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NEW DEVELOPMENTS IN FLUX MONITORING FOR TURBINE GENERATOR ROTOR CONDITION ASSESSMENT

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Abstract

Flux monitoring via permanently installed air gap flux probes is a proven technology used for many years in synchronous machines to determine presence of turn-to-turn shorts in a rotor winding. This information is critical in planning maintenance and vibration analysis. Traditionally, flux measurements have been done using flux probes installed on a stator wedge and portable or permanently connected instruments. To achieve a reliable diagnostic, the signals from the flux probe had to be measured under different load conditions ranging from no load to full load. This requirement presented a serious obstacle in application of this method on base load units. A new design of flux probe, installed on a stator tooth, and novel approach in methods 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.

Introduction

A turbine generator rotor usually 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, end 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 usually the result of failed insulation between rotor turns and are a 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 at operational speed and at standstill. Consequently, on-line testing is a more effective way to detect shorted turns.

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

Total Flux Probe Design

Some of the limitations of existing probe design are related to its design and installation methods. Commercially available leakage flux probe typically is a custom-wound wire coil, on a flexible mount or encapsulated in epoxy body [5]. Such probes typically include a solid ground plane shield, producing eddy currents when exposed to strong magnetic field present in air gap of a rotating machine. These 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 pulls.

To minimize risks associated with this, some flux probe manufacturers require that wedges where flux probe will be installed should be drilled and support dowels installed. This operation may affect mechanical properties of the wedge.   A new type of the probe has been designed to overcome disadvantages of existing designs. The new probe compromises 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.

Figure 1. Total Flux Probe™ mounted on a tooth

New Flux Measuring Instrument and Software

New portable instrument and interpretation software have been developed and will be available in two different options, for salient pole and non-salient pole rotors. The new instrument is equipped with inputs for different types of flux probes and three different synchronization methods are possible: using dedicated synchronization shaft-mounted marker, internally to AC power input, or externally to any other signal in 40-240 V range. The instrument is based on a custom designed 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, LAN) can be used for connection to a PC. Data acquisition without a PC is also possible, if test parameters and measurement intervals are previously defined. Two stand-alone data acquisition modes are available, time and load based. Time based 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.

Figure 2. Portable Rotor Flux Analyzer

All measurements collected are stored in the instrument internal memory and can be downloaded to a 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 new instrument measurements do not have to be performed at different generator loading points to achieve maximum sensitivity to shorted turns.
The use of multiple patents pending algorithms to detect a shorted turn significantly improved reliability of data analysis. In addition, analysis results can be shown in multiple ways, enabling easy trending of measurement results and rotor summary display.

CASE STUDY ONE

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 (i.e. the position of Flux Density Zero Crossing (FDZC) did not match the coil evaluated) to a coil with shorted turn. To achieve the maximum sensitivity to a shorted turn, the FDZC position had to be changed by the machine load change.

