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India's largest short circuit generator & its salient features

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Short circuit test is one of the very important tests on electrical power equipment to verify its design aspects to withstand the critical severities under the condition of actual fault. To perform these tests a high power source is required. This source can be a grid supply with a high fault level or can be a high power short circuit generator. This paper gives the salient features of high power generator installed at Central Power Research Institute (CPRI), Bangalore. This 2500MVA short circuit generator is of highest capacity in the sub-continent of South Asia as on date. The design features are intricate in nature and complex in terms of stator, rotor damper winding and stator end winding. This paper presents the specification, design concept, constructional features, comparison between salient pole and turbo type of generators and other auxiliaries of the generator. Mechanism of achieving the maximum short circuit current is broadly discussed in this paper. This rare facility at CPRI meets high power testing requirement for the electrical industry and utilities of India and other part of the world. In this paper attempts are also made to bring out the highlights of operational features of capital intensive 2500 MVA SC generator. This generator has been used for short circuit testing of various power system components over the period of time.

Keywords: *Short circuit generator, design, construction, testing capabilities*

1.0 INTRODUCTION

Electrical power system is expanding exponentially. In this wide network a gamut of electrical equipment e.g. switch gear, transformer, insulator, cable etc. are invariably used. Reliable and safe operation of each of these equipment without outages is of utmost importance for uninterrupted power supply. To achieve this goal all the connected equipment must be capable of withstanding various faults occuring in the system. Hence these power equipment need to be verified for its ability to with stand system faults before putting into service. Quality of electrical equipment can be ensured by performing tests on them as per stipulated national and international standards. Among various type tests short circuit test is one of the most critical and important test to be conducted on all high power equipment.

In the year 1989, Central Power Research Institute (CPRI) had established a short circuit testing facility at High power Laboratory, Bangalore to support India's electrical equipment manufacturers to perform the short circuit tests as per the national and international standards and also for R & D of new equipment.

This generator, in Figure 1, is used as power source for short circuit testing which can deliver an initial short circuit power of 6530 MVA at its terminals and 2500 MVA short circuit power at test cell after 0.08 seconds after initiation of short circuit. The generator can be operated at both 50

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and 60 Hz. The generator has a rated terminal voltage of 14 kV.

FIG. 1 A VIEW OF SHORT-CIRCUIT GENERATOR AT CPRI, HIGH POWER LABORATORY, BANGALORE

Due to ever increasing demand for electricity, there is a continuous increase in the system voltage levels and hence short circuit current levels. In order to cater to the new requirements, High Power Lab is augmenting its capabilities. Under the XII plan, two more generators of 2500 MVA capacity will be added to achieve a short circuit power of 7500 MVA.

2.0 BASIC DESIGN

The short circuit generator is different from a generator for power stations. Short circuit generators are designed for special use and manufactured with different constructional features. A conventional generator is normally designed for electric power production, to supply a continuous rated output at constant voltage. But short circuit generator is characterized by pulse and cycle operation. Such a generator must be able to supply one or more consecutive test cycles, the basis of the cycle being defined as:

a) One short no-load operation period with energizing to rated voltage at the terminals.

b) One sudden short circuit connecting the generators armature to an external low impedance circuit which includes the circuit breaker under test.

c) One current interruption by the device under test after a short period, with instantaneous recovery of a voltage close to that of the initial voltage at the armature terminals.

This sequence may be repeated many times in short period.

3.0 HIGH SHORT CIRCUIT CURRENTS

In the performance of short circuit generator, the short circuit current has to be high and decrement in current value has to be minimum. The crucial points in electrical design of these types of generators are to reduce the transient and sub transient reactance and to increase the short circuit time constants [3].

To increase the interrupting power for a given reactance Xe, where Xe is the external reactance in series, it is necessary to:

- Reduce as much as possible the values of transient and sub transient reactance by minimizing the stator winding leakage reactance, as shown in Figure 2.
- Provide rotor with complete damper winding with significantly reduced resistance and inductance values,
- Design a rapid over-excitation capability into the generator to reduce the natural decrease of the short circuit current.

