The Journal of CPRI,
Vol. 7, No. 1, March 2011 pp. 45–52

Failure of Short - Circuit Generators: A Case Study by CPRI, Bhopal

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Switchgear Testing and Development Station prevalently known as STDS was established in 1965 at Bhopal by the Government of India as one of the units of Central Power Research Institute. The predominant objective of setting up this institute was to cater the short-circuit testing needs of various LT/HT power equipments in switchgear, controlgear and transformer field. Over the years, the unit has expanded and received all the national/international accreditations, and further became the member of Short Circuit Testing Liaison (STL). Today, CPRI's short circuit laboratories of generator based and direct on-line based are one of the leading laboratories in south east Asia.

Year 2006–2007 was a test time for CPRI, Bhopal, when both the short-circuit generators have developed technical snag, resulting in an interruption of short-circuit testing. It was a challenge for CPRI as well as for the service provider to take repair work, as so many technical intricacies were involved including the reverse engineering process. Nation realized the importance of CPRI during the shutdown period. This paper discusses about the occurrence of failure, its detailed diagnosis, root cause analysis and the action taken thereafter. Short-circuit generator is different from conventional one in many aspects. Repairing experiences of these generators, along with the re-commissioning process, are also shared herewith.

1.0 INTRODUCTION

Short-circuit test plays an essential role in certifying the performance of any electrical power equipment. Equipments connected in the complex power system are prone to undergo many short circuits in their lifetime. Hence, these equipments should be subjected to short-circuit test to ensure the design performance before putting into service. Short-circuit generators are very much different from the conventional generators used in power generating stations. Therefore, a typically designed short-circuit generator suitable for different loading cycles with dedicated protection system is required to create different types of short circuit faults which normally occur in power system. Driving these generators and extracting power from them are indeed a specialized job. Protection and control of these short-circuit generators are utmost important, as the power drawn from these generators is substantially high.

During the short-circuit period, it has to be taken care that the grid should not be loaded. CPRI, Bhopal, unit is having two short-circuit generators, both are rated 1500 MVA, 12.5 kV, 69 kA, 3000 rpm, 50 Hz. These generators are specially designed 3-phase alternators, capable of supplying the required fault power to the equipment under test for short duration.

2.0 CASE STUDY I

2.1 Fault and Fact Findings on Generator 1

In 2006, the generators after more than 45 years of operation, was tripped after experiencing

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very abnormal high vibration and sound under 12 kV excited condition during a station test. Field current was recorded to be 840 Amps instead of normal 720 Amps. It was noticed that under unexcited conditions at 3000 rpm (rated speed), the vibration and sound were normal. Observations recorded are tabulated in (Table 1).

TABLE 1

OBSERVATION DURING FAILURE

Shot number	**I_f (Amps)**	**V_t (kV)**	**Remark**
1	115	2	–
2	250	5	–
3	405	8	–
4	840	12	Abnormal sound and vibration
5	>840	8*	-do-

*The plant was set for 12 kV, but it was tripped at 8 kV.

2.2 Diagnosis at Standstill

Winding resistances of stator and rotor were taken. Recurrent Surge Oscillograph (RSO) test was conducted on the rotor. Reports are given below.

Winding resistance measurements are listed in Table 2.

TABLE 2

STATOR AND ROTOR WINDING RESISTANCES

Terminal	**Design value at 75°C**	**Measured value at 32°C**
STATOR		
U-X-U'-X'	1.228 mΩ	1.6230 mΩ
V-Y-V'-Y'	1.228 mΩ	1.6260 mΩ
W-Z-W'-Z'	1.228 mΩ	1.6078 mΩ
ROTOR		
Between slip rings	152 mΩ	149 mΩ

RSO test did not show (Figure 1) much deviation in wave shapes in the transmitted and reflected waves.

