On-line Flux Monitoring of Hydro-generator Rotor Windings

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ABSTRACT

On-line monitoring systems to assess the condition of generator stator windings, bearings and the air gap are now widely employed by hydro-generator plant operators. However, there is no on-line monitor that explicitly determines the condition of the rotor field windings. Although salient pole field windings tend to be very reliable, in each major outage plant personnel spend a considerable amount of time doing the 'pole drop' test, to assure themselves that there are no shorted turns on the field poles. In addition, the pole drop test may not be effective in detecting shorted turns in the standstill condition.

For moderate and large size hydro-generators and pump-storage generators, the most common type of salient pole rotor has a 'strip-on-edge' type of winding on each pole. Such winding is composed of strips of copper that are fabricated around the pole piece much like a picture frame. Electrical insulation, most commonly fiberglass reinforced epoxy, is used to insulate each copper turn from adjacent turns, as well as provide ground insulation between the copper and the rotor pole.

Failure of this insulation can result in shorted turns. Shorted turns on rotor may lead to unbalanced magnetic pull, which in turn may cause an increase in bearing vibration. However, shorts can exist with no increase in vibration and thus bearing vibration is not an infallible way to detect rotor winding aging.

On high speed turbine generators, rotor shorted turns can be detected at lower cost during normal generator operation by measuring the magnetic flux from each pole as it passes a probe that is placed in the air gap. On line monitoring of rotor has been used for years on high-speed turbine generators.

This paper will describe application of the new flux probe and new test and data analysis method applicable to hydro-generators rotor windings.

Introduction

The most reliable and common way to detect shorted turns (and incipient ground faults) on salient pole windings is to perform a 'pole drop' test [1]. In the pole drop test, an AC voltage, for example 120 VAC is applied between the positive and negative slip rings when the hydro-generator is shut down and partly disassembled. The voltage across each pole is then measured. If shorted turns are present, there will be a smaller than average voltage drop across that pole. This test has three significant disadvantages:

- It can only be performed with the generator shut down – implying a loss of revenue.
- It is time consuming to perform, especially on a large rotor with many dozens of poles

- Since the rotor is not rotating, the centrifugal forces are not occurring, and thus some shorts may not be present in the pole drop test, which nevertheless will be present at normal rotating speeds.

As utilities try to minimize the work (such as pole drop tests) performed during unit shutdowns due to restricted resources, and as they move to predictive maintenance to plan any repair work based on on-line condition monitoring, there is a need for an on-line tool that can replace the pole-drop test. For the past 20 years, utilities have been implementing magnetic flux monitoring in the air gap between the rotor and stator to detect shorted turns on the cylindrical rotors of high speed steam-turbine generators [1]. This technology has rarely been applied to salient pole windings, possibly because the salient pole rotors are very different from cylindrical pole rotors and interpretation of the flux patterns is not obvious. Recognizing this, the American Electric Power Research Institute funded a research project to assess a probe suitable for hydro-generator applications [3] and to investigate algorithms for detecting shorted turns in their windings [2].

Principles of Flux Monitoring

Rotor flux monitoring involves measuring the magnetic flux in the generator air-gap to determine if field winding shorts have occurred in the rotor poles. The radial magnetic flux is detected by means of a flux probe consisting of several dozen turns that is glued to stator teeth. As each rotor pole sweeps by the flux probe, a voltage is induced in the flux probe that is proportional to the change in flux from the pole that is passing the probe. The voltage is then measured by a rotor flux analyzer. In a salient pole machine, the radial magnetic flux profile across each rotor pole depends on the MW and MVAr loading of the machine. Shorted turns will cause a change in the flux profile within a pole at a given load.

As each pole in the rotor passes, there will be a peak in the induced signal caused by the magnetic flux from the pole. The signal can then be recorded and each peak of the waveform represents the “peak” flux across one rotor pole. Any turn short in a pole reduces the effective ampere-turns of that pole and thus the signal from the flux probe associated with that pole. The recorded waveform data can then be analyzed to locate the poles containing the fault, as long as one has calibrated the pole location from a ‘start’ location marked on the rotor shaft.

An algorithm was developed to maximize the sensitivity to a pole with shorted turns. The algorithm involves integrating the data from each pole, applying autocorrelation, and comparing the integral from each pole to an opposite polarity pole. This algorithm was verified in real machines where artificial shorts were induced in a pole and then removed for comparison [2].

New Total Flux Probe Design

Flux probes used in high speed turbine generators are usually designed in a shape of a cylinder and installed in the air gap between stator and rotor. Since air gap in hydro-generators is much smaller and construction of rotor is different, flux probes used in high speed turbine generators could not be used in hydro-generators.

