

# Recurrent Surge Oscillograph (RSO) for Rotor Winding Shorts Detection

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**Abstract—** Detection of inter turn shorts in rotor windings of high voltage turbine generators (TG) has emerged as one of the important diagnostic measures in condition monitor (CM) for uninterrupted power generation. Conventional test methods cannot identify the location of defects. Recurrent Surge Oscillograph (RSO), an off-line novel technique method has widely supported the quality of decisions of diagnosticians to locate the shorts in rotor windings.

This paper begins with traditional techniques in use to observe inter turn shorts of the field windings. Principle of time domain reflectometer ( TDR) is presented. Methodology of applying RSO technique for rotor windings is detailed. Wave patterns for possible inter turn shorts with a demo delay unit are depicted. Case study on faulty windings of TG is presented. This novel detection technique benefits the customers to avoid sudden outages.

**Keywords-** Excitation winding, inter turn shorts, recurrent surge oscillograph(RSO), time domain reflectometry

## I.INTRODUCTION

**E**XCITATION winding (Fig.1) of turbine generators (TG) is a highly stressed component and prone to inter turn shorts during service life. Operating the rotors with shorted turns



Figure.1 Typical excitation winding of 2 pole category TG

may limit the loads due to higher excitation energy, abnormal vibration behavior, bowed rotors and more thermal dissipation. Catastrophic effects such as earth faults and bearing damages will happen. Huge power generation loss, halt of economic growth and financial crisis are the ultimate

result. Detection and location of inter turn shorts is the key approach in condition monitoring of TGs which enable pro active plans of rectification to minimize further deterioration.

This paper deals with Recurrent Surge Oscillograph (RSO) test method to effectively detect and locate inter turn shorts of rotor windings. Traditional test methods and disadvantages are narrated. Effects of inter turn shorted field windings are mentioned. Owing to the benefits of the novel approach, RSO test has been viewed as mandatory for condition assessment diagnosis (CAD) of TGs in recent years. Time Domain Reflectometry, the principle behind RSO is briefed. Waveforms of various faults are depicted by delay unit demo. Case study on 15MW TG is presented and rectification methods to isolate the fault is recommended.

## II.TRADITIONAL DETECTION OF INTER TURN SHORTS

Assessing the condition of field winding which is hidden in rotor slots and end bells is a challenging domain. Incorrect decisions may result into power plant shut down for long time.

Traditional methods to observe inter turn shorts of field windings are

- 1) Open circuit (OC) and load current (LC) test
- 2) Ohmic resistance measurement
- 3) Impedance measurements in static and running condition
- 4) Pole and turn to turn volt drop test
- 5) Vibration analysis
- 6) Flux probe analyzer

In residual life analysis (RLA) and condition monitor (CM) diagnosis studies, above methods are being used as off-line and flux probe is recommended for on-line detection of shorts.

In OC and LC tests, an increase in excitation energy for the same output voltage and load current is indication of shorts in the field winding. Vibration behavior is different. Up rise of DC current in rotor circuit will be the result if the shorts are >5%. Location of the defects are not in the per view of this performance test.

A rotor slot contains 10 to 15 turns and no. of coils are 6 to 7 per pole. The order of resistance is in hundreds of milli ohms. One turn short due to damaged insulation may result in no variation in resistance. DC winding resistance measurement will not provide data on inter turn shorts.

Impedance method is practiced as off line test at standstill and running condition with no excitation. Low AC variable voltage is fed to the winding and current is recorded. The calculated impedance is studied over the prevailed signatures to assess the extent of shorts. 50 to 500HZ power supply is used for magnification. Accuracy and sensitivity of the measurements are highly variable vowing to rotor position whether it is stand alone, inside the stator, placed on steel rollers nearer to ground level, running speed etc. Associated tests shall be conducted to frame the decisions.

Flux probe test requires pre installation of flux probes in the stator slots. A shut down of the power plant and threading out of rotor is necessary for assembly of the sensor. It will scan and measure each slot magnetic flux while in rotation. Display of the flux pattern on oscilloscope will reveal the condition of turns in the slots. It is a costly proposition to provide flux probe system.