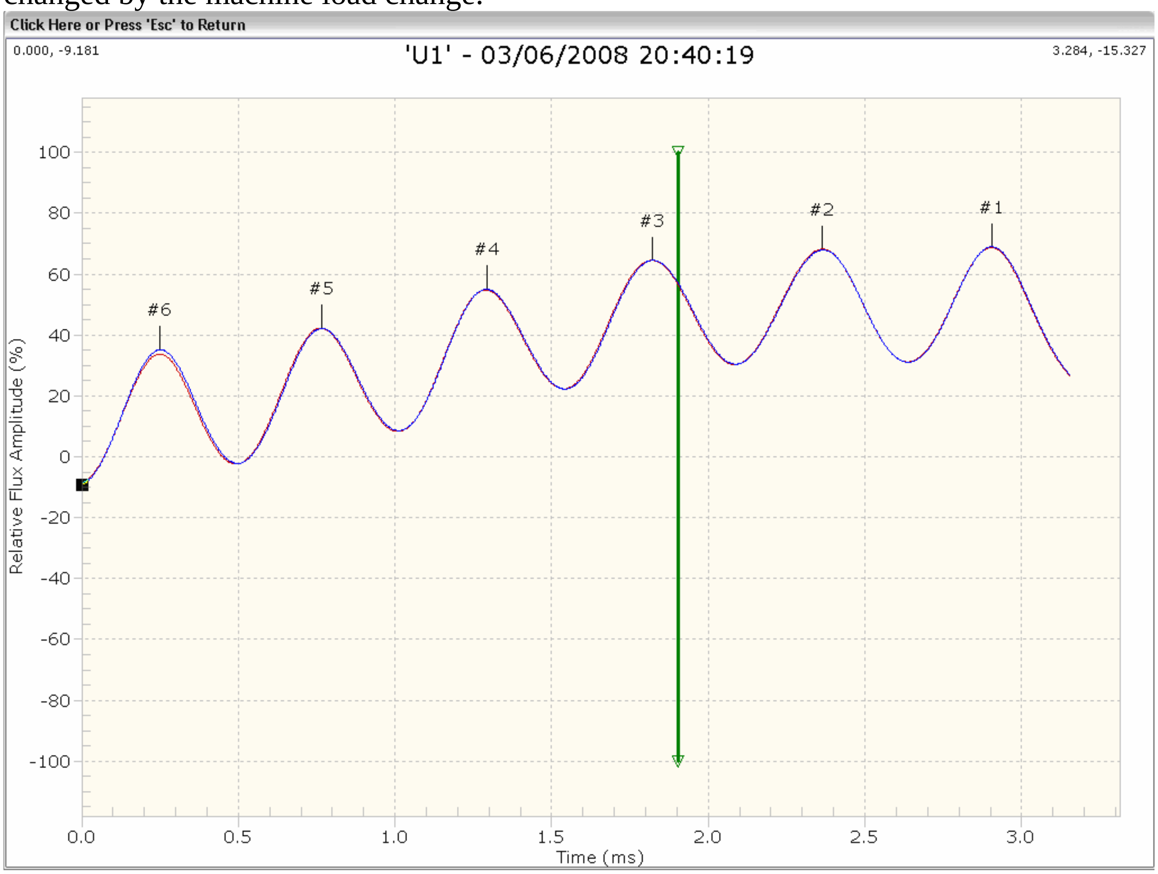

Figure 3. Leading poles comparison, FDZC close to coil 3, short detected

This requirement could 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 1 or 2 (closer to the pole axis) and traditionally used methods were not sufficiently sensitive to reliably detect shorted turns in higher number coils.

A series of tests were made using the new instrument and the new analyzing algorithms indicated consistent sensitivity to shorted turn in highest numbered coil on a two pole 13.8 kV, 115 MVA turbine generator under different loading conditions. Figure 3 indicates pole A to pole B leading slots comparison at the maximum load available, 80 MW, 12 MVAr.
A turn short in coil 6 is clearly identified in Fig. 3, although the FDZC is far away from this coil. Figure 4, is again comparison of pole A to pole B leading slots, this time at the minimum 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.

