FLUX MONITORING IMPROVEMENTS FOR ON-LINE CONDITION MONITORING OF TURBINE GENERATOR ROTORS

M. Sasic
Iris Power LP
Mississauga, Canada
msasic@irispower.com

S.R. Campbell
Iris Power LP
Mississauga, Canada
msasic@irispower.com

B. Lloyd
Iris Power LP
Mississauga, Canada
msasic@irispower.com

***Abstract* - Flux monitoring via air gap flux probes is a proven technology used for many years in synchronous machines to determine the presence of turn-to-turn shorts in a rotor winding. This information is critical in planning maintenance outages and in augmenting on-line vibration analysis. Traditionally, flux measurements have been done using flux probes installed on a stator wedge and a portable or permanently connected instrument. To achieve a reliable diagnostic, the signals from the flux probe had to be measured under different generator load conditions ranging from no load to full load. This requirement presented a serious obstacle in the application of this method on base load units where load adjustments are difficult. A new design of flux probe, installed on a stator tooth, and a novel approach in algorithms used to analyze measurements can help minimize the need for tests at different load conditions and still provide reliable diagnostics. This paper describes the implementation of new hardware and software and case studies that demonstrates the effectiveness of the new method in eliminating the need for load maneuvering.**

I. INTRODUCTION

A turbine generator rotor consists of a solid forging made from magnetic alloy steel and copper windings, assembled in slots machined in the forging. The winding is secured in slots by steel, bronze or aluminum wedges. At each end of the rotor, sections of the rotor winding are supported by retaining rings. Modern rotor winding insulations are made mostly from epoxy/polyester glass/Nomex™ laminate strips and channels. The strips are used to provide inter-turn insulation and molded channels are used to provide ground insulation. The rotor insulation should be designed to withstand electrical, mechanical, thermal and environmental stresses. Shorted turns are the result of failed insulation between rotor turns and are a relatively common occurrence in large turbine generators. Major causes of shorted turns in rotor windings are contamination with conductive debris and turn-to-turn movement of the rotor windings caused by high centrifugal loads and axial thermal expansion forces. The condition of the rotor winding insulation is difficult to assess during a shutdown due to limited access and the frequently intermittent nature of faults during operation versus at standstill. Consequently, on-line testing is a more effective way to detect and locate shorted turns during operation that can then be repaired during scheduled outages.

Flux monitoring using temporary or permanently installed flux probes has been used since the early 1970's [1]. Flux measurements are used to determine the existence of turn-to-turn shorts in the rotor winding. All of the methods available are based on measurement of the relatively weak stray flux (rotor slot leakage flux) using flexible or non-flexible polymer encased stator wedge mounted probes [2-4]. The stray flux from each rotor slot is proportional to the total ampere-turns in each slot. If shorts develop between turns, then the ampere turns in that slot drop, and the stray flux is reduced. The magnitudes of these stray fluxes can be measured using portable or permanently installed instruments and shorted turns can be identified by comparing the difference in the induced voltages from one pole to another pole. The main challenge in earlier technologies is the need to maneuver the generating unit load to achieve the maximum sensitivity to shorted turns in every slot of a rotor. Other problems in diagnosing turn to turn shorts are related to both the type of the probe and instrumentation/algorithms used for detection of shorted turns. [2-4]

II. TOTAL FLUX PROBE DESIGN

Some of the limitations of existing probe designs are related to their design and installation methods. Commercially available leakage flux probes typically consist of a custom-wound wire coil, on a flexible mount or encapsulated in epoxy body. Such probes typically include a solid ground plane shield, producing eddy currents when exposed to strong magnetic fields present in the air gap of a rotating machine. These eddy currents may interfere with stray flux measurements. Another disadvantage of existing flux probe designs is that they can be displaced under high wind forces generated in the air-gap, due to their mass and size, or can be damaged during rotor insertion after major outages.

To minimize risks associated with this, some flux probe manufacturers require that wedges where a flux probe will be installed to be drilled and support dowels installed. This operation may affect mechanical properties of the wedge and is highly invasive to the machine. Some more current probe designs are able to overcome disadvantages of existing designs. The new design probes are comprised of a number of printed circuit layers, configured on a flexible base material. The flexible probe is designed for application on a stator tooth (Fig. 1). The new probe directly measures the main magnetic flux since it is mounted on the steel core tooth, rather than a wedge.