A new type of the probe [3] has been designed to overcome disadvantages of existing designs. The new probe compromises of a number of printed circuit layers, printed on a flexible base material. The flexible probe is designed for application on a stator tooth. The very low profile of the installed probe enables its use on hydro-generators with small air gaps.

Figure 1. Total Flux Probe (Black), with connecting lead (White)

RFA II, new Flux instrument and software

A new portable instrument has been developed and will be available in two different options, for salient pole and non-salient pole rotors. The new instrument, RFA II is equipped with inputs for different types of flux probes and three different synchronization methods are possible: using dedicated synchronization from a shaft-mounted marker, internally to AC power input, or externally to any other AC signal in 40-120 V range. RFA II is based on a custom designed field programmable gate array and is 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 and standalone semi-permanent data acquisition without a PC is also possible, if test parameters and measurement intervals are previously defined. In addition to manual test mode, two stand-alone data acquisition modes are available. The first one, 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 during fast load changes. The second stand-alone data collection method is designed to save only the data with significantly different flux patterns, avoiding storage of data with the same flux patterns.

All measurements collected are stored in RFA II internal memory and can be downloaded to an Access data base, consisting of a number of folders representing stations and assets-machines tested. Use of multiple patent ending algorithms to detect a shorted turn significantly improved reliability and sensitivity of data analysis. In addition, analysis results can be shown in multiple ways, enabling easy trending of measurement results and rotor summary display.

Figure 2. RFA II Portable Rotor Flux Analyser

Test results

Data collected from Total Flux probe installed in a hydro-generator are shown in the following Figure. To correlate which part of the rotor pole is associated with what part of the signal, a photograph of four rotor poles is shown above the signal recorded. The generator was operated at no load conditions, 0 MW and 0 MVAr, resulting in symmetrical shape of both, raw signal measured (blue line) and integrated values of raw signal (red line). Since the shape of the signal is changed at different loadings of the machine, see Figure 4, raw data should be integrated for further processing.