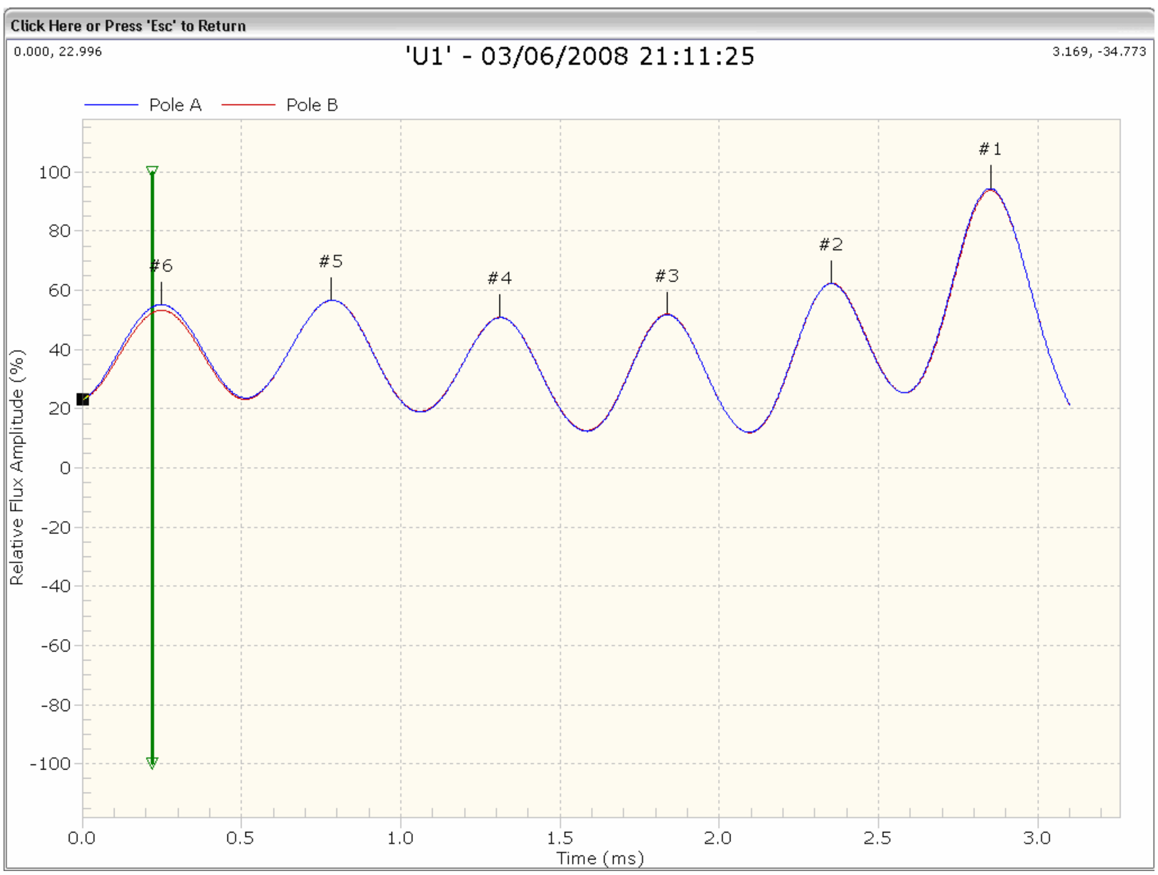

Figure 4. Pole A to pole B comparison, no load test

Figure 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 percents (shown on Y axis) of two poles for different positions of FDZC (shown on X axis) for all coils is shown in Figure 5. Coil 6, indicated by the red square had a normalized difference pole to pole of more than 3% in all loading conditions. At the same time, all other coils did not show pole A to pole B difference higher than 1%. As demonstrated, this new system yields uniform sensitivity to a short in coil 6 at different loads which is not possible with traditional measurements.

