TURBO-GENERATOR WINDING FAULT DETECTION BY A RECURRENT SURGE METHOD

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This is a copy of the first paper describing the use of the RSO method for detecting winding faults in turbo-generator rotors. It was written by A.E. Grant of the UK Central Electricity Generating Board (CEGB) in 1973.

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Summary:

Short circuited turns in rotor windings may give rise to excessive vibration and to shaft magnetisation. They are not easy to detect in situ by conventional methods. A method of fault detection and location, based on the recurrent surge oscillograph, is described. It is quick and easy to apply.

Introduction

Recurrent surge methods have been used for several years by manufacturers of high voltage power transformers to determine the distribution of surge voltages through the windings (Refs.1,2).

The recurrent surge technique has potential for in situ testing of the security of rotor winding interturn insulation of turbo-generators without modifying or dismantling the machine.

The presence of a short circuited turn may cause vibration due to magnetic unbalance and uneven heating of the rotor (Ref.3),

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and shaft magnetisation due to magnetic unbalance (Ref. 4). In the latter case homopolar generation may occur, giving rise to excessive shaft voltages and bearing corrosion, and also to enormous circulating currents if the electric circuit is completed.

Recurrent Surge Generators

The circuit diagram of a simple battery operated recurrent surge generator (RSG) is given in Figure 1. The e.m.f. source is a capacitor of high value (100 µF to 1,000 µF) charged from a primary cell via a current limiting resistor so that for several microseconds it has virtually zero impedance The effective source impedance may then be adjusted to any desired value by external connection of non-inductive resistors.

The surge is generated by a mercury-wetted contact relay, which has a constant low impedance across closed contacts of less than 40 milliohms, and gives clean makes and breaks at currents of up to 5 A at 500 V. The relay is driven at a nominal 50 Hz by a multi-vibrator circuit and the output of the RSG is a nominal square wave with a very fast (20 ns) rise time. The output waveform can be adjusted to give the usual surge waveforms by external differentiating and integrating circuits (Ref. 1). The RSG may be used for this application with most wide-band oscilloscopes. A suitable method of connection is given in Figure 2.

The Rotor Winding as a Transmission Line

The recurrent surge method depends on the fact that the rotor winding approximates to a transmission line, when a surge is applied between one slip ring and the rotor body as in Figure 2.

The surge performance of an ideal line is adequately described by two parameters viz, surge impedance (Zo) and velocity of propagation (v) (Ref. 5).

It is usual to consider the response of the line to a steep fronted surge; that is, a surge whose rise-time is a very small fraction of the time required for the surge to travel from one end of the line to the other, as the reflections and refractions of the surge at changes of surge impedance are then well developed. The basic principle of the recurrent surge method is shown in Figure 3. In an ideal line, the surge impedance has dimensions of resistance. When switch S is closed, the amplitude of the surge entering the line is determined by the source impedance R and the surge impedance of the line Zo. The surge reaches the far end of the line after a delay (T) determined by the length and propagation velocity of the line, and is there reflected, its magnitude depending on reflection factor k. For an open-circuited line k = +1 and for a short-circulated line k = -1. The reflected surge returns to the source and if the source impedance equals the surge impedance of the line (the reflection factor k = 0), it is absorbed without further reflection (Figure 4). The rotor winding of a turbo-generator approximates to a transmission line. As each coil of a concentric winding is in a pair of slots and is independent of the others, a surge launched between one slip ring and the rotor body will not cause mutual effects between slot windings.

Mutual effects will occur between end windings, but those form only a small proportion of the total winding. The propagation of the surge will be mainly between conductor and slot and the velocity will be determined principally by the permittivity of the insulation, and the permeability of the rotor iron.

Rotor windings have a surge impedance which, depending on size and construction, may lie between 20 and 300 ohms.

Application of Recurrent Surge Method

The surge is applied between one slip ring and earth and the other slip ring may be earthed or earth free. The signal may be applied through the brushgear but the exciter connections must be disconnected as they give rise to confusing reflections.

The rise time of the surge will affect the sensitivity of the method. This must be less than the propagation time for the wave front through a single turn for sharp reflections to occur. With slower rise times the sensitivity will be reduced.

