A REPORT

ON

Maintenance and Overhauling of Generator

BY

Prakhar Sharda	2015A3PS274G
Digvijay Bansal	2015A3PS187P
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ADANI POWER LIMITED, MUNDRA

A Practice School-I station of

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July, 2017

BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI (RAJASTHAN)

Practice School Division

Station: Adani Power Limited, Mundra

Center: Mundra

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Title of the Project: *Maintenance and Overhauling of Generator*

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Key Words: Stator, Rotor, Coolant, Generator, Turbine, Exciter, Windings, Core

Project Areas: *Electrical Machines, Power Plant Engineering*

Abstract: *This project basically aims to study the functioning of 330/660MW generator. As per the title of project, we study the constructional features of 330/660MW generator. As generator is one of the most important functionary of the power plant, its maintenance and caring must be properly done. Recently the Unit 4 of Power Plant has created a World Record of Power Generation for coal based production. Its maintenance is currently being carried out by Team of Adani Power, since it was a great opportunity to discover the nuts and bolts of Generator and how it's overhauling is done for its healthiness. The core aim of the project is to highlight the timeline of maintenance and overhauling of Generator, practically observe the maintenance work and try to understand the processes theoretically. At last we try to propose the methods by which the overhauling process could be done in efficient manner.*

Signature of Student **Signature of PS Faculty**

Date: **Date:**

ACKNOWLEDGEMENT

We would like to extend our earnest gratefulness to all those who have supported us in direct or indirect ways to complete this report.

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We would also like to thank our PS Instructor **Dr. Debasis Das**, for his excellent personal guidance and help throughout the project.

Last, but not the least, we would like to thank the team of **Adani Power,** for all the help and knowledge imparted to us, during the maintenance work. Without this knowledge, we could never have completed this project.

These factors have greatly contributed to our report.

Thank you.

TABLE OF CONTENTS

INTRODUCTION

A power plant is a necessary part of the contemporary eco-system. Sustainable energy is an indispensable part of our daily lives, and we as electrical engineers have our goals fixed on meeting the electrical energy needs of the society in a clean, optimized and efficient manner.

As a part of our journey in doing so, we obtained a great opportunity to research and train at the nation's biggest power plant, located in Mundra, Gujarat. Introduction to the basic working of the plant itself demanded a separate section in the report. We were lucky enough to be present here during the overhaul of Unit 4, which set an incredible world record for running more than 600 days in a row. We were instantly attracted to the sheer scale of the electrical equipment here and fell in awe with the life size machinery which were just line drawings in our books before.

The four of us, as a team shared a common interest in the working and maintenance of one of the most vital part of the Power plant, the generator. Ever since that, we have been tirelessly spending most of our time here enriching ourselves with details about this technological marvel. In this report, we focus on covering the construction, operation and maintenance of the generator essentially covering its entire life cycle. We have also included suggestions to improve the current methodologies involved in the overhauling process, which however can seem to be very minor in comparison to the technical vastness of these tests.

We hope the readers of this report gain as much knowledge as we have over this tenure.

ADANI POWER LIMITED

Figure 1.1 – Adani Group Logo

ABOUT THE COMPANY

Adani Power Ltd. is the power business arm of Indian powerful business house Adani Group, having its head offices in Ahmedabad, Gujrat. The conglomerate is India's biggest private power generator, with capability of 10,440 MW and also it is the biggest solar power producer of India with a capacity of 688 MW. Adani Power Limited is placed 334th in the top companies in our country in Fortune India 500 list of 2011. It is the nation's 1st company to achieve the supercritical technology. The Mundra power plant is the only thermal power plant in India to be certified by UN under CDM. [1]

COMPANY AT A GLANCE

Established:	*22 August 1996*
Base of Operation:	*Ahmedabad, India*
Key Personalities:	*Gautam Adani (Chairman)*
	Vineet S Jaain (CEO)
Renowned Products:	*Electricity transmission and distribution*
Parent:	*Adani Enterprises Ltd.*
Accreditation:	*An ISO 9001 - 2008 & OHSAS 18001 - 2007 Company*