None of the above examinations solely can significantly decide the shorted turn status. Probability of confirmation of the shorts increases significantly by other related tests. Course of action for rectification involves disassembly and reassembly of rotor, removal of retaining rings and major rewinding etc which costs lakhs of rupees.

Recurrent surge oscillograph (RSO) test will confirm positively the inter turn shorts and also possible location on percentage basis. It is widely recognized by the generator community. Power plant customers are insisting to conduct this diagnosis tests for condition assessment.

### III.RECURRENT SURGE OSCILLOGRAPH (RSO)

RSO test technique is used to capture on dual channel oscilloscope, the reflected waves of the input rectangular pulse travelled in the field winding simultaneously at the two slip rings. It is a non destructive off line method to locate inter turn faults of windings. Principle of time deflection reflectometry (TDR) has been extended to visualize the inter turn short defects in TG excitation windings.

### IV.EXCITATION WINDING OF TG

Slot fill is of Cl.F insulation system with pre moulded slot liners of single length. Top insert are of epoxy glass laminated strips with suitable ventilation ducts for effective cooling paths. Current carrying turns are separated by cl. F flexible epoxy resin glass content which are bonded by special technological process. Contents of the slot are wedged with extruded copper alloy profiles of high mechanical strength as shown in the Fig.2. Connections of coils to form N and S poles are depicted in Fig.3

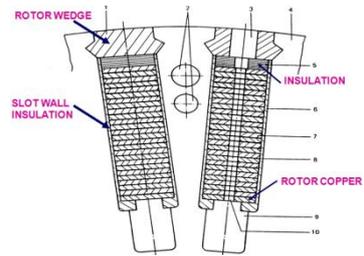


Fig.2 Cut section of Field slot

Connections of coils to form N and S poles are depicted in Fig.3

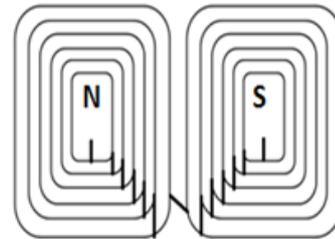


Fig.3 Scheme of Connections

Equivalent circuit (Fig.4) of the two pole field winding for high frequency travelling wave is presented with distributed resistance, inductance and capacitance elements along the circuit.

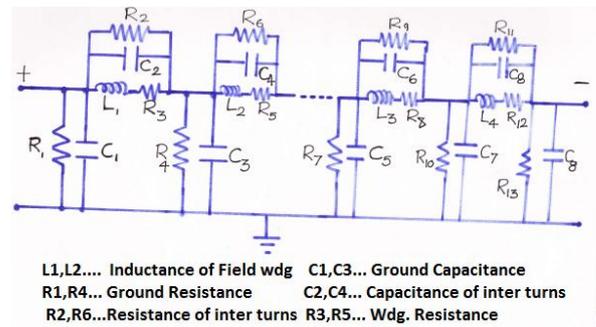


Fig.4 RLC circuit for field winding

Calculation of magnitudes of the distributed electrical elements are difficult due to variable geometry configuration of machine size and design. Measurements are carried with travelling waves to find the anomalies of windings.

### V.TIME DOMAIN REFLECTOMETRY

High frequency disturbances travel as waves on transmission lines upto the end of the line. Part of the wave is reflected back and some amount of energy is transmitted further. Abrupt change in impedance of line will result into reflected and transmitted voltage and current signals of varied magnitudes. Principle of travelling waves is utilized to rotor windings of TGs for shorts detection.

## VI. TRAVELLING AND REFLECTION WAVES

A transmission line possess two wires of distributed resistance, capacitance and inductance all along its length. A high frequency surge wave when applied at one end of the line travels at approximately speed of light to the other end through the characteristic impedance of the symmetrical R-L-C network.

$$Z_0 = \sqrt{\frac{L}{C}}$$

Where  $Z_0$  = Characteristic impedance of transmission line

L = Inductance per unit length

C = Capacitance per unit length

For an open ended transmission lines, the incident surge current will reflect back in succession to the sending end as a reflected wave. For a length of one mile cable line, with a propagation velocity of 66% of speed of light, a time of 8.146  $\mu$ sec. is needed for signal to travel from one end to dead end. Double the time ( 16.292  $\mu$ sec. ) is required to complete the circuit for the reflected signal. Time domain reflectometer (TDR), a special instrument is used to observe the transit time of the reflected pulse which is useful to determine the length of the conductors. This art is used to determine shorts in cables and now it is adopted to TG field windings to locate hidden inter turn shorts and earth faults.