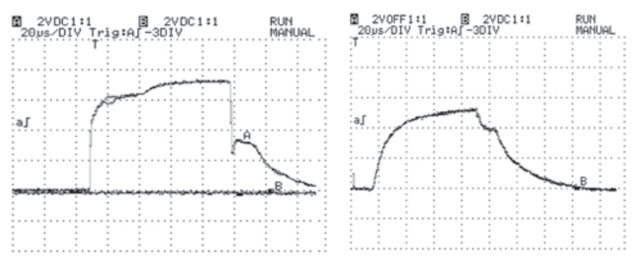

FIG. 1 RSO AT STANDSTILL

IR value and rotor impedance (at 50 Hz) were measured. All the test results were showing normal values at standstill condition. Hence, it was decided to conduct further investigations in running condition.

2.3 Diagnosis under Spinning

2.3.1 Impedance Measurement of Rotor Winding (Table 3)

Impedance was falling drastically as the speed reached beyond 2000 rpm.

TABLE 3

ROTOR IMPEDANCE

rpm	**App. volts**	**Current meas**	**Imped-ance**	**Imped-ance change**
0	10.18	2.70	3.77	–
>2000	10.08	3.30	3.05	–19.09 %
3000	15.18	5.20	2.92	–22.54 %

2.3.2 Insulation Resistance Value of Rotor Winding (Table 4)

IR value was reducing with the rpm and became negligible at full speed.

TABLE 4

IR VALUE OF ROTOR WINDING

rpm	**Megger value at 250 V, 1 min**
0	331 MΩ
<2000	175 MΩ
3000	0.0002 M Ω

2.3.3 OCC Values at 3000 rpm

To check further, the generator was excited up to 3 kV. This time, excitation current was abnormally high, about 93 % more than the specified value (Table 5).

TABLE 5

OCC AT RATED SPEED

Stator volt. (kV)	Field volt. (VDC)	Field (A) (Design value)	Field (A) (Value meas.)	Change in If
1.0	13	70	115	+64 %
2.0	30	110	215	+95 %
3.0	38	150	290	+93 %

2.3.4 RSO

RSO at spinning showed (Figure 2) abnormality in rotor circuit at speed above 2000 rpm and that indicated earth fault or zero IR value between rotor winding and shaft.

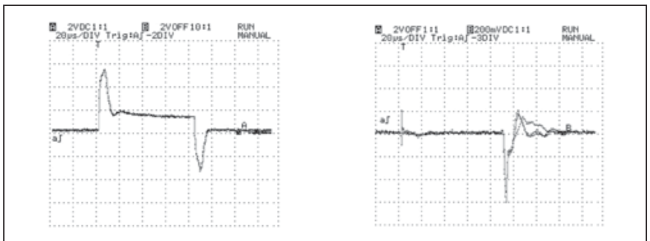

FIG. 2 RSO AT SPINNING

Hence, it was concluded that the rotor was having flying earth fault, and also higher field current indicated inter-turn short during running at rated speed. Rotor was threaded out from the stator bore and for further action, it was sent to the works of the service provider.

3.0 ROOT CAUSE ANALYSIS

The flying earth fault of this rotor was a typical condition which could not be pin-pointed accurately at standstill condition. This machine was more than 45 years old with class 'B' insulation, which got deteriorated over the years. A complete rewind with upgraded insulation was the only complete proof method of addressing the problem. Any other patch work would have involved high degrees of risk.

4.0 REPAIR WORK

Retaining rings were removed from the machine (Figure 3). Complete disassembling of rotor was carried out. Rotor disassembling included dismantling of slip rings, CC bolts and D leads. Rotor coils were of continuous type.

FIG. 3 DISASSEMBLY OF ROTOR

A few slot wedges had shown hair-line cracks of about 10 mm length during DP test. Wedges (both ends) were strengthened with brazing alloy as a preventive action for future. Rotor body was sand-blasted and thereafter, insulating paint was applied on it.

Rotor rewinding (Figure 4) was done using same copper with new class 'F' imported insulation.

FIG. 4 PROCESS OF ROTOR REPAIRING

5.0 TESTS ON RE-WOUNDED ROTOR

- Over speed test at 10 % above nominal speed was carried for 2 minutes [1].
- Rotor balancing was done at 3000 rpm and vibration values (Figure 5) were taken.