OPERATIONS

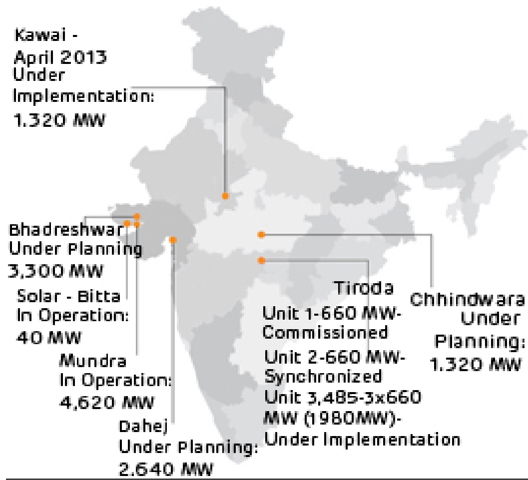


Figure 1.2 – Location of Adani Power Limited Power Plants

Thermal Power Plant situated at Mundra

This is a 4620 MW (4x330, 5x660 MW) thermal power plant at Mundra, Kutch district, Gujarat which produces energy utilizing the high calorific value of coal. This plant is completely functional. It operates 1st power transmission project of 400 kV Double Circuit Transmission System starting from the Mundra plant to Dehgam which is 430 km away.

Thermal Power Plant situated at Kawai

This is a 1320 MW (2x660 MW) coal-based thermal power plant at Kawai village, Baran district, Rajasthan. This plant is fully functional.

Thermal Power Plant situated at Tiroda

This is a 3300 MW (5x660 MW) thermal power plant at Tiroda, Gondia district, Maharashtra which produces energy utilizing the high calorific value of coal. All units are completely functional.

Thermal Power Plant situated at Udupi

This is a 1200 MW (2x600 MW) thermal power plant at Padubidri, Udupi district, Karnataka which produces energy utilizing the high calorific value of coal. Both units are completely functional since September 2012. Adani Power acquired this power plant from Lanco Infratech in August 2014 for Rupees 6000 crores.

Solar Power Project situated at Kamuthi

A 648 MW solar photo-voltaic power generating station.

FUTURE VISION

As of the month of January, 2011, the company has 16500 MW under implementation and planning stage.

- A 3300 MW Thermal Power Plant at Bhadreswar in Gujarat
- A 2640 MW Thermal Power Plant at Dahej, Gujarat,
- A 1320 MW Thermal Power Plant at Chhindwara in Madhya Pradesh,
- A 2000 MW Thermal Power Plant at Anugul, Orissa, a 2000 MW Thermal Power Plant at Sambalpur, Orissa, and
- A 2000 MW gas-based power project at Mundra, Gujarat.
- A 1000 MW lignite coal-based power plant in Kosovo showing its project ambitions outside the country. [1]

It targets achieving a total power producing capacity of 20000 MW by 2020.

MUNDRA THERMAL POWER PLANT

Mundra Thermal Power Station is located at Mundra in Kutch district in the state of Gujarat. The power station is based on coal. The coal required for running the power plant is imported primarily from Bunyu in Indonesia. The water required for the power plant is obtained from Gulf of Kutch.

It is the 11th-largest single location coal-based thermal power plant in the world, also India's second largest operational power plant.

The plant has 9 power generating units; the last 5 units involve a super-critical boiler technology. [2]

LOCATION

Figure 2.1 – Location of Adani Power Limited, Mundra Power Plant

<u>Site Location:</u>

Nearest Village:	Tunda, Taluk Mundra, District Kutch
Mean Sea Level:	5.1m
Total Area:	294Ha