🡐direction of rotor movement

Figure 3. Shape of the signal at 0 MW, 0 MVAr

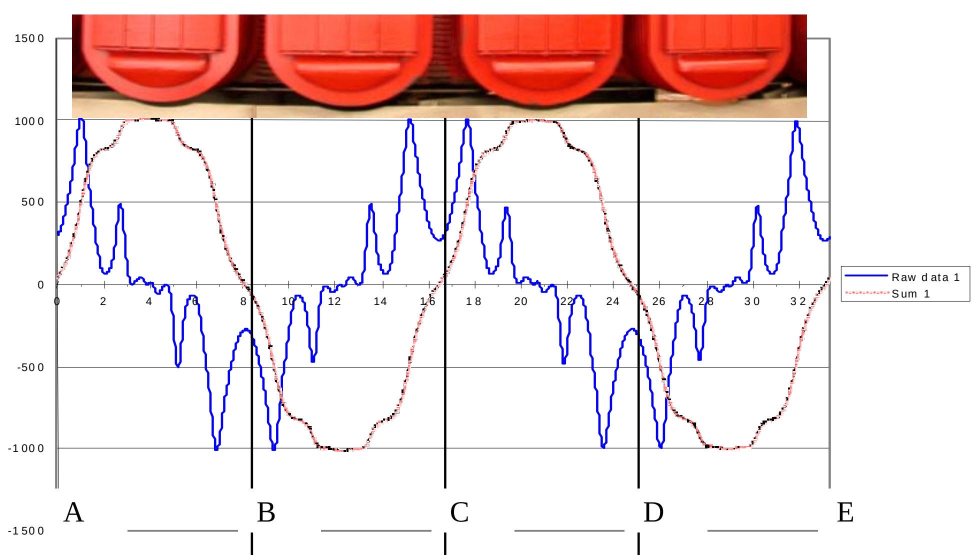
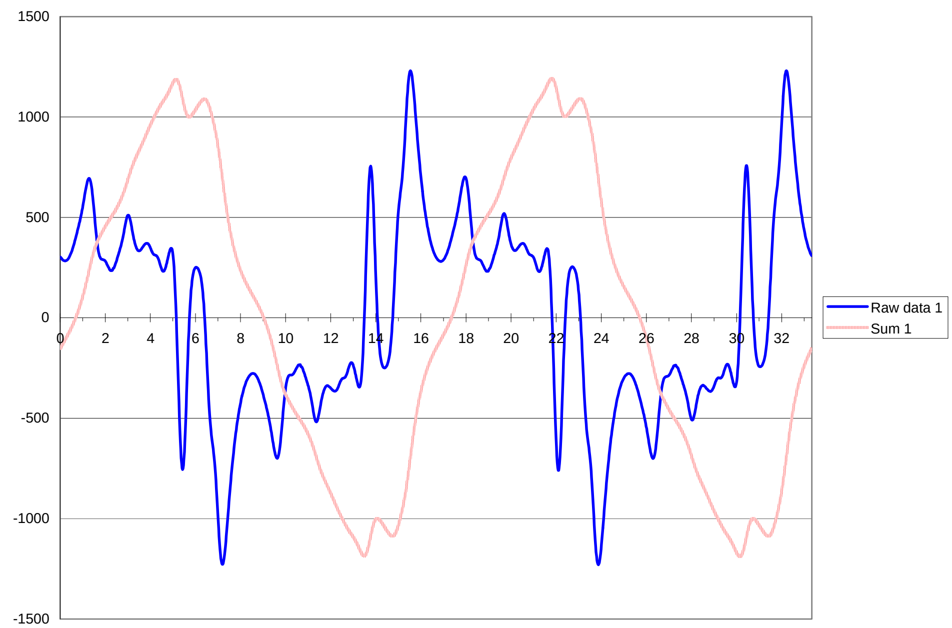
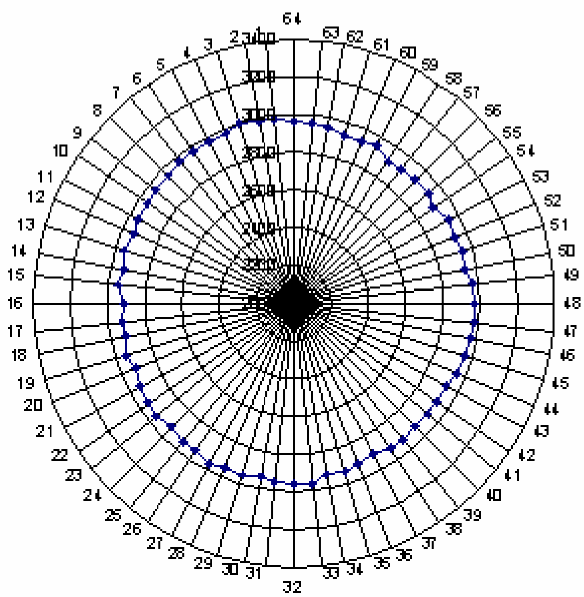


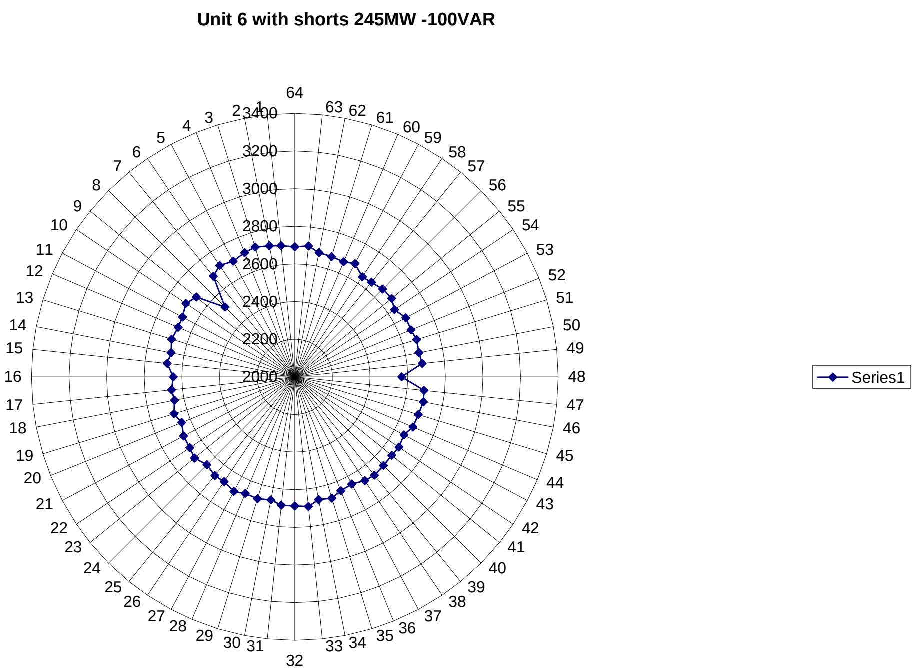
Figure 4. Shape of the signal at 125 MW, 0 MVAr



Given that change in the flux profile within a pole at a steady load must be due to shorted turns, comparison of one pole to another can be used as an indication of shorted turns. Such comparisons are usually shown as polar plots, see Figure 5.

