

On-line Hydrogenerator Rotor Winding Condition Assessment Using Flux Monitoring

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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 hydrogenerator 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

Investigations have occurred to determine if 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. Such monitoring has been used for years on high-speed turbine generators. The paper presents the results of tests on several hydrogenerators which show there is some promise in the method.

INTRODUCTION

For moderate and large size hydrogenerators and pump-storage generators, the most common type of salient pole rotor has a 'strip-on-edge' type of winding on each pole [1]. That is, the 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. Generally, the salient pole rotor windings are very reliable. However, over the years the insulation in the rotor windings may age, eventually leading first to shorted turns, and then ground faults. Most plants will trip the generator once a rotor ground fault occurs. Insulation aging occurs as a result of overheating, load cycling and/or contamination of the winding by partly conductive materials such as insects or dust mixed with oil or water [1].

Shorted turns may lead to unbalanced magnetic pull, which in turn may cause an increase in bearing vibration. Virtually all generators are monitored for bearing vibration. Unfortunately, there are many causes of high vibration, of which rotor shorted turns is just one. Thus bearing vibration is not an infallible way to detect rotor winding aging.

The most reliable and common way to detect shorted turns (and incipient ground faults) is to perform a 'pole drop' test [1]. In the pole drop test, an AC voltage, for example 120 V ac is applied between the positive and negative slip rings when the hydrogenerator 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. In 2003, EPRI and the New York Power Authority initiated a research project to determine if a variant of flux monitoring could be applied to salient pole rotors, so that an online monitor could produce a reliable indication of rotor shorted turns. This paper discusses the results from this research project.

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 flat coil (or 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 coil that is proportional to the flux from the pole that is passing the coil. The voltage is measured by electronic instruments such as a digital oscilloscope or analog-digital (A/D) converter. In a salient pole machine, the radial magnetic flux profile across each rotor pole depends on the MW and MVAR loading of the machine. Any change in the flux profile within a pole at a given load must be due to shorted turns.

As each pole in the rotor passes, there will be a peak in the induced voltage caused by the magnetic flux from the pole. The voltage can then be recorded and each peak of the waveform represents the "average" 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 [2].

INITIAL MEASUREMENTS

Data was collected from 5 different machines, partly to get a reliable indication of the noise conditions, and partly to see the variety of signals (Table 1). Unfortunately, none of the machines measured had real pole winding shorts. Any change in signal from pole to pole on a 'good' machine is considered noise. This change in signal can be due to physical differences from pole to pole.

Company	Power (MW)	No. of Poles	Turns per Pole	Machine(s) Measured	Comments
A	60	76	17	U17, U25, U26	Measurements spanned two trips
B	330	64	21	U1, U2, U3, U4, U5, U6	Installed Shorts across Turns
C	140	30	42	U2, U3	
D	125	52	27	U3	
D	120	48	?	U8	

Table 1: Machines where flux probe data was collected

Figure 1 shows a polar plot of pole number (circumferential axis) vs. relative magnetic flux for the 330 MW, 64-pole rotor with no shorts. The flux readings are transformed according to the algorithm described above. The magnetic flux is essentially uniform around the circumference of the rotor. This flux pattern was similar on all 5 rotors that were measured.

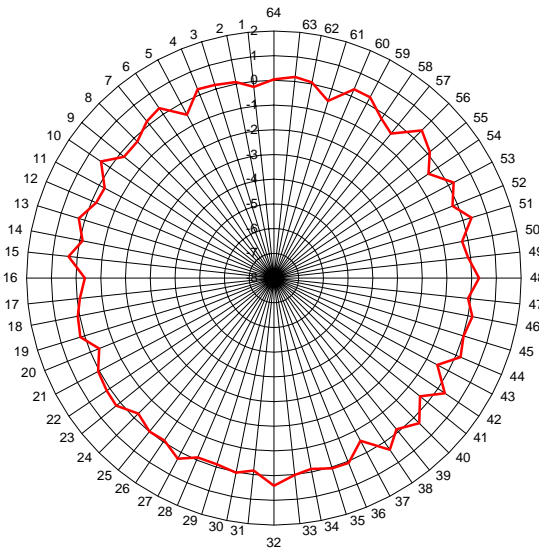


Figure 1: Polar plot of the transformed magnetic flux (on a normalized scale) versus rotor pole number for a rotor with no shorted turns. Ideally the trace would be a perfectly round circle. Differences from perfect roundness are due to normal physical differences around the rotor.

None of the 5 rotors had shorted turns. Fortunately we were able to install temporary shorts on the 330 MW pump storage machine. Figure 2 shows a photograph of a single shorted turn. Either 1 or 3 turns were shorted, on two different poles. Figure 3 shows the magnetic flux when two poles (numbers 8 and 48) contain temporary shorts. Pole 8 has one shorted turn whereas pole 48 has three turns shorted. In comparison to the plot in Figure 1, it is clear that the algorithm cannot only identify the poles with shorts, but how severe the shorting is.



Figure 2: Example of a temporary shorted turn placed on one pole of a 330 MW machine with a strip on edge winding.

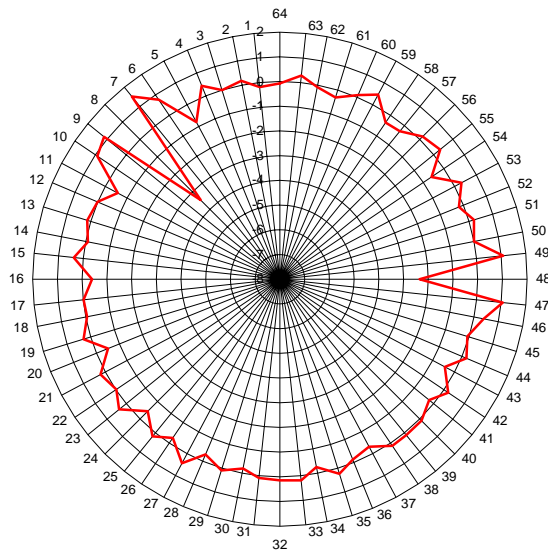


Figure 3: Polar plot of a transformed magnetic flux versus pole position when two poles (8 and 48) contain 1 or 3 shorted turns, respectively.

CONCLUSIONS

An algorithm has been developed that enables the on-line detection of shorted turns on salient pole rotor poles. With a suitable shaft marker, the shorted poles can be identified and the severity of the short (as determined by the number of turns that are shorted), can also be estimated. A continuous monitoring instrument is now being constructed that will automatically perform the measurement and analysis, and provide an alarm in the event of a shorted turn. When deployed, this new technology can remove the need for off-line pole drop tests, eliminate or confirm shorted turns as a cause of high vibration, and will allow hydro plants to plan when rotor winding maintenance is prudent.

References:

1. G.C. Stone, A. Boulter, I. Culbert, H. Dhirani, "Electrical Insulation for Rotating Machines", IEEE Press-Wiley, Jan. 2004.
2. Jan Stein, "Field Testing of Continuous Hydrogenerator Air-Gap Flux Monitor: Feasibility Study" (1011282), 2004

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