OVERVIEW

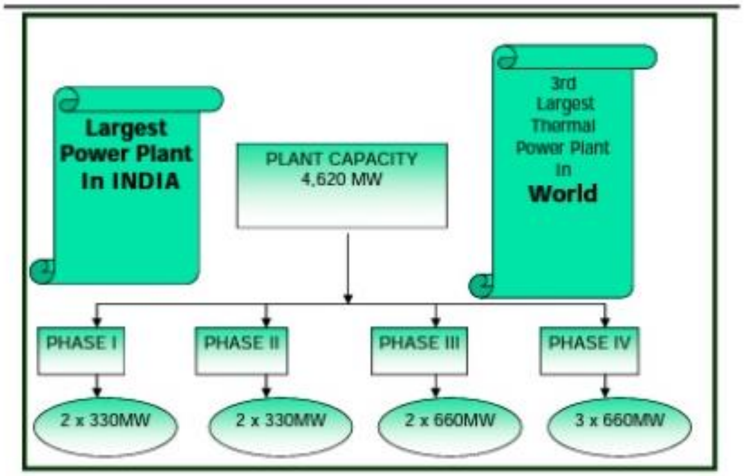


Figure 2.2 – Plant Overview

Adani Power has set up 4620MW plant at Mundra based on imported coal.

The execution carried out in following Manner,

- 2*330 Phase 1 (Sub-Critical)
- 2*330 Phase 2 (Sub-Critical)
- 2*660 Phase 3 (Super-Critical)
- 3*660 Phase 4 (Super-Critical)

Figure 2.2 – A view of Adani Power Plant, Mundra

PLANT SPECIFICATION

For Adani Power Ltd., Mundra, the generator rating of the two systems varies as given underneath:

Parameters	Values
Active Power	330 MW
Rated Speed	3000 rpm
Power Factor	0.85
Rated Capacity	388.2 MVA
Rated Voltage	24 kV
Rated Current	9339 A
Number of Poles	2
Frequency	50 Hz
Excitation Current	2495 A
Excitation System	Brushless

Table 2.1 - Phase 1 & 2 generator specification

Parameters	Values
Active Power	660 MW
Rated Speed	3000 rpm
Power Factor	0.85
Rated Capacity	776 MVA
Rated Voltage	22 kV
Rated Current	20377.1 A
Number of Poles	2
Frequency	50 Hz
Excitation Current	4484 A
Excitation System	Static

Table 2.2 - Phase 3 & 4 generator specification

GENERATOR CONSTRUCTION

Generator is one of the most vital parts of a Power Plant. It converts mechanical energy of a turbine into electrical energy. It is a critical unit of power plant. In our plant, the source of mechanical energy is steam turbine, which rotates the generator rotor at a speed of 3000RPM.

The Generator consists of:

- **Stator**
  - Stator Frame

    The stator frame is constructed using steel plates which are rolled and welded into the desired shape. Its supports the stator core, stator winding and the rotor. It also contains the coolant (Hydrogen gas), prevents leakages and minimizes the damage caused by hydrogen explosions.
  - Stator Core

    Stator core is build-up of segmented, insulated, cold-rolled silicon steel with high permeability and low losses to provide a low reluctance path for flux. To reduce the core vibration transfer to the foundation, axial spring support system is used to stator core.
  - Stator Winding

    It is a two layer basket type with a single turn coil. It features a fully integrated, F class mica-epoxy insulation system and anti-corona system for the stator bars.

- **Rotor**
  - Rotor Shaft

    The shaft is made of single piece high-strength, high magnetic permeability, and alloy steel forging. It contains coils in the slots longitudinally attached on the rotor body to provide a low reluctance path for magnetic flux, transmits torque provided by turbine even caused by system faults, withstands great centrifugal force due to high speed rotation.
  - Rotor Winding

    Rotor winding is composed of silver-bearing copper strip, with high conductivity, mechanical strength. Rotor winding is direct cooled by hydrogen with a gap pick-up diagonal flow system in slot portion, and two path axial flow system for the end turns.
  - Retaining Ring

    Retaining ring, which retains the end turns of rotor winding against centrifugal force, is made of high strength, cold-expanded, non-magnetic alloy steel forging.
  - Collector String

    Collector rings, made of wear-resistant steel, shrunk over insulation ring, which assembled on the end of shaft, provide contact surface for brushes to carry excitation current corresponding to generator Maximum Continuous Output and even force exciting.

