turn-to-turn movement of the rotor windings. Relative movement of turns can degrade the intervening insulation layer or cause misalignment that can result in turn-to-turn contact. Failures in any of the subsystems designed to contain the thermal and mechanical forces that develop in the rotor at speed can also give rise to turn-to-turn movement. Some of these failure mechanisms include coil foreshortening, end-strap elongation or inadequate end-turn blocking. Metallic contamination can also result in shorted turns by forming conductive bridges between turns. In addition to the turn-to-turn contact within a single coil, turn-to-turn contact between coils in the end-turn region can occur that will remove one or two entire coils from the field circuit.

Fig. 3 failed field winding.

3. ON-LINE INTER-TURN SHORT CIRCUITS DETECTION SYSTEM

3.1 Analysis of field

Development magnetic field intensity using Biot-Savart's low and Ampere's circuital low, then inducted magnitude of voltage develops by Faraday's law. In Fig. 4, if at the origin O, current fact on z-axis is , point P of magnetic field intensity H by is following as Biot-Savart's low.

$$H = \frac{I}{2\pi a}[AT/m] \qquad (1)$$

If, Eq (1) develops by magnetic flux density

$$B = \mu H = \mu_0 \mu_r H = \mu_0 \mu_r \frac{I}{2\pi a}[Wb/m^2] \qquad (2)$$

And if Eq(2) develops by flux

$$\phi = BA = \mu_0 \mu_r HA = \mu_0 \mu_r \frac{I}{2\pi a} A[Wb] \qquad (3)$$

Where, A : cross area of sensor coil. if Eq (3) develops by voltage

$$e = -N\frac{d\phi}{dt} = -N\frac{d}{dt}(\mu_0\mu_r\frac{I}{2\pi a}A)[V] \quad (4)$$

Therefore, in Eq(4) flux phase delays 90 degree inducted voltage in sensor and conse quences a inverse proportion adjacent coil and the gap.

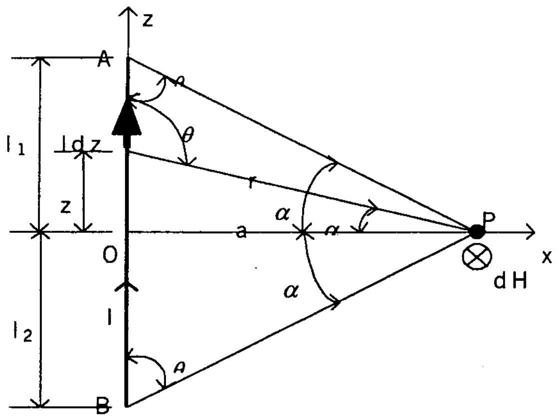

Fig. 4 magnetic field indensity with current.

3.2 Manufacture of practical product

First, it manufactured practical product. Fig.5. shows sensor of produced product, previously.

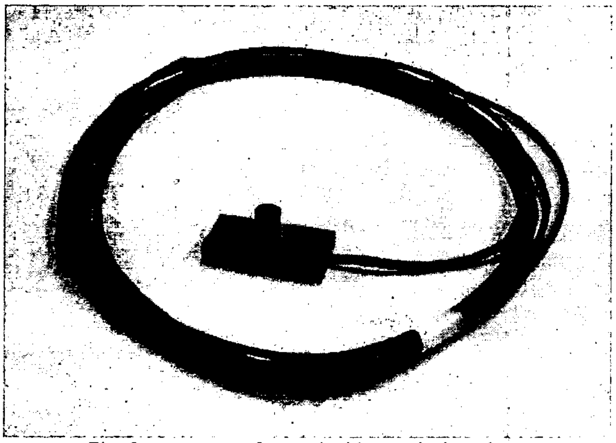

Fig. 5 sensor manufactured with practical product.

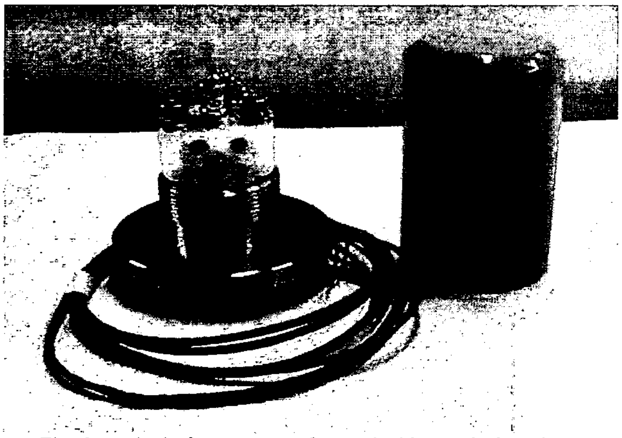

Fig. 6 terminal of sensor manufactured with practical product.

Fig.6. shows set of generator outside for measurable induced voltage from sensor as terminal of practical product.