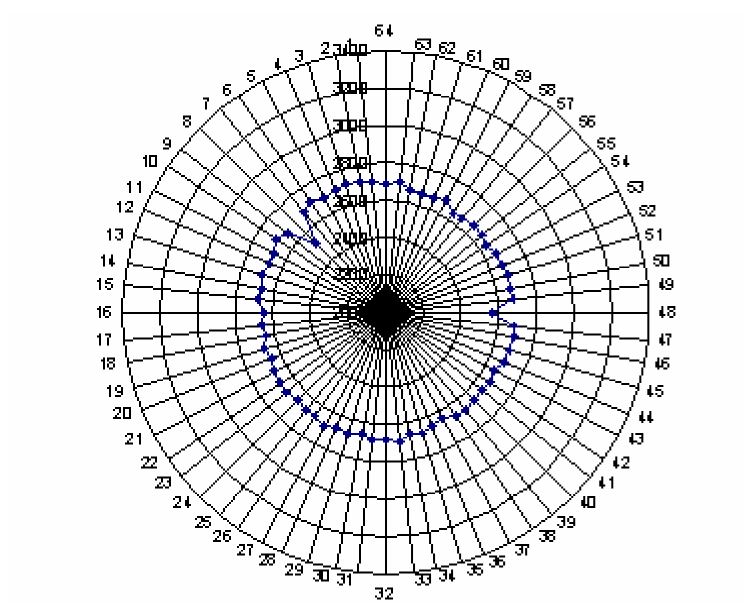
Figure 5. Polar diagram of 64 pole rotor with no shorts





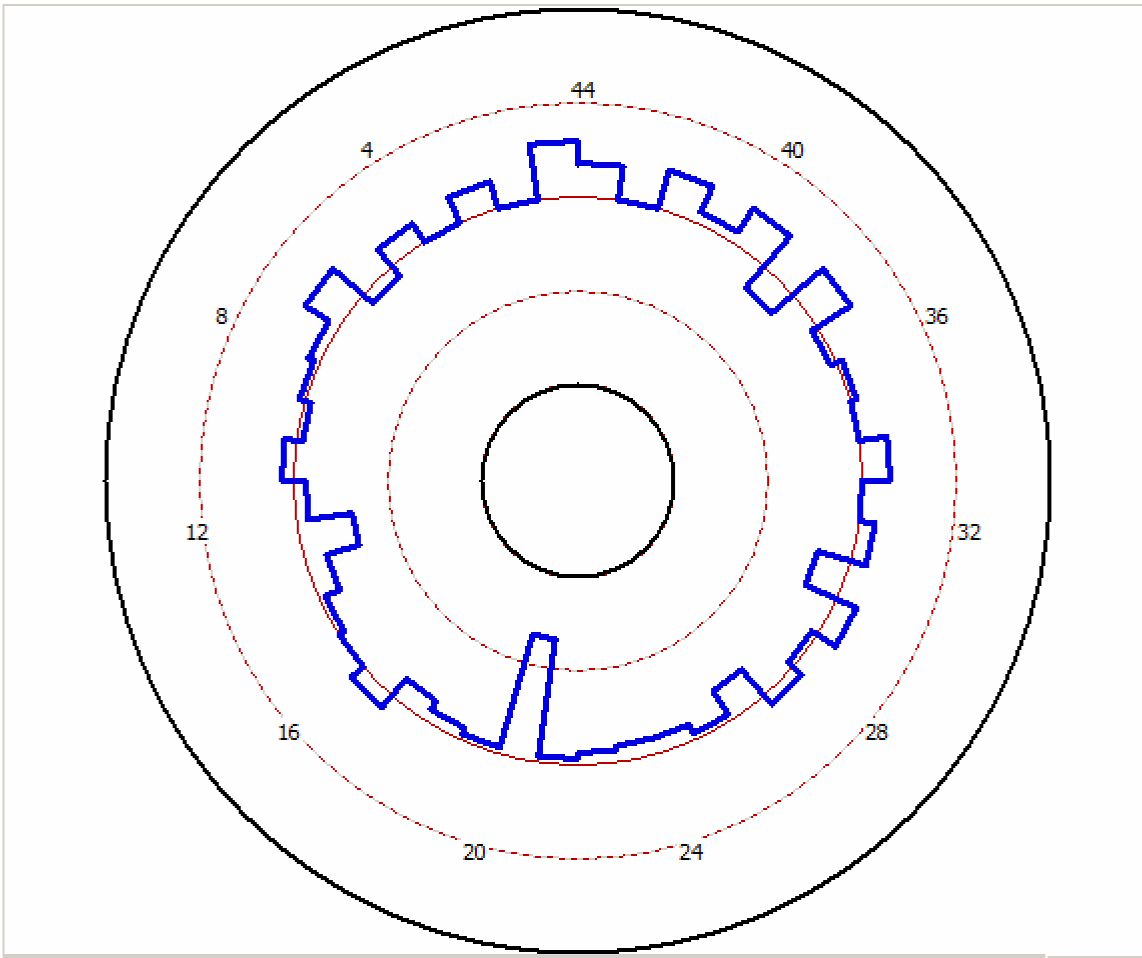
Minor differences between poles and ex-centricity of the rotor will result in a less than perfect circle, as seen in Figure 5.