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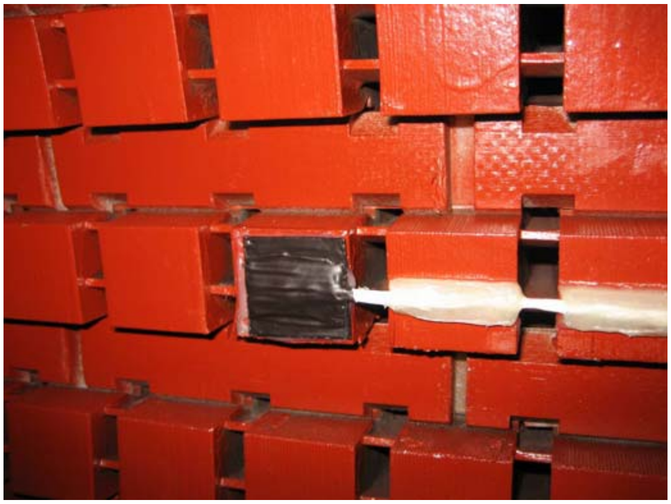


Fig 1: New probe design shown mounted on a stator core tooth

III. NEW FLUX MEASUREMENTS

Along with the more current design of probe, a second generation of electronics and interpretation software has been developed. The software and electronics are available for both salient pole and round rotor machines. The instrument shown in Fig. 2, is equipped with inputs for different types of flux probes and three different synchronization methods are possible: using a dedicated synchronization shaft-mounted marker, internally to AC power input, or externally to any other AC signal in the 40-240 V range. This key-phasor signal is used to locate the shorted coil for repair. Both portable and continuous flux monitoring instruments can be applied. The electronics is similar in both and is based on a custom designed Field Programmable Gate Array (FPGA) based circuit capable of fast data acquisition at a very high sampling rate. This sampling rate enabled the use of new algorithms for detection of shorted turns. Different communication protocols (USB or Ethernet) can be used for connection to a PC. Time based measurements can be used to collect data in user specified time intervals, as short as one measurement every five seconds. This method is very useful to collect different load data automatically at different loads during fast load changes.

Fig 2: Portable Rotor Flux Analyzer

All measurements collected are stored in the instrument internal memory and can be downloaded to a Microsoft Access™ data base, consisting of a number of folders representing stations and machines tested. Although different acquisition methods enable it, unlike with traditionally used techniques, the instrument measurements do not have to be performed at different generator loading points to achieve maximum sensitivity to shorted turns.

High resolution signal acquisition and the use of multiple analysis algorithms have significantly improved the reliability of detecting shorted turns even at non-optimum load points. In addition, analysis results can be shown in multiple ways, enabling easy trending of measurement results and rotor summary display.

IV. CASE STUDY

One of the difficulties in existing shorted turn detection techniques was the detection of shorted turn at machine loads that did not provide maximum sensitivity. Maximum sensitivity to the leakage flux is obtained when the main flux goes thru zero. To achieve the maximum sensitivity to a shorted turn, the Flux Density Zero Crossing (FDZC) position had to be changed by a machine load change (traditional measurement technique). This requirement can be a serious obstacle to detect a shorted turn in higher number coils in base load units running consistently at or close to full load. At full load FDZC is closer to coils 2 or 3 (closer to the pole axis) and traditional methods were not sufficiently sensitive to reliably detect shorted turns in higher number coils. At the same time, if shorts are in lower number coils, due to design limits, it is impossible to move the FDZC closer to coil 1 and properly assess that coil.

A series of tests were made using the new instrumentation and the new analyzing algorithms indicated consistent sensitivity to a shorted turn in the highest numbered coil on a two-pole 13.8 kV, 20 MVA turbine generator under different loading conditions. Fig. 3 indicates pole A to pole B leading slots comparison at the minimum load available, 2 MW. A turn short in coil 2 is clearly identified in Fig. 3, although the FDZC is far away from this coil. Fig. 4 is again comparison of pole A to pole B leading slots, this time at the maximum load available during the test. In both graphs, the vertical green line is an indication of Flux Density Zero Crossing position, between coils 2 and 3 for 80 MW load and close to coil 6 at no load condition. Coils without shorted turns are expected to have equal peak amplitudes, compared to opposite pole coils.