The preferred method is to apply a square wave with a rise time of the order of 20 ns, with the remote slip ring earth free (Figure 2). A source voltage of between 10 and 100 V is used. A higher surge voltage is undesirable as a large proportion of it will appear across interturn insulation particularly near to the slip rings, and may overstress aging or weak insulation. Oscillograms are made for each slip ring individually and superimposed (Figures 7,8). Faults are indicated on the oscillograms by deviation of the superimposed traces. Both the source voltage and the response at the slip ring are displayed on a two channel oscilloscope, with both channels set to the same sensitivity. The measurements are standardised by making the source voltage produce full scale deflection of the oscilloscope, and by adjusting the series resistance (R in Figure 2) so that the initial step of the response is approximately half full scale deflection. The source is then matched to the surge impedance of the winding so that spurious reflections are minimised. In this way, repeatability of results is ensured in future tests.

From the oscillograms the winding end reflection point is determined (Figure 6). Faults may then be approximately located by taking the ratio of times for reflections from the fault and from the end of the winding. The velocity of propagation varies with time and the variation may be estimated by measurement of the times for a single and double passage through the winding as in Figures 5 and 6. This will improve the accuracy of estimation of fault location.

The surge tends to separate into two modes:

(a) between conductors,

(b) between conductors and rotor body.

These travel at slightly differing velocities. Mode (b) predominates and should be used for calculations. The maximum amount of information can be obtained if recurrent surge oscillograms (RSO) can be made on machines immediately after they are taken off load.

The generator is isolated, the field is de-energised and exciter connections are disconnected. RSO's are made with the machine still running at rated speed. The machine is then allowed to slow down to barring speed and RSO's are again taken and repeated after an interval of about 1 hour. There is at present no convenient way of making RSO's on excited machines.

Faults which are present when the machine is at speed sometimes disappear at standstill or barring and vice versa. Movement of the rotor winding occurs during barring, under the influence of centrifugal and gravitational forces, and sometimes produces periodic variation in the RSO during rotation, which may be due to intermittent faults.

When oscillograms are made with the rotor spinning, contact to the rotor body is made via the shaft earth brush and this is not always effective. Random noise on RSO's taken at rated speed and during the run down is caused by intermittent earth brush contact. In this case a temporary brush of copper braid provides an effective earth connection to the rotor shaft.

The recurrent surge method may also be used to obtain an approximate location of open-circuit faults. The fault location is given by the ratio of the times of reflections from the fault, measured at both slip rings. Earth faults of low resistance may also be located by this method.

The method is sensitive enough to detect single turn faults and faults having a contact resistance of several ohms. Such faults may have no apparent effect on the running of the machine and may be undetectable by other test methods.

Conclusions

1. The recurrent surge oscillograph is a very sensitive method of detecting interturn faults in the turbo-generator rotor windings.

2. It indicates the location of the faults. The results are not significantly affected by the temperature of the winding.

3. It is very quick and easy to apply as it requires only the disconnection of the exciter connections to the brushgear.

4. The method is suitable for use as a routine method for periodic checking of rotor windings for deterioration.

5. When used with other methods of fault detection it is a convenient way of checking the security of the winding in situ.