Figure 3 shows the effect of over-excitation on short –circuit current decrease. In order to reduce the transient and sub transient reactance the following measures were taken in the generator construction.

- Wide shallow slots
- Short stator end windings
- Flux shields in the end windings
- A large section of rotor damping winding

Smaller field resistance is considered to increase transient and sub-transient time constant.

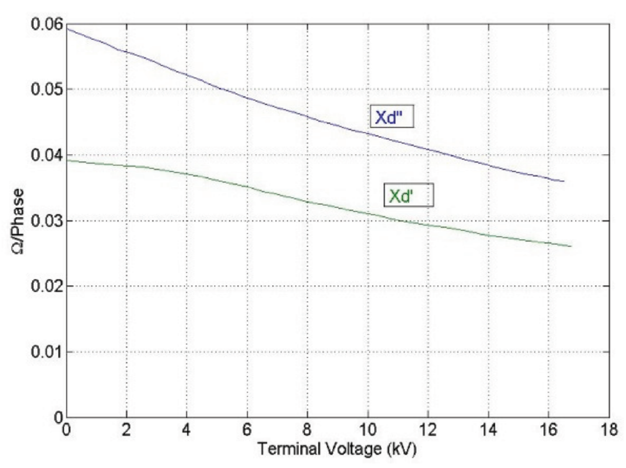

FIG. 2 VARIATION IN TRANSIENT AND SUB-TRANSIENT REACTANCE VERSUS VOLTAGE AT THE TERMINALS BEFORE A SHORT CIRCUIT [1]

The onset of high short circuit current would cause a dip in the terminal voltage due to armature reaction effects. Hence, in order to maintain the terminal voltage, the effect of armature reaction has to be neutralized by an increase in the excitation. This can be achieved by applying a higher value of excitation voltage or by cutting off resistors which are initially included in the circuit. The effect of super-excitation is shown in Figure 3.

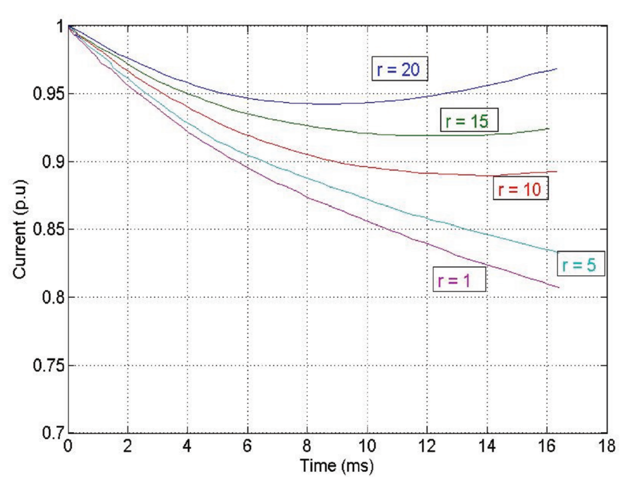

FIG. 3 EFFECT OF OVER – EXCITATION ON SHORTCIRCUIT CURRENT DECREASE [1]

4.0 SPECIFICATION[1]

Specification of the CPRI generator includes:

Initial short circuit power	-	6530 MVA
Rated Voltage	-	kV
Maximum Voltage	-	15 kV
Operating frequencies	-	50/60 Hz
Rotational speed	-	3000/3600 rpm

Interrupting power for 50 Hz operating conditions is as follows:

- 2500 MVA in three-phase short circuit
- 1760 MVA in line-line short circuit

Figure 4 shows the short circuit power versus short circuit time at the breaker opening.