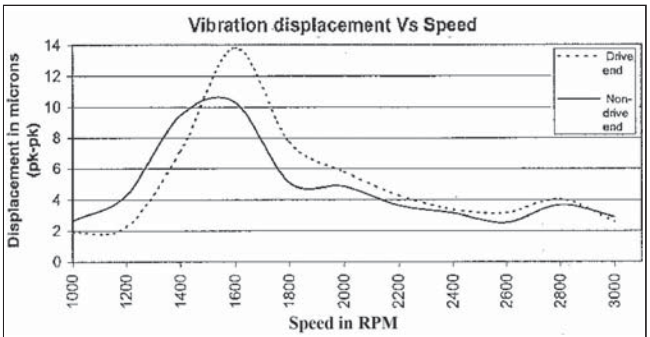

FIG. 5 VIBRATION DURING BALANCING

- Surge comparison tests were performed during and after balancing (Figure 6).

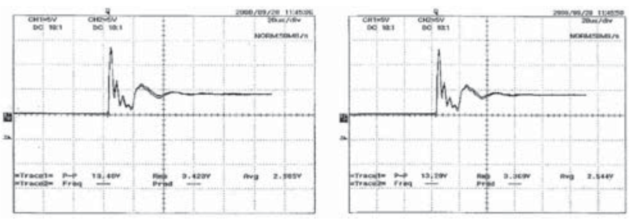

FIG. 6 SURGE COMPARISON TEST

- A few other measurements before commissioning (Table 6).

TABLE 6

MEASUREMENTS ON ROTOR AFTER REPAIR

Insulation resistance	Winding resistance	High-voltage test
Test voltage: 500 VDC After 15s: 430 MΩ After 60s: 886 MΩ	133.16 mΩ at 33°C	Test voltage: 1700 VAC for 1 min. Withstood, leakage current: 188.8 mA

6.0 TESTS ON STATOR

6.1 Electromagnetic Core Imperfection Detection (ELCID) Test

This test is carried out on the stator winding of generator to detect imperfections, faults and hot spots in the stator core. Core laminations are coated with a thin layer of electrical insulation to prevent eddy currents being induced between them by rotating magnetic field. ELCID test was conducted by passing an exciting current of 13.45 Amps through six turns of looped wire around the stator frame. Test results showed that inter-laminar insulation of the stator core is healthy (Figure 7).

6.2 Wedge Mapping Test by Electronic Wedge Tightness Detector

Wedge mapping test (Figure 8) revealed that about 19.5 % of the wedges were loose and about 19.6 % of the wedges were slightly loose. Hence, according to the recommendation, re-wedging of the stator winding was carried out.