Fig. 5 indicates the normalized pole to pole difference for all coils for all loads available during the tests on this generator. The normalized difference in percent (shown on Y axis) of

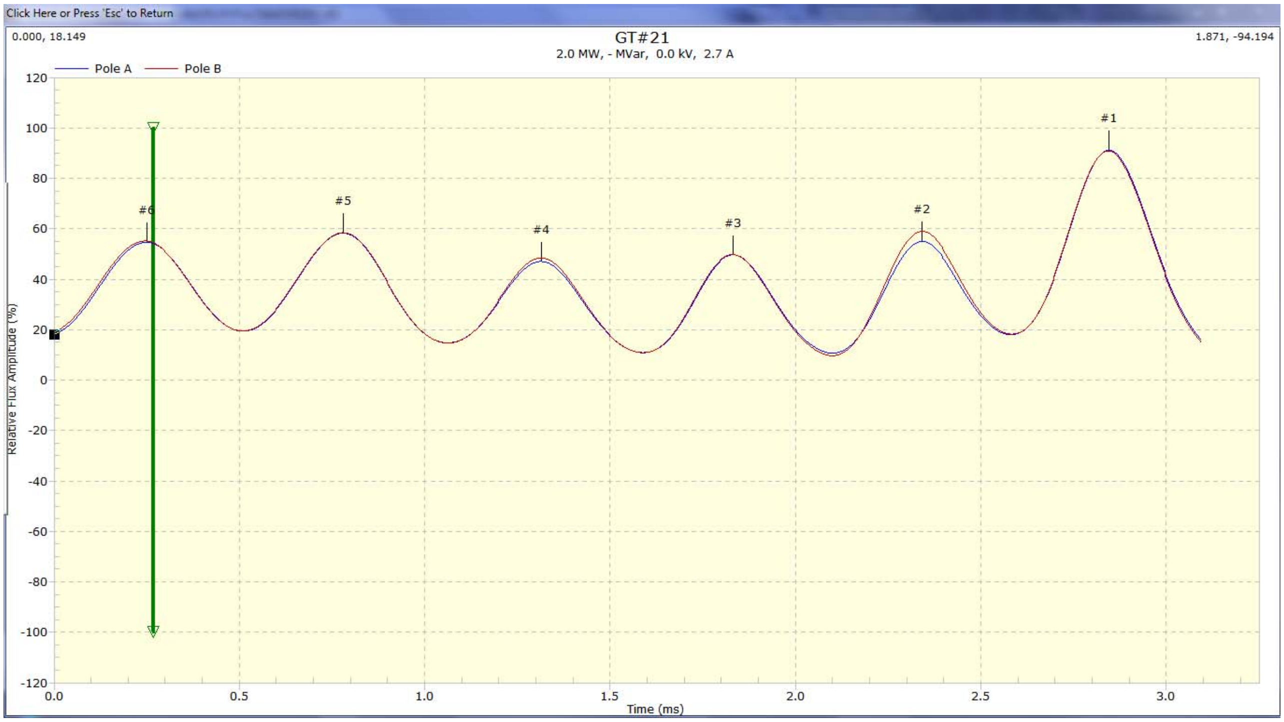


Fig 3: X-axis is time, Y-axis is normalized flux in percent. Plot shows comparison of the leading poles flux signals. FDZC is close to coil 6 (green line), short detected in coil 2