References

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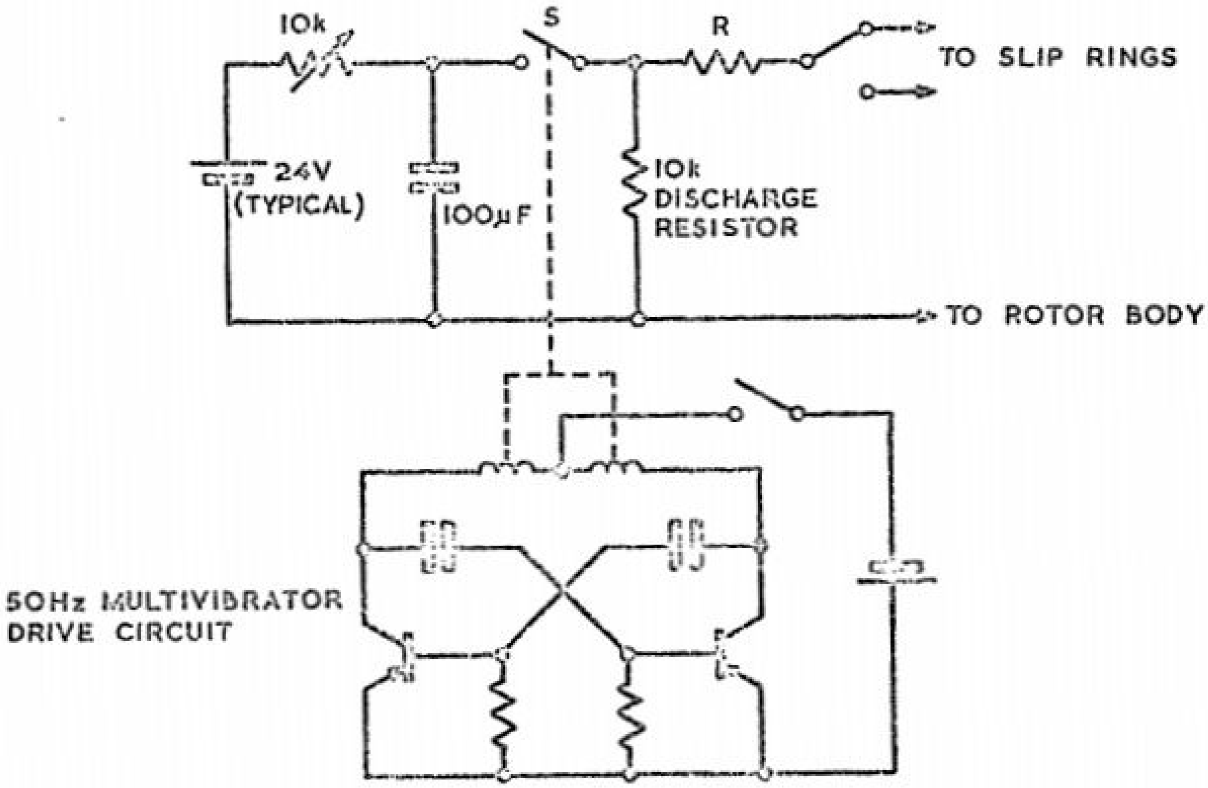
5. "Travelling waves on transmission systems", L.V. Bewley; New York : Dover publ. (1963) 543 pp.



NOTES

1. 'S' IS A MERCURY WETTED CONTACT RELAY, RATING 5A 500V SUCH AS CLARE TYPE HG. OR ELLIOT TYPE EB.
2. SOURCE VOLTAGE & RESISTANCE 'R' MUST BE SELECTED SO THAT RELAY RATING IS NOT EXCEEDED.