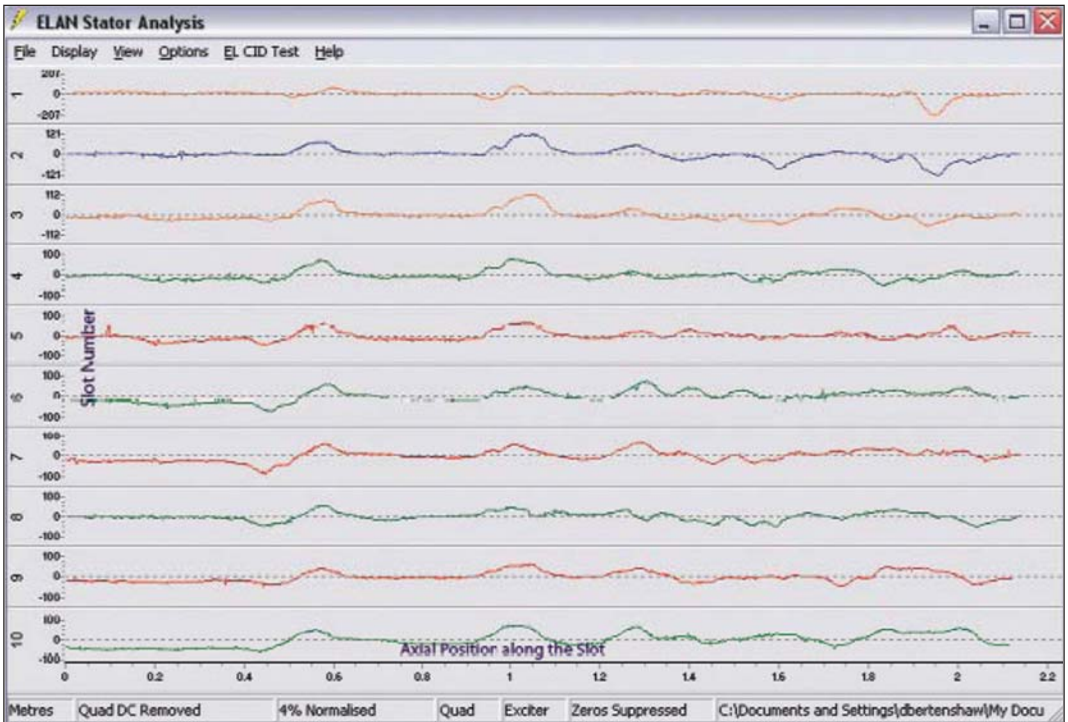

FIG. 7 ELCID TEST

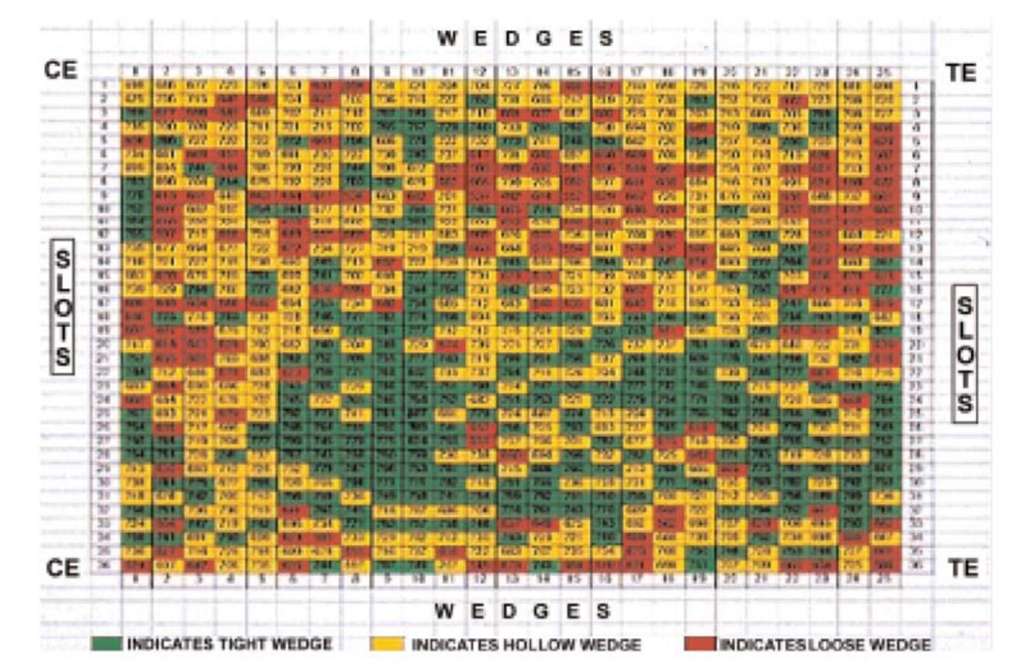

FIG. 8 WEDGE MAPPING

7.0 GENERATOR RE-COMMISSIONING

The re-wounded rotor was threaded inside the stator bore and all the required pre-commissioning tests were carried out after the alignment of shaft line (Figure 9). Generator was commissioned successfully.