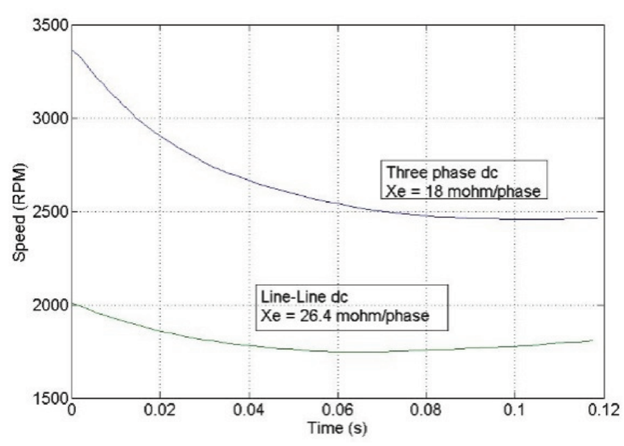

FIG. 4 THE POWER AT INTERRUPTION VERSUS THE SHORT CIRCUIT TIME [1]

5.0 CONSTRUCTIONAL FEATURES[1]

5.1 STATOR

In this type of generator, the forces on the stator winding during a typical test are about 30 to 50 times greater than the ordinary turbine generator operating under rated condition. The shape and supporting structure of the stator winding ends of the short circuit generator differ from the ordinary turbine generator. The stator winding support constitutes a robust structure and capable of ensuring the capability to support the sudden and repetitive stresses delivering from the electrodynamic forces of short circuits (Figure 5).

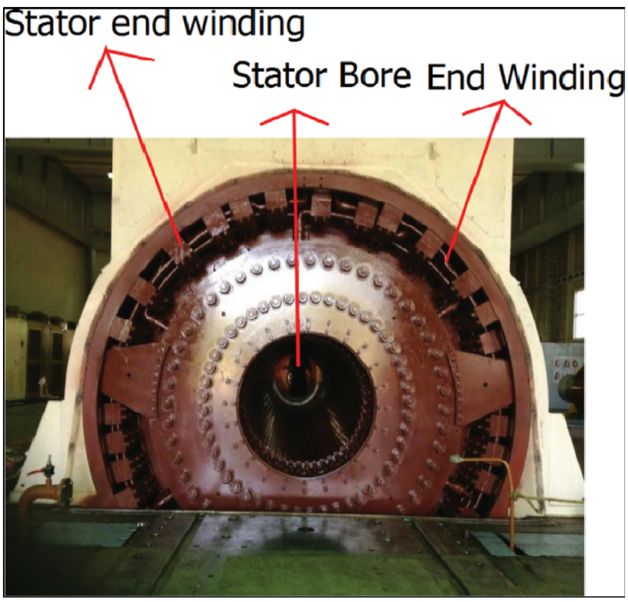

FIG. 5 THE CONSTRUCTIONAL VIEW OF GENERATOR STATOR

5.2 STATOR WINDING

- Straight bars with transposed conductors in the central section, located in the slots
- End winding situated in two planes perpendicular to the machine axis at each stator end.

The portion subjected to highest stress is the insulating sheath of the bars at the slots bottom and which must be able to withstand a compressive force of up to 3 meganewtons per meter (3x106 N/M) in the event of an accidental three–phase short circuit at the generator terminals. In this special Isotenaxinsulation material has been used which is having outstanding mechanical properties.

A special method was used to support the stator end winding. The stator end winding of this generator has an overhang portion which projected outside the core and for this reason end winding of this generator was fixed by insulation blocks between the coils along the entirety of the end windings.

5.3 ROTOR SHAFT

Rotor is the one of the most key component of the Generator. The rotor shaft is manufactured from a single forging and rotor body is heat treated, with high strength and high magnetic permeability. Special care has been taken in sizing of shaft as rotor to withstand huge pulsating short circuit torque stresses and fatigue stresses caused by the huge number of foreseen start-stop cycles. The rotor diameter suitably designed in order to have a large inertia constant to reduce the speed drop during short circuit testing. The centrifugal forces caused by the rotor winding and slot wedges are taken care by the teeth in the active part of the rotor [3]. The mass of the rotor is around 57 tonnes.

5.4 ROTOR WINDING

The purpose of the rotor winding is to carry the excitation current required for magnetizing the rotor. Rotor winding comprises a number of turns stacked inside the rotor slots, which constitute the field coils making up the poles of the rotor. The retaining rings hold the end winding of the rotor against the effect of centrifugal force and prevents from alternating short circuit torque imposed by acceleration and deceleration on the rotor during short circuit test. To prevent the grounding an isolation cylinder is placed around the end winding inside the retaining rings. The end winding and its wedging press against the retaining ring via an insulating cylinder as shown in Figure 6. In order to provide low transient and sub-transient reactance a wide and shallow rotor slots were made on the rotor body as adopted in the stator winding slots.