The travelling wave gets disturbed at faulty junctions due to sudden change in impedance of the line. Voltage magnitudes will differ from case to case of impedance values as below.

- For an open circuit of long lines with surge impedance  $Z$

Voltage of incident wave is  $e = EU(t)$   
 $Z_1 = Z; Z_2 = \infty$

Coefficient of reflection  $\Gamma = \frac{(Z_2 - Z_1)}{(Z_2 + Z_1)} = 1$

Voltage of the reflected wave,  $e' = \Gamma e = e = EU(t)$

- For a line ending with resistance same as surge impedance  $Z$  of the line

Voltage of incident wave is  $e = EU(t)$   
 $Z_1 = Z; Z_2 = R = Z$

Coefficient of reflection  $\Gamma = \frac{(R - Z)}{(R_2 + Z)} = 0$

Voltage of the reflected wave,  $e' = \Gamma e = 0$

No reflected wave present at the junction in this case.

- For a long line with sudden change in impedance L

Voltage of incident wave is  $e = EU(t)$

$Z_1 = Z; Z_2 = LS$

Coefficient of reflection  $\Gamma = \frac{(LS - Z)}{(LS + Z)}$

Voltage of the reflected wave,

$e' = \Gamma e = - \left[ 1 - 2 \exp\left(-\frac{Z}{L}t\right) \right] EU(t)$

Exponential decay of the reflected wave exists at the junction.

## VII. APPLICATION OF RSO FOR SHORTS DETECTION IN WINDINGS

Application of time domain reflectometer (TDR) for rotor windings inter turn shorts detection is referred as recurrent surge oscillograph ( RSO).

A signal generator produces step voltage of 5 to 10 volts magnitude of high rise wave front. This high frequency rectangular pulse is directed into the characteristic impedance of the distributed R-L-C circuit of the rotor winding through the slip rings against earthed shaft in succession( Fig. 5).

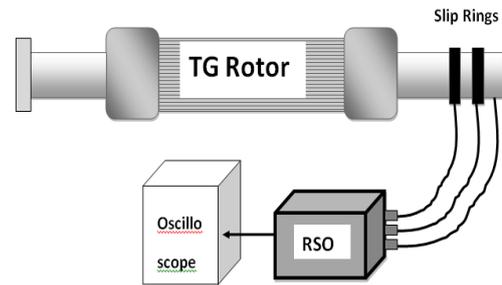


Fig.5 Circuit connection of RSO

Incident pulsating wave will travel at one slip ring into the field circuit with speed of light and reaches other slip ring in a healthy field winding with no inter turn shorts and earth faults. Reflection wave will travel back from open end of the other slip ring to the input slip ring point. Both the traces are identical and the summation after inversion will be a straight line with no ripples. Healthy winding will be symmetrical electrically and travelling time of transient pulse injected at both the slip rings will be same. It results into identical reflections as shown in the fig.6 if superimposed a single trace is visible.

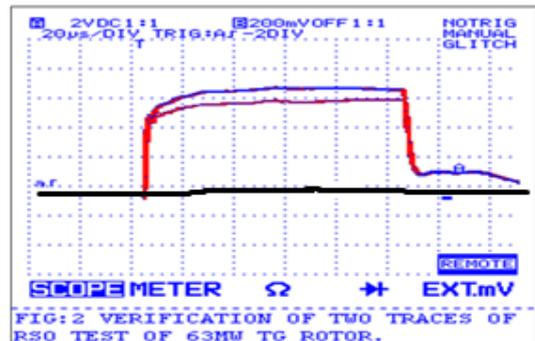


Fig.6 Two traces & Super imposed straight trace of healthy field winding

Resulting reflected signals at the shorted turns due to sudden change in impedance travels back to the front end of the winding. It can be observed on dual channel oscilloscope as two different waves with kinks(Fig.7). A comparison between the super imposed incident and reflected waves will be used for finding out the abnormal contacts of turns.