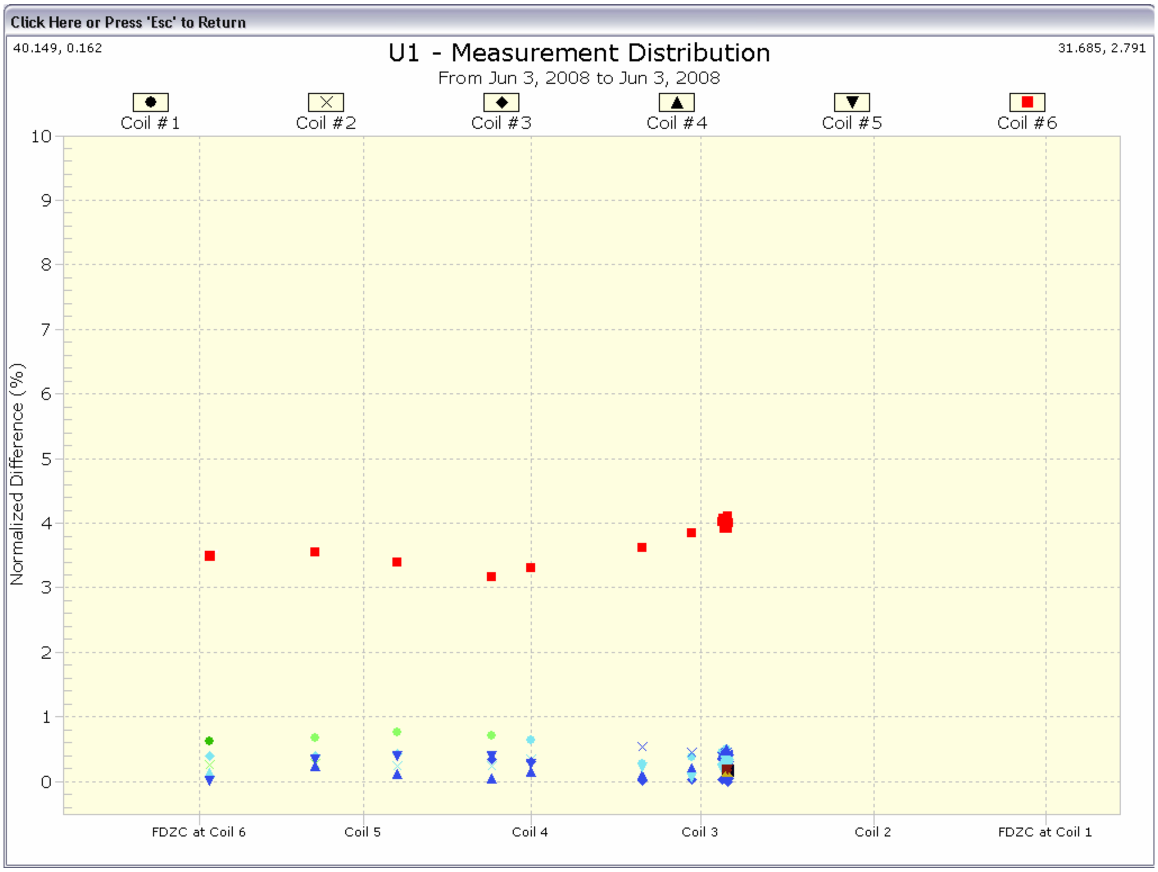

Figure 5. Normalized pole A to pole B difference at different FDZC positions

It can be observed that with the new algorithms the difference is actually slightly higher at the least sensitive FDZC position, close to coil 3, compared to the most sensitive FDZC position, close to coil 6.

Figure 6 indicates pole A to pole B difference for coil 6 over a period of the time for all loads available during the test. Shedding of the load was performed from 21.05 to 21.10, and during that time FDZC position moved from coil 3 to coil 6. Similarly to Figure 5, it can be observed that pole A to pole B difference stayed close to 4% in all tests, indicating that load change (i.e. different position of FDZC) did not negatively affect the quality of the measurement.