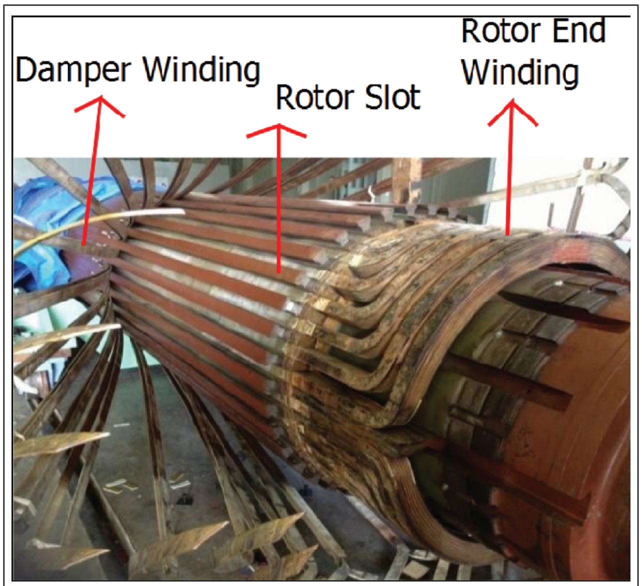

FIG. 6 THE PICTORIAL VIEW OF ROTOR STRUCTURE SHOWING END WINDING AND ROTOR SLOTS

5.5 DAMPER WINDING

The damper winding consists of large section of copper elements which is located under the closing wedges. The damper forms a complete Squirrel cage whose function is to channel current induced on the rotor periphery during operation. Rotor losses are primarily dissipated on the outer surface.

The damper winding also has the following tasks:

- Damping the magnetic forces which accompany a sudden load change.
- Preventing local overheating due to current flowing on the rotor's surface during short circuit on asymmetrical load in special case.

The design of damper winding is very important because during the short circuit phase(specially in case of non-symmetrical short circuit), the value of the inverse I2 is very high and it is fundamental that it is driven into a dedicated circuit avoiding that it can flow through the shaft and retaining ring causing pitting phenomena which can limit the life of these components as shown in Figure 7.