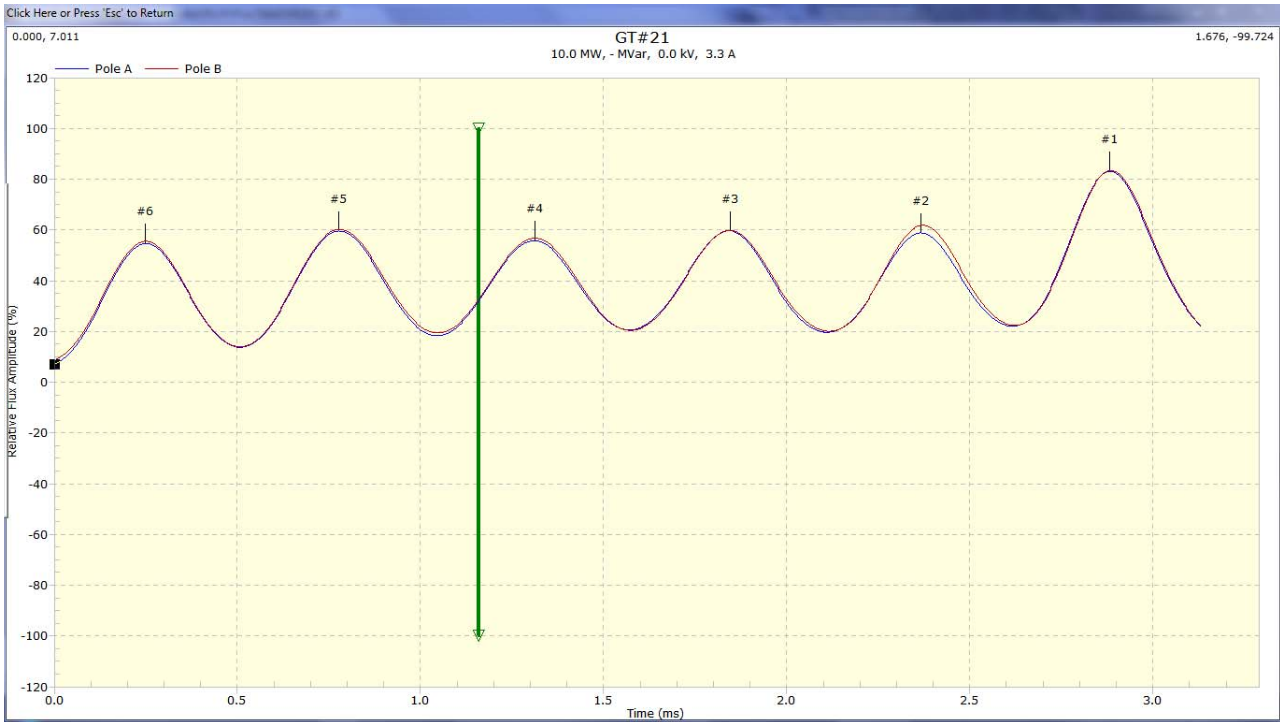


Fig. 4: X-axis is time, Y-axis is flux in percent. Pole A to pole B comparison, 10 MW load test

pole A and pole B for different positions of FDZC (shown on X axis) for all coils is shown. Coil 2, indicated by the green square had a normalized difference pole to pole of more than 5% in all loading conditions. At the same time, all other coils did not show pole A to pole B difference higher than 3%. As demonstrated, this system yields uniform sensitivity to a short in coil 2 at different loads which is not possible with traditional measurements. It can be observed that with the advanced algorithms the difference is actually slightly higher at the least sensitive FDZC position, close to coil 6, compared to the most sensitive FDZC position during this test, close to coil 4.

Fig. 6 indicates any pole A to pole B difference for all coils over a period of the time for all loads available during the duration of the time-based tests.