4. EXPERIMENT AND RESULTS

4.1 Experiment under construction

Manufactured this product is based on West-Inchon combined cycle power plant G/T(Gas Turbine), S/T(Steam Turbine) generator and set G/T #6, S/T #14 for aim of preventing maintenance. which is measured sensitivity of sensor in trial by measurable system with assistance of KEPRI(Korea Electric Power Research Institute)

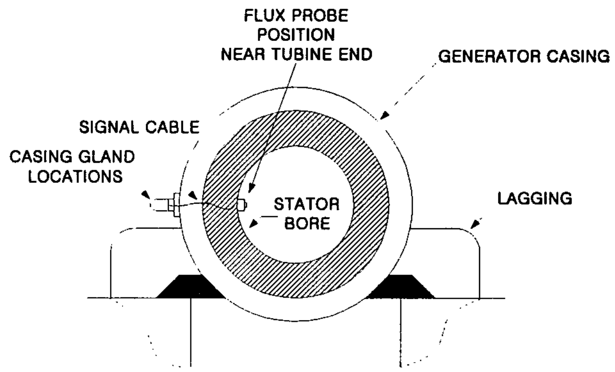

Fig. 7 Location of sensor from generator.

Magnetic wedges in the rotor coil slots reduce the air-gap slot leakage flux signal. Thus, inter-turn short circuits detection sensitivity is reduced in these slots. If plans air being made to assemble an air-gap probe, extra effort and possibly cost should be expended to ensure that all wedges in the leading slots at the axial position of the flux probe are non-magnetic.

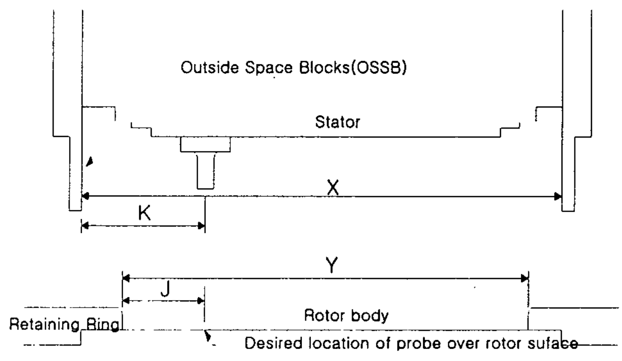

Fig. 8 Location of sensor from generator.

The technology uses a simple permanently mounted air-gap flux probe positioned on a stator wedge. The probe is sensitive to changes in radial flux density magnitudes as the rotor surface passes by. This waveform is the time rate of change of the radial air-gap flux density waveform. Analyses of the flux probe waveforms can detect critical inter-turn short circuits conditions.

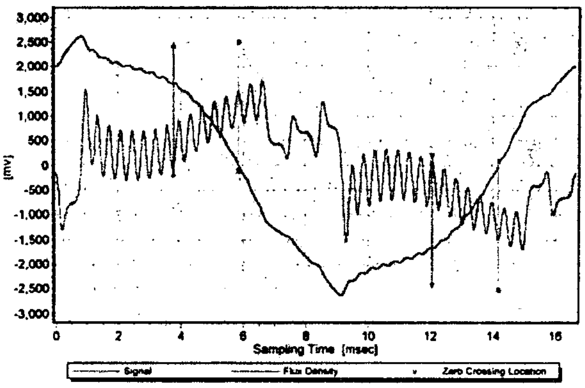

Fig. 9 voltage waveform from existing-product.

Fig.9. shows an acquired data with measurable system through an attached existing-product in West-Inchon combined cycle power plant S/T #12.

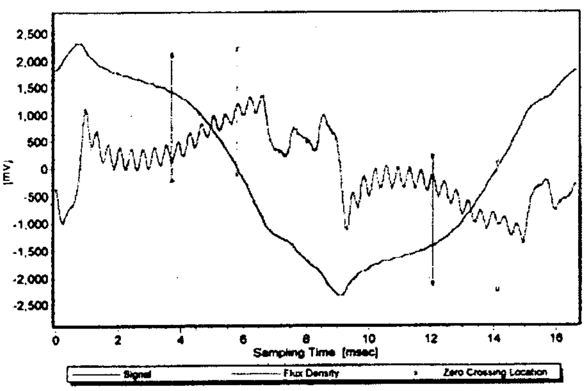

Fig. 10 voltage waveform from practical product.

Fig.10. shows an acquired data with measurable system through an attached practical-product in West-Inchon combined cycle power plant S/T #14.

5. CONCLUSION

In this paper, it developed that the inter-turn short circuits sensor of generator and applied to experience. But, it occurred a defect of dropping sensitivity in contrast to existing-product and verified an interactive by turns and gap. In conclusion, presently, it is to make the next product for a setting shorted turns sensor under regurated maintenance of West-Inchon combined cycle power plant #11GT. In next project, it is aim of a perfect product. Conclusively, which is a demonstration of product in the works.

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