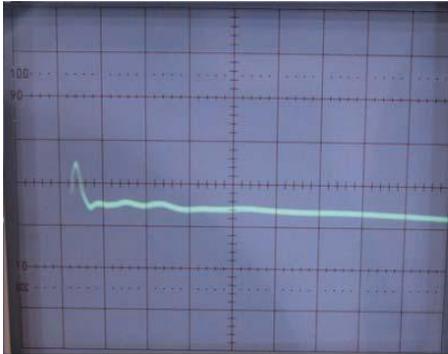


Fig.7 Trace with kink of shorted field winding

VIII. DEMO WITH DELAY UNIT

RLC network with 10 sections with a characteristic impedance of 100 ohms is used as delay unit. Terminations of each section is for simulating the shorts and observing the wave patterns on digital oscilloscope.



Fig.8 Waveform with inter turn short

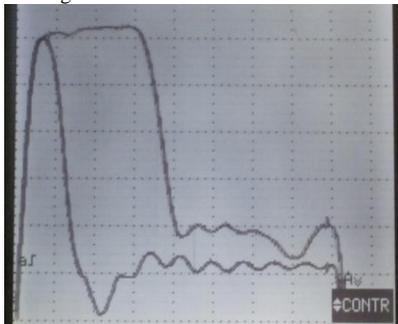


Fig.9 Waveform with earth fault

Effect of inter turn shorts and earth faults are depicted in the fig. 8 & 9.

IX.CASE STUDY

This case study illustrates the difference in waveform pattern for healthy and inter turn shorted rotor windings of 2

pole category. 15MW,11KV TG rotor was excited and as the DC energy was increasing, vibration levels were shooting up. Generator was loaded and vibration were at alarming position. Excitation energy was not matching with the protocols and field winding was drawing higher excitation current. Machine could not be loaded to rated capacity due to excess energy levels.

A shut down had been taken and condition assessment diagnosis tests were conducted. RSO waveforms ( fig.10 ) revealed inter turns shorts in the winding overhang zone beneath end bells.

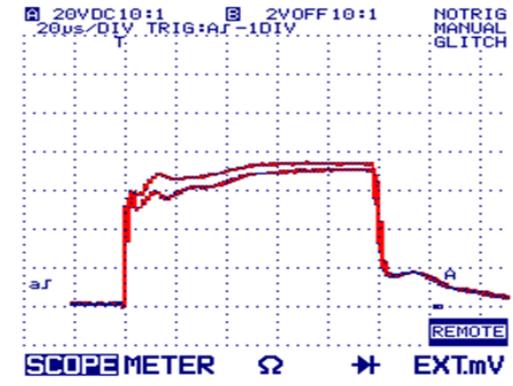


Fig.10 Waveform for shorted turns

Retaining rings were removed and shorted turns ( fig.11) were noticed between the coils.



Fig.11 Typical shorted turns of rotor winding

After correction, RSO repeated and single trace waveform was observed on the screen which approved the repair procedure.

X. CONCLUSION

Aim of this paper is to familiarize the RSO technique for application engineers of power plants. It is found that RSO test waveforms are specific over conventional tests to recognize inter turn shorts of field windings of 2 pole version TGs. It is low cost and small voltage diagnostic test to assess the condition of windings during manufacture and at sites. Reflected waveforms will possess approximate percentage location of the fault which none of the traditional tests provide. Safety to personnel and equipment is ensured as the input voltages levels are of the order of 10 to 15 volts. Appropriate action plans for rectification of inter turn shorts is

possible with this method. It has been recognized a condition based diagnostic tool by asset managers of power plants. Maintenance staff will be relieved of surprise shut down of the machine by introducing RSO test as mandatory diagnostic test in service. The case study on one of the TG by RSO identified the fault location and rectification has been carried effectively.

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