FIG. I. RECURRENT SURGE GENERATOR

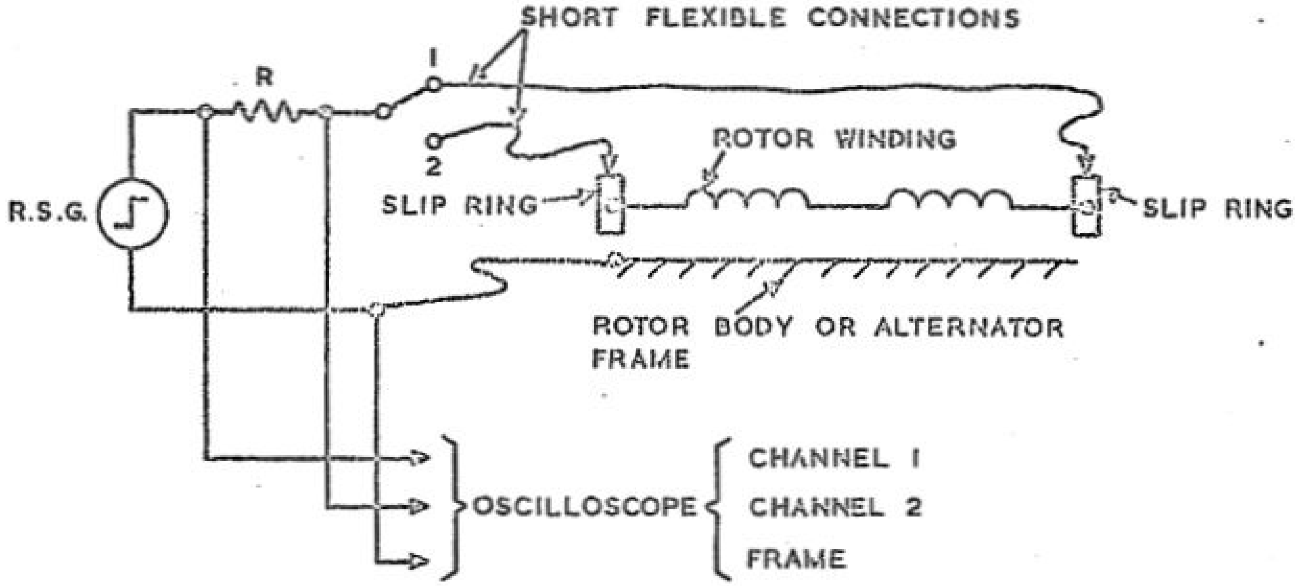


FIG. 2. CONNECTION OF R.S.G. TO ROTOR WINDING

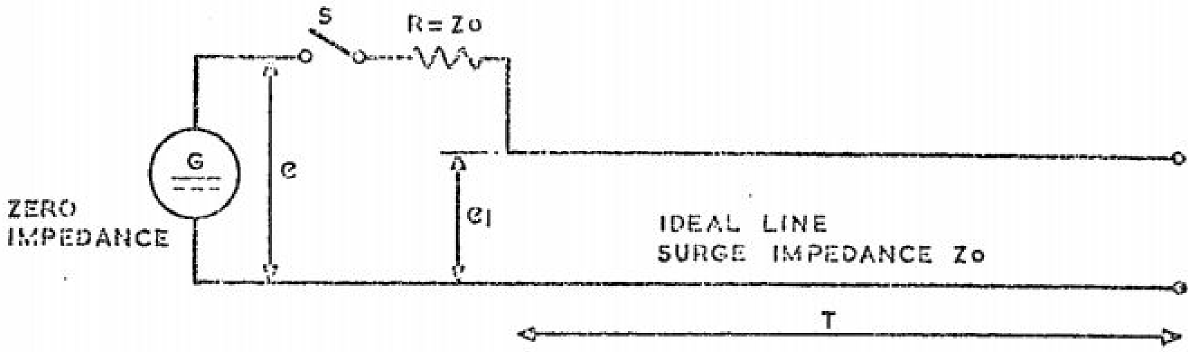


FIG. 3. RECURRENT SURGE GENERATOR AS A REFLECTOMETER

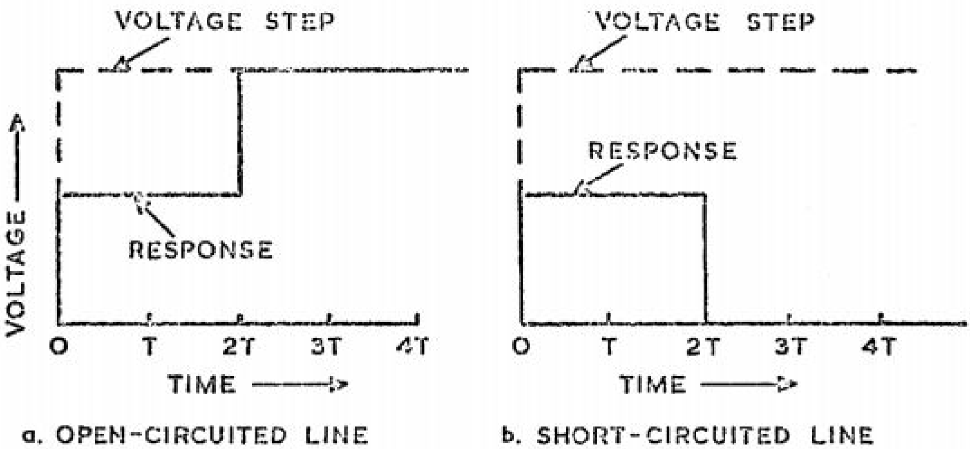


FIG. 4. RESPONSE AT START OF AN IDEAL LINE

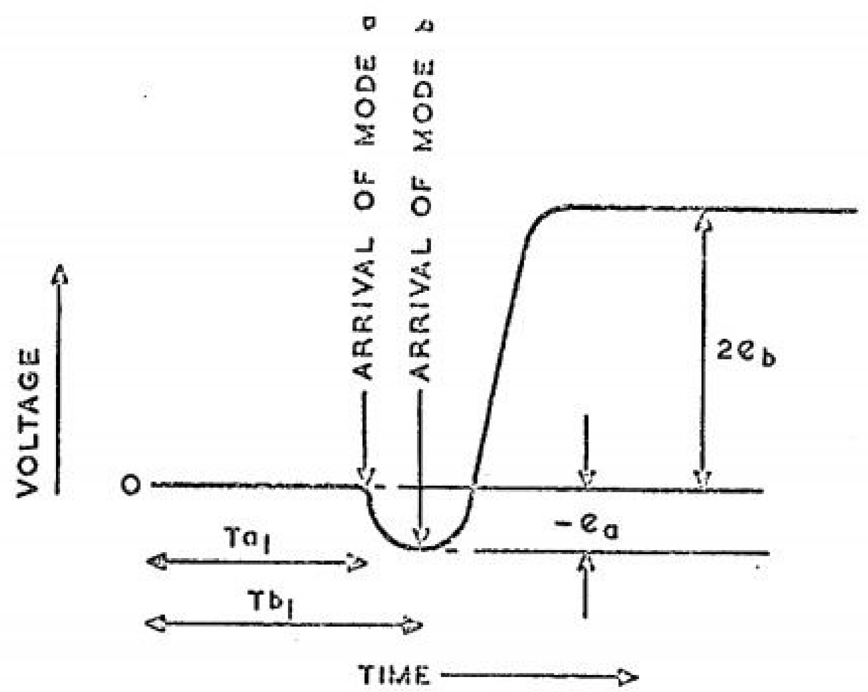