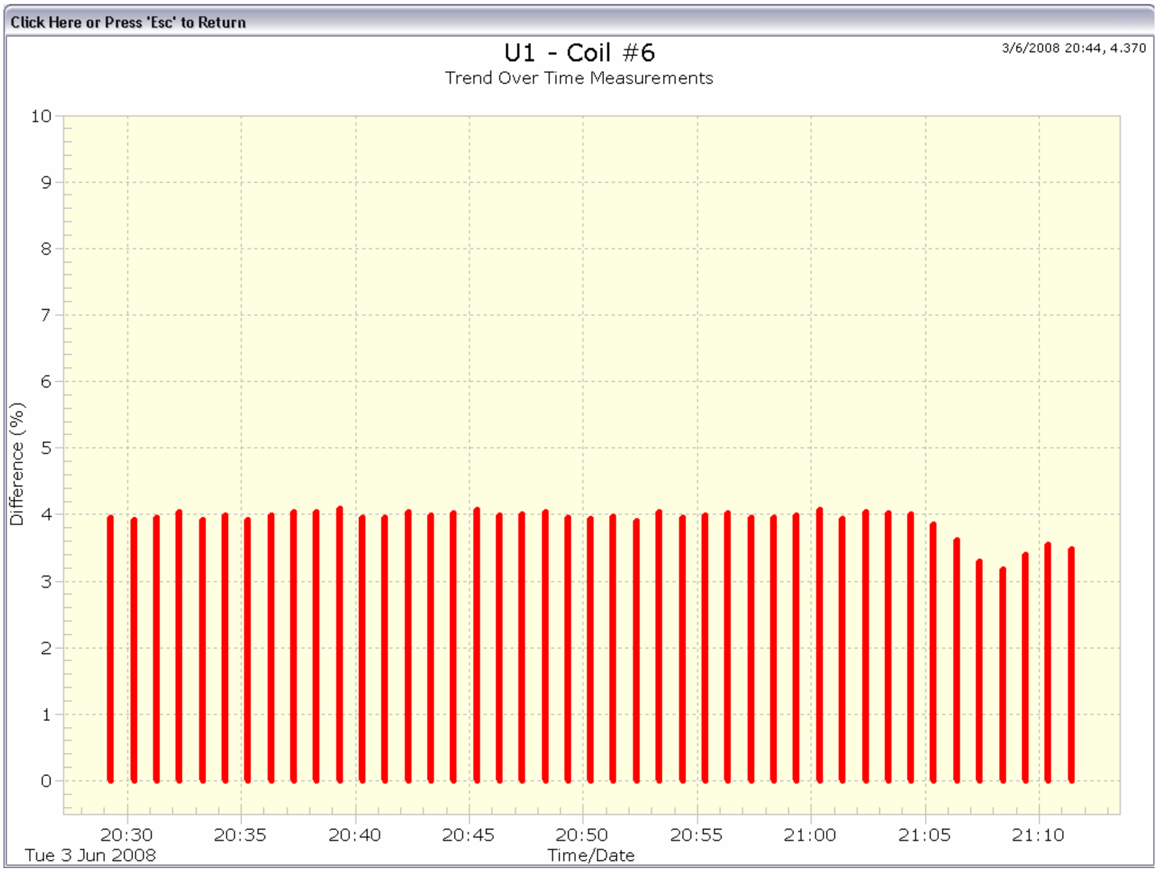

Figure 6. Coil 6, trend over time

CASE STUDY 2

Flux measurement data collected on a two pole, 20 kV, 208 MVA turbine generator indicated four coils with shorted turns. The load on this unit was changed from 0 MW to 170 MW and FDZC position moved from rotor quadrature axis to coil 3. See Figures 7 and 8 for two