Figure 6. Polar diagram of 64 pole rotor with shorts detected at poles 8 and 48



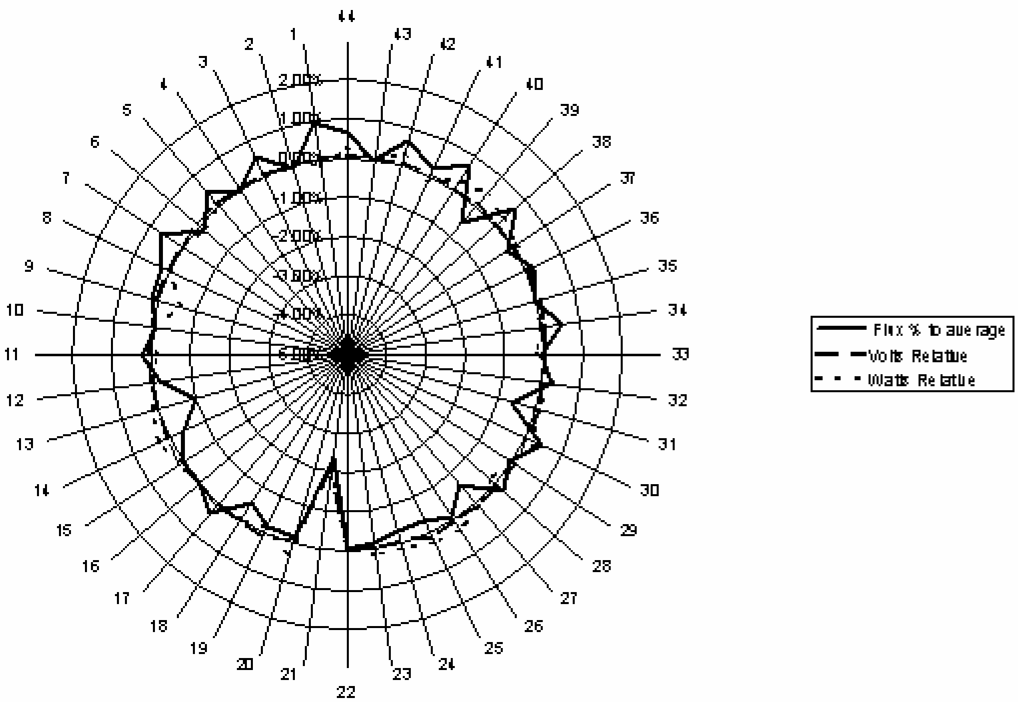
In most of the field tests, correlation of on-line flux shorted poles detection and off-line pole-drop tests was not possible. One reason is lack of positive pole number identification in off-line and on-line tests. The other reason is that two tests are significantly different in approach and in test conditions. The pole drop is AC test, more sensitive to first turn shorts, but less sensitive to other turns shorts. The on-line flux measurement is a DC test, sensitive to all shorts proportionately. In some tests, both methods identified one pole with shorted turns. Because there was no rotor sync we cannot be completely sure that these tests indicate the same pole. RFA II result is shown in Figure 7.

Figure 7. Shorted pole detected on-line, shorts detected in pole 21



In Figure 8, results from two off-line voltage and power measurements and on line flux measurements are shown, indicating that one pole has shorts detected using all three methods.

Figure 8. Off-line and on-line test results comparison, indicating one pole with shorts



Conclusion

An innovative on-line system for detection of shorted turns on rotor coils has been developed. The system consists of the new flux probe that measures the main flux in the airgap, and a portable Analyzer utilizing a patent pending algorithm for detection of shorted turns.

References:

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