FIG. 5. VOLTAGE Vs. TIME FOR SURGE ARRIVING AT END OF WINDING

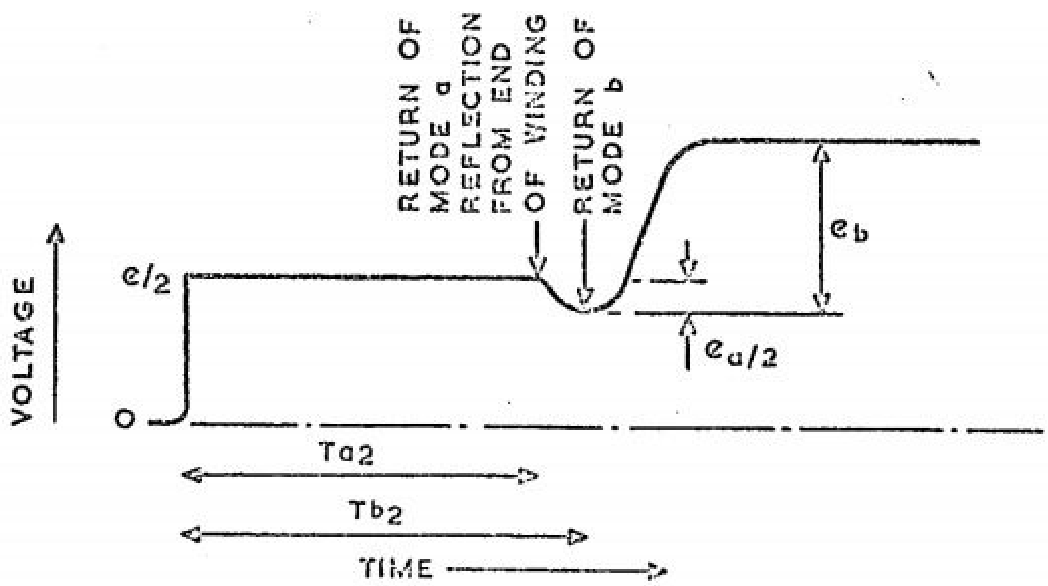


FIG. 6. VOLTAGE Vs. TIME FOR SURGE RETURNING TO START OF WINDING

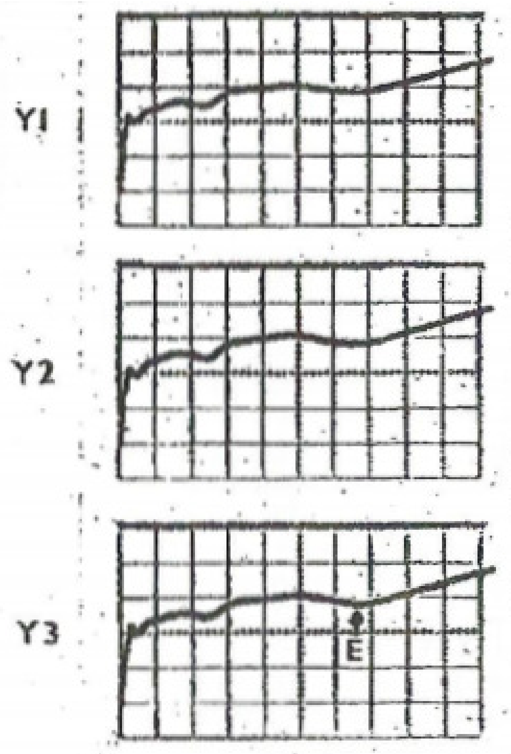


FIG. 7

X = 10μs/DIV.
Y1 SLIP RING 3 TO EARTH
Y2 SLIP RING 4 TO EARTH
Y3 Y1 AND Y2 SUPERIMPOSED
E START OF REFLECTION FROM WINDING END (OPEN CIRCUITED)