FIG. 9 RE-ASSEMBLED GENERATOR

8.0 CASE STUDY II

8.1 Fault and Fact Findings on Generator-G2

A 12 kV VCB was under test. One complete test duty and one shot for second test duty were completed without any problem. During the second shot for second test duty, when the excitation request was made and the voltage was on the rising side, the excitation breaker tripped at around 4 kV and ‘Rotor earth fault’ appeared on the control panel. Simultaneously, plant tripped automatically through relay. No abnormal vibrations and other parameters were recorded/ observed during or prior to that incident.

8.2 Diagnosis

Rotor insulation resistance value between slip ring and earth was measured after disconnecting the input cables to the rotor. It was showing zero value.

Resistance of the rotor winding was checked and was found very high compared to its value during commissioning (33.71 mΩ). Such high resistance indicated the opening of winding and conduction through the rotor body.

The D-lead connections were also inspected and found intact. Hence, it was obvious that the fault must be in the rotor winding. To check the condition of the rotor winding, RSO test was conducted which confirmed the rotor winding insulation failure.

For further investigation, the rotor was sent to the works of the service provider. After opening of retaining rings, it was noticed that the melted copper had pierced the insulation under the retaining ring (Figure 10). When the insulation sheet was removed, voids were observed on a few coils and between the copper strands at the brazed junction.

FIG. 10 INSULATION FAILURE AND CREATION OF VOID

8.3 Root Cause Analysis

The failure occurred after 1500 starts, and consequently 1500 heat cycles. It was supposed that the cracks occurred due to a mechanical fatigue inside the copper strands at the brazed junction level. The voids at the brazed junction made stress concentration (Figure 11) in those areas. That was the most probable aggravating factor. The brazing of the copper made the copper material softer and consequently reduced the fatigue limit of the junction. This rotor was manufactured at England. The brazing material contained phosphorus. The brazing material was used due to safety rules in England [2]. A lot of cracks were found mainly on the brazing between the coil-to-coil connection pieces and the copper strands.

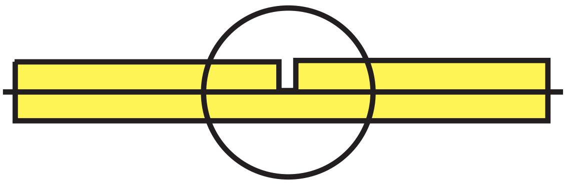

FIG. 11 STRESS CONCENTRATION

The failure had happened as follows:

- Opening of the turn at the brazed junction level.
- When the conducting surface was too small, some copper strands melted.
- Some short circuit occurred between the turns which had melted copper stands.
- The melted copper flew towards the outer diameter and pierced the insulation under the retaining ring.
- DP test was performed on the retaining rings. No crack was discovered. They are not damaged by the electric flash because the earth fault was made with the dampers.

8.4 Repair Work

- Disassembled the complete rotor.
- Replaced the copper strands which were submitted to high stresses.
- Suppressed the stress concentration by filling all the voids between the copper strands at the brazed junction level with new brazing material.
- The rotor was rewounded (Figure 12) with new Class F insulation (slot liners and the top packers).