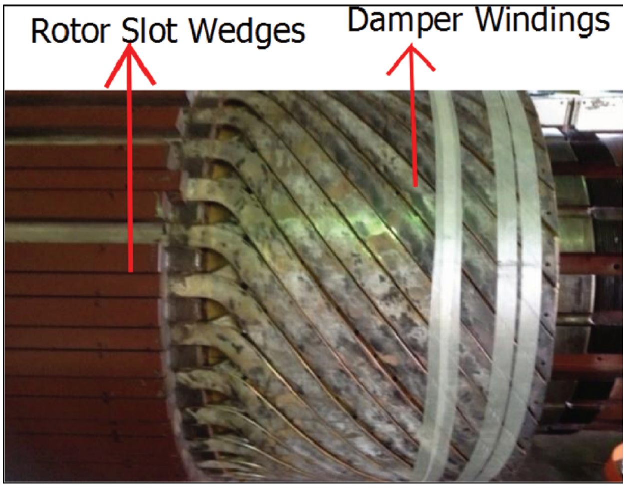

FIG. 7 THE PICTURE SHOWING ROTOR DAMPER WINDING

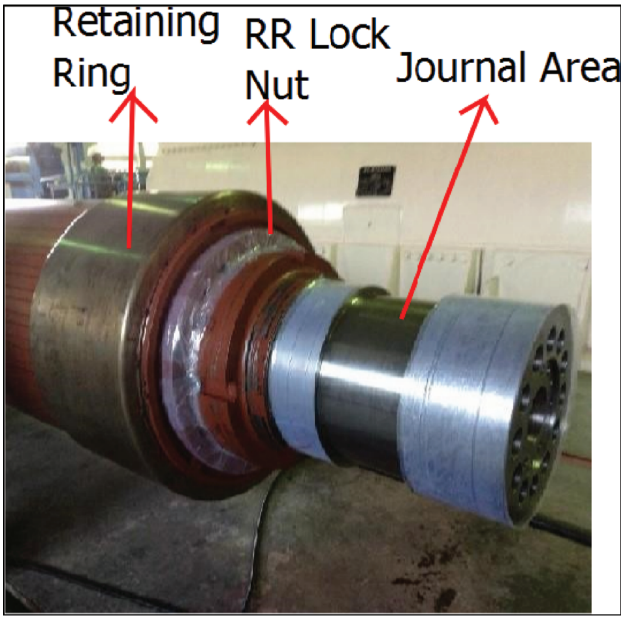

FIG. 8 A VIEW OF GENERATOR ROTOR WITH RETAINING RING (DRIVE END)

Apart from the above components, the generator consists of the following systems.

- Driving system
- Static Frequency converter
- Static Excitation
- Pilot Generator
- Lube Oil System
- Cooling System
- Generator protection and Monitoring system

The speed of the generator is controlled by SFC at the different speeds of 250 rpm, 3000 rpm, and 3600 rpm. The excitation system is to feed D.C. supply to the field winding of the generator in order to establish the rated voltage at the stator terminals as per the short circuit test requirement. Figure 9 shows the lay out of the static frequency convertor (SFC) and static Excitation system [2].

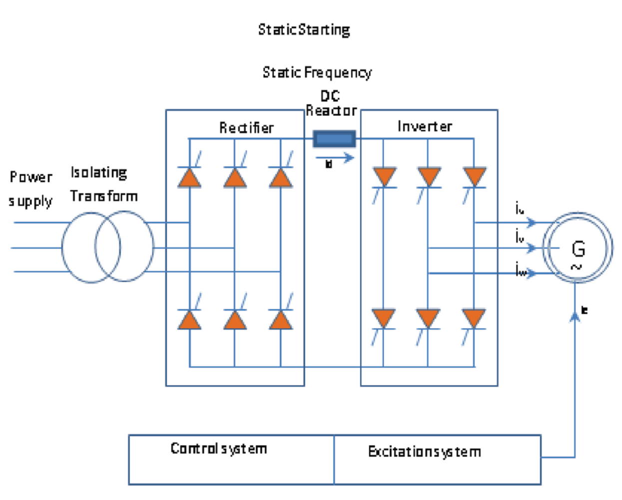

FIG. 9 CIRCUIT DIAGRAM OF COMPLETE GENERATOR SYSTEM, NOMENCLATURE: ID-DIRECT CURRENT, IE-EXCITATION CURRENT, IU. IV, IW- MACHINE PHASE CURRENTS

TABLE 1

COMPARISON BETWEEN SALIENT AND NON-SALIENT POLE GENERATOR

	Turbo type	**Salient pole type**
Speed (rpm) (Basis 50 Hz)	3000	750
Voltage kV)	14 - 16	20
Power in the test cell after 0.08 S (MVA)	2500	2500
Ratio (X''_d/X'_d)	0.6 to 0.7	0.9
T''_d (mS)	30 to 50	200
Approximate weight: stator (tonnes) rotor (tonnes)	250 60	2 x 150 180
Size L (meter) Rotor Outside diameter (m) stator	6 4	6/7 5/6

TABLE 2

RANGE OF TESTING AND MAGNITUDE OF CURRENT THAT COULD BE ACHIEVED THROUGH THIS GENERATOR

Equipment	**Type of test**	**Range**
Circuit Breakers	Basic Short Circuit Test Duties & out of phase making and breaking tests	Up to 36 kV 40 kA and 72.5 kV 20kA
	Single Capacitor Bank Breaking Current Tests	3 Phase - 36 kV 800 A; 11 kV 1100 A 1 Phase – Up to 36 kV 1250 A
	Line/Cable charging current test	Upto 36 kV
Power transformers	Dynamic and thermal ability to withstand short circuit	Up to 72.5 kV 25 MVA 3 phase; Up to 245 kV 250 MVA Single Phase depending upon the percentage impedance
Other Apparatus	Short Circuit Withstand Tests	Up to 72.5 kV 2500 MVA 3 phase; Up to 245 kV 1400 MVA 1 phase
	Short Circuit Current Tests	Up to 120 kA for 3 sec
	Power Arc Tests	Up to 40 kA for 0.5 S