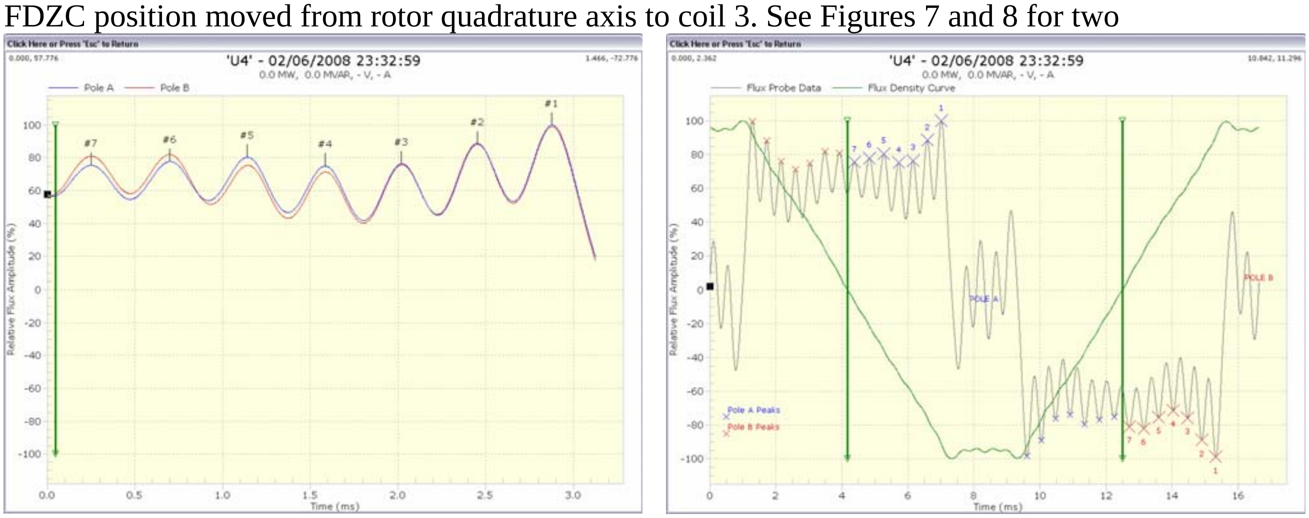

Figure 7. Shorted turns detected in four coils, no load condition

results displays at extreme loads, both indicating shorted turns in coils 4, 5, 6 and 7.

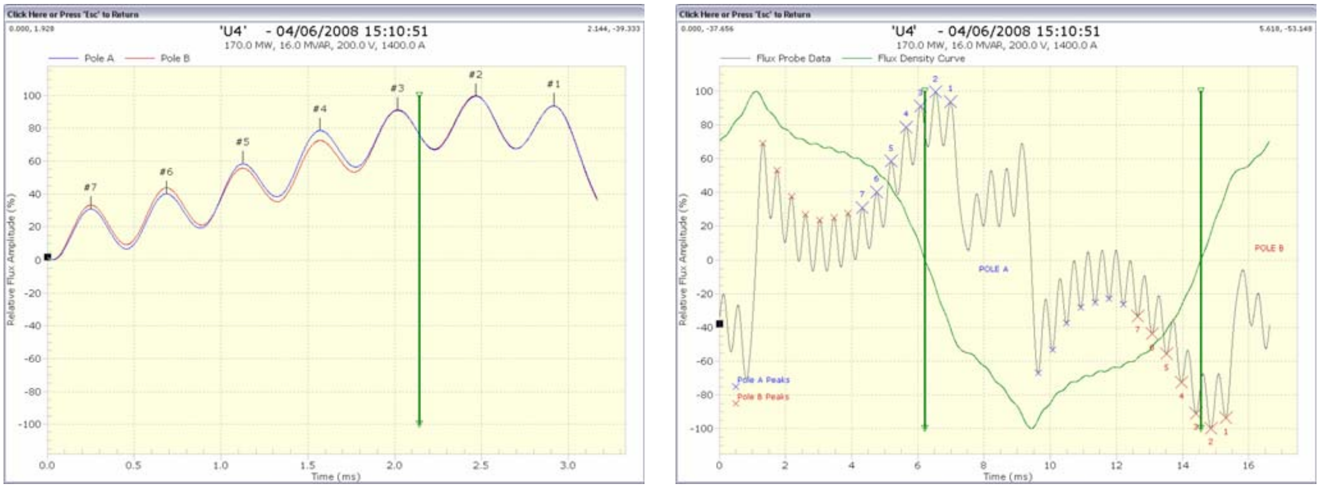

Figure 8. Shorted turns detected in four coils, 170 MW

Although the position of FDZC changed from rotor quadrature axis to coil 3, all four coils with shorted turns can be detected in all loadings.

Figure 9 is a statistical summary produced by the software of all tests performed, for all coils. Four coils with shorted turns had pole A to pole B difference greater than 4% in all load conditions, while three coils with no shorted turns had a difference lower than 1%.