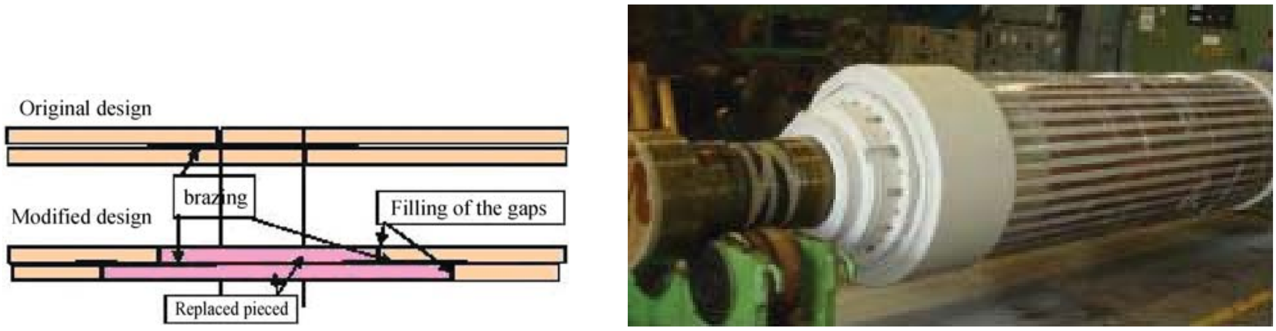

FIG. 12 COIL REPAIR AND REWINDED ROTOR

8.5 Tests on Re-wounded Rotor

- After assembling all pressing tools, rotor coil insulation polymerization cycle was performed at 100°C.
- Over speed at 10 % above nominal speed was carried for two minutes [3].
- Rotor was balanced at 3000 rpm and vibration values were NDE: 7.067 microns (pk-pk) and DE: 5.115 microns (pk-pk).
- During balancing, RSO test was performed (Figure 13) in running condition at nominal speed.
- IR value, winding resistance and high-voltage test results are tabulated below (Table 7).

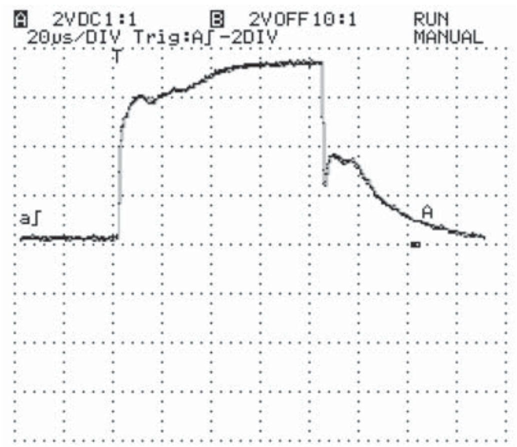

FIG. 13 RSO DURING ROTOR BALANCING

TABLE 7		
MEASUREMENTS AFTER REPAIR		
Insulation resistance	**Winding resistance**	**High-voltage test**
Test voltage: 500 VDC After 15s: 1.64 GΩ After 60s: 3.0 GΩ	38.6 mΩ at 31°C	Test voltage: 1500 VAC for 1 min Withstood leakage current: 105 mA

8.6 Tests on Stator

ELCID test and Wedge mapping were conducted for this stator also. Test results showed a healthy core and tight wedges. Hence, no work was required to be done on the stator except complete cleaning.

8.7 Re-commissioning of the Generator

Re-commissioning work (Figure 14) was carried out, and OCC was also plotted (Figure 15), which was identical to the earlier characteristics.

FIG. 14 RE-ASSEMBLED GENERATOR AND OCC THEREAFTER

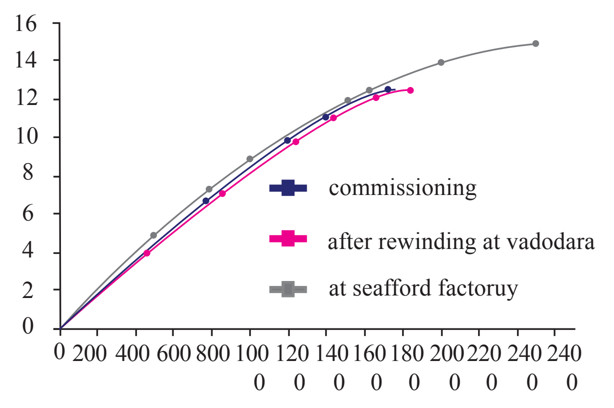

FIG. 15 OCC CHARACTERISTICS

9.0 CONCLUSIONS

Both the generators were put into service after successfully commissioning. They are operating absolutely trouble free since then.

Reformation of both the generators has improved the reliability of the short-circuit testing station, so it will be available for more numbers of equipment testing.

CPRI takes pride in going above and beyond the call of duty when it comes to customer service and quality.

REFERENCES

[1] "Rewinding of 1500 MVA Oerlikon make Short Circuit generator rotor", October 2008.

[2] Technical Report by Alstom, France. "Analysis of the rotor inspection following the 2006 rotor earth fault dtd. 12.12.2006".

[3] Rewinding report by Alstom, Vadodara, August 2007.