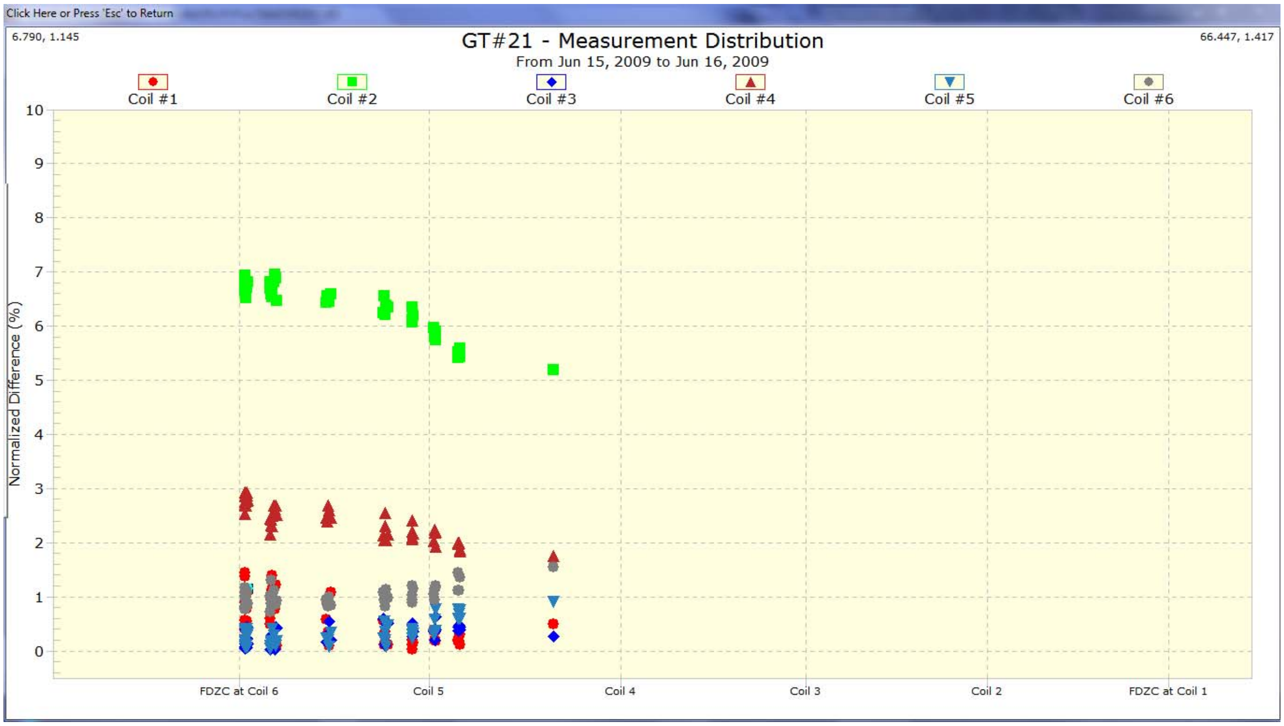
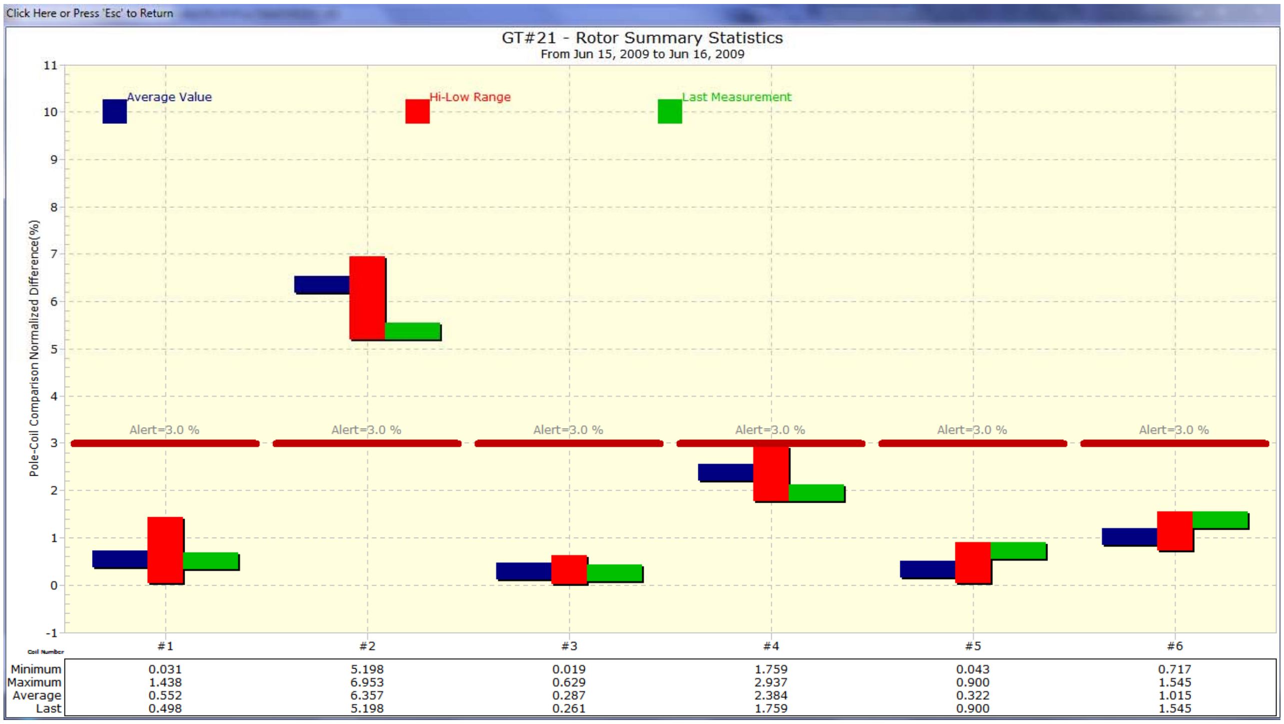


Fig. 5: X-axis is FDZC position on rotor, Y-axis is the normalized flux difference from pole A to pole B



	#1	#2	#3	#4	#5	#6
Minimum	0.031	5.198	0.019	1.759	0.043	0.717
Maximum	1.438	6.953	0.629	2.937	0.900	1.545
Average	0.552	6.357	0.287	2.384	0.322	1.015
Last	0.498	5.198	0.261	1.759	0.900	1.545

Fig 6 X-axis is rotor coil number, Y-axis is normalized difference between Pole A and Pole B
Range of results, all rotor coils over time

V. CONCLUSION

The Flexible Printed Circuit Magnetic Flux Probe has been developed [5] to improve shorted coil detection. The probe is easily installed to measure the main flux in the air gap. Combined with a portable or continuous on-line analyzer incorporating proprietary algorithms the rotor short detection sensitivity has been significantly improved. This allows detection of shorted turns even at machine load conditions which are less than ideal.

VI. REFERENCES

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