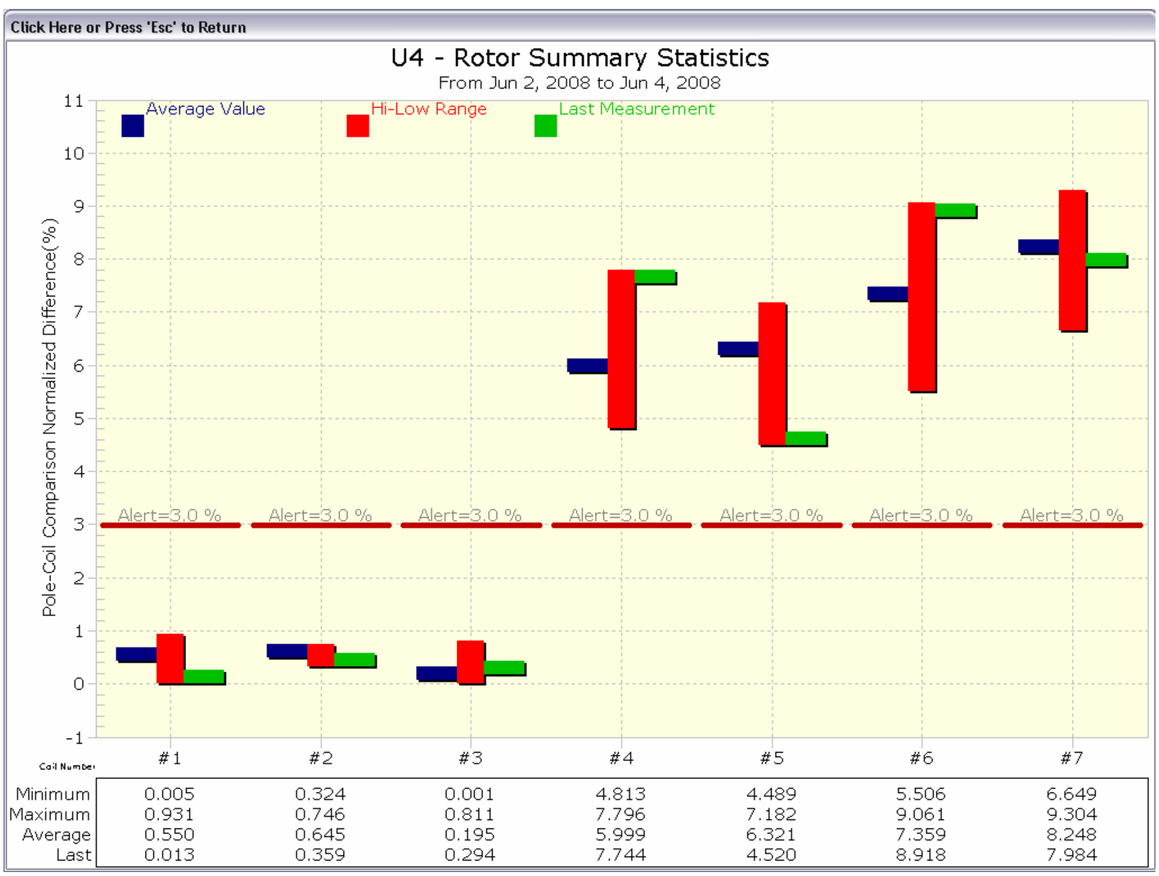

Figure 9. Statistical distribution of results for all coils

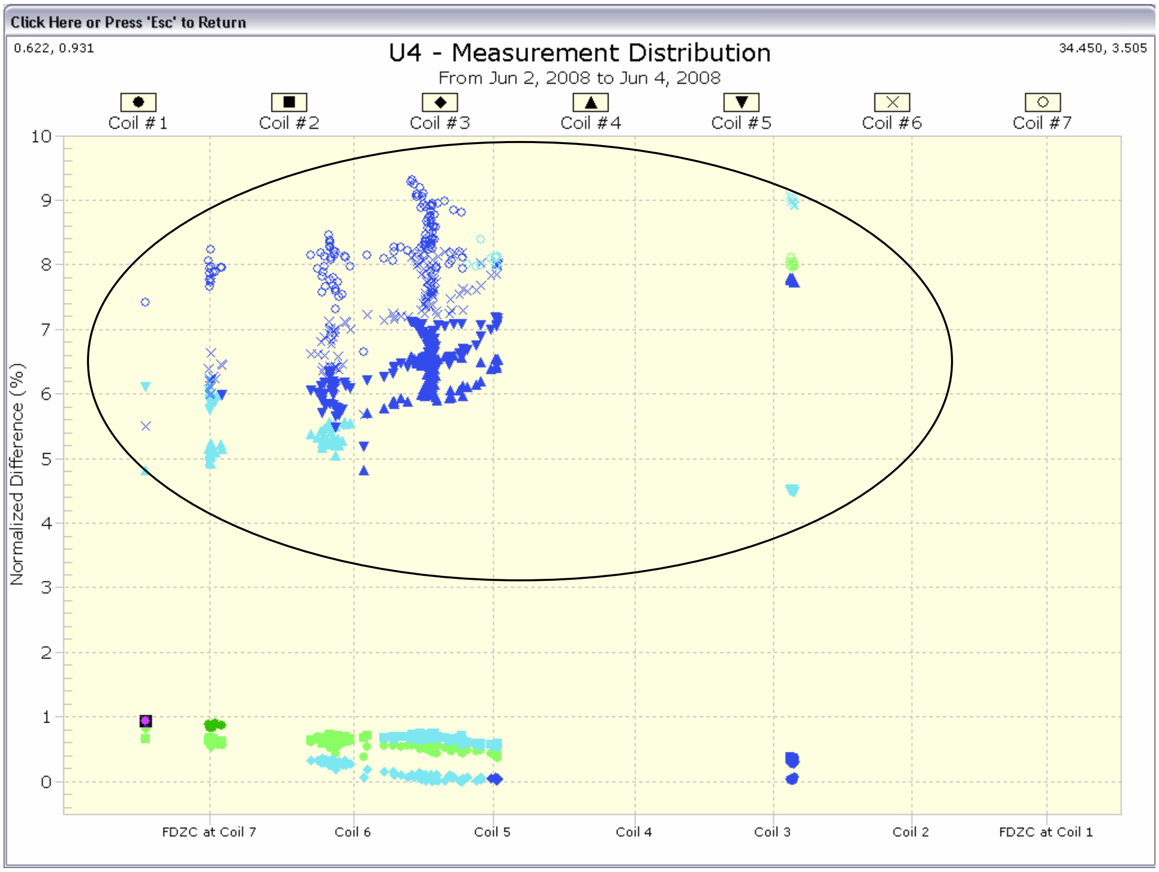

Figure 10. Measurement distribution for different loads, all coils

In Figure 10, the load change from 0 to 170 MW resulted in FDZC position shift from pole quadrature axis to coil 3. In all load conditions all four coils with shorted turns detected had normalized pole A to pole B difference higher than 4%.

Conclusion

An improved system for detection of shorted turns on rotor coils has been developed. The system consists of the new probe that measures the main flux in the air gap, the portable Analyzer, and a patent pending algorithm for rotor short detection. As a result, overall system sensitivity has been improved, allowing detection of shorted turns at various load conditions which are less than ideal test conditions.

References:

[1] Albright, D. R. "Interturn Short-circuit Detector for Turbine-Generator Rotor Windings", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-90 Number 2, March/April 1971
[2] Donald R. Albright, David J. Albright and James D. Albright "Generator Fields Winding Shorted Turn Detection Technology" IRMC, May 1999
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[5] US Patent No. 6466009, Flexible Printed Circuit Magnetic Flux Probe, issued October 15^{th}, 2002