F START OF REFLECTION FROM FAULT
SPEED 0 RPM
WINDING TYPE : PROGRESSIVE

FIG. 7 RSO FOR HEALTHY ROTOR WINDING

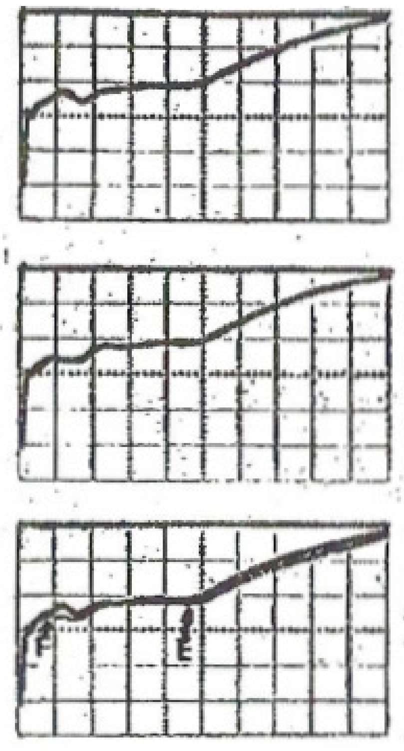


FIG. 8a

X = 10μs/DIV.
Y1 SLIP RING 1 TO EARTH
Y2 SLIP RING 2 TO EARTH
Y3 Y1 AND Y2 SUPERIMPOSED

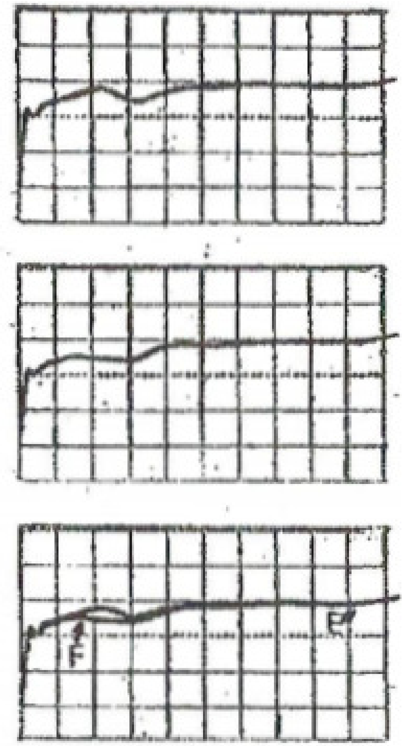


FIG. 8b

X = 5μs/DIV.
DITTO

FIG. 8. RSO FOR FAULTED ROTOR WINDING