6.0 SAMPLE TEST WAVEFORMS

The short circuit generator has since been used for testing various power equipment. In order to illustrate the test applications the generator is subjected to, some sample waveforms are provided below:

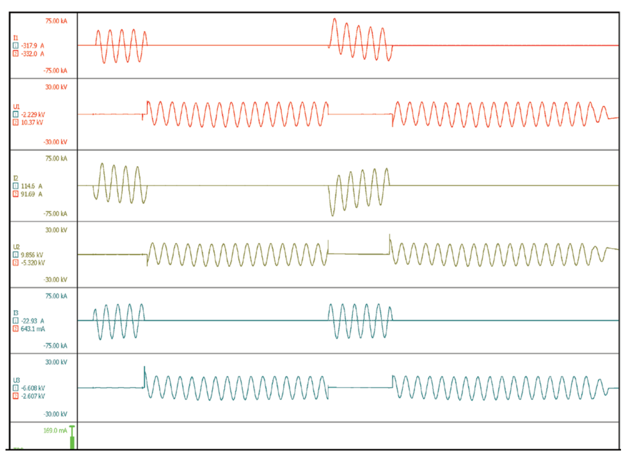

FIG. 10 VOLTAGE AND CURRENT WAVEFORMS DURING A CIRCUIT BREAKER TEST

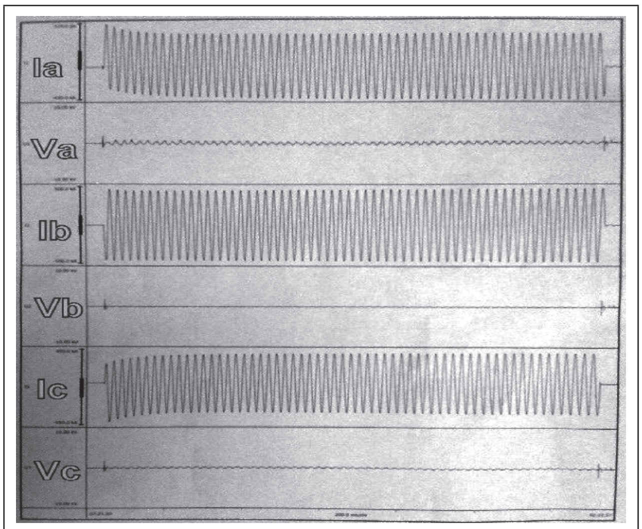

FIG. 11 THREE PHASE CURRENT AND VOLTAGE WAVEFORMS DURING A SHORT CIRCUIT TEST

Figure 10 shows the Open-Close-Open operation of a test breaker. This is a usual test done on circuit breakers as given in Table 2. Each set shows a current waveform and voltage waveform and there are three sets representing three phases. In Figure 11. shows the three phase short circuit current and voltage waveforms during a typical short circuit test. The characteristic asymmetry is clearly visible in two of the three phases.

7.0 CONCLUSION

In this study, the design, constructional and operational features of short circuit generator are discussed. The maintenance of such a gigantic facility is critical in the context of vital structure of stator and rotor. This largest SC capacity facility not only caters to power sector stake holders but also sustains and maintains the development in electrical power helping technological growth. This unique facility paves the way for country's self-sufficiency in short circuit testing in this region.

REFERENCES

[1] Alstom Review No.12 -1988

[2] Converteam (C-005886) SFC_GEX_ CONTROLUPGRAD Technical Document

[3] H Yoda, M Fujita, E Nakamura, T Ikuzawa, T Otaka and S Nagano, "The World's Largest Class 8,880MVA Short Circuit Generator", IEEE Power Engineering Society Summer Meeting, 2002.