- Hydrogen Coolers

  These are used to cool the hydrogen (coolant for rotor and stator core). Is capable of handling at least 10 Kg/cm^2 gauge pressure irrespective of the casing pressure. These are shell and tube type heat exchangers and they cool the hydrogen in the generator itself.

  The cooling tubes are corrosion resistant and feature integral fins. They are arranged in the stator casing so as to avoid the direct fall of water, during leakage, on the winding insulation. Temperature and pressure gauges on inlet and outlet of cooling water are provided. Air-tight sealing is achieved using a gland type seal.

- Bearing

  These self-aligning sleeve bearings are located in stator end shields. They provide support to the rotor. They feature labyrinth shaft seal and hydrostatic jacking arrangement aligned with the turbine bearings. They feature 'B' type insulation. Arrangements are made to measure the generator insulation during testing process.

- Shaft Seal

  It is used to prevent the escape of hydrogen from the part where rotor shaft crosses the stator. The seal is achieved using a continuous film of oil between the seal ring and the shaft on the hydrogen and air side. To achieve this, oil from two separate circuits, i.e. the air side and the hydrogen side, is fed to the seal ring at a pressure slightly higher than the hydrogen pressure. The shaft is adequately insulated to prevent circulation of shaft current.

- Seal Oil System

  This system comprises deals with the supply and control of the seal oil. It consists of coolers, AC/DC operated pump sets, filters, oil tanks, pressure regulators, degasification tanks, thermometers, regulating and control valve gauges and other instruments such as interconnected piping and control/annunciation panel. Blowers are provided, to vent out the H_2 gas liberated from oil, where such a gas accumulation is likely to occur.

- Gas System

  The gas system contains all equipment necessary for filling or exhausting the generator of hydrogen. During operation, the generator is filled with hydrogen. The gas system provides CO2 and air as well to expel the hydrogen safely. The gas system also includes a Nitrogen supply. During purging and filling, the gases are expelled to the atmosphere. Gas analyzer should be present to measure the purity and percentage of gases. DDCMIS system should be there to monitor all the parameters.

- Primary Water System

  Direct cooling dissipates the losses occurring in the phase connectors and stator windings terminal bushings. Water is the primary coolant to dissipate the losses. Cooling is provided using a closed loop stator cooling system. The conductors are made hollow. Water for the primary water system is tapped from the condensate extraction pump.

GENERATOR OPERATION

GENERATOR OUTPUT

In a synchronous generator with rotor running at constant speed, the instantaneous voltage induced in a stator conductor is proportional to the magnetic flux density experienced by conductor.

$$E = kd\emptyset/dt$$

Where,
E - Instantaneous voltage induced across the length of conductor, Volts
$\emptyset$ - Rate of change of magnetic flux, Tesla/sec
L - Length of the conductor exposed to the flux, m
k - Constant

As the rotor rotates inside the stator bore, a conductor fixed in the stator will be subjected to magnetic flux density and will have an approximately sinusoidal voltage generated across its length.

The magnitude of the generated of the generated voltage can be changed by varying the DC supplied to the excitation coils on the rotor.

Both stator and rotor are wound with different coils known as stator winding and rotor winding.

When the rotor coils is excited through an external DC Source, an alternate voltage is generated stator coil terminals.

Value of voltage generated (induced) depends upon the excitation of rotor.

SPEED, FREQUENCY AND POLES OF GENERATOR

$$NP = 120f$$

Where,
N - Synchronous speed of generator, 3000RPM for steam turbine generator.
f - Frequency 50Hz
P - Number of poles of generator, 2 for steam turbine generator

POWER OUTPUT OF A TURBO GENERATOR

$$P \propto NLBAD^2$$

Where,
P- Power in MVA
D- Bore Diameter of Core in Meters
L- Length of Active Rotor Body in Meters
B- Air Gap flux density in Tesla
A- Stator Ampere-Turn
N- Speed in RPM

LOAD, RATING AND POWER FACTOR

The relationship between voltage and current is dictated by the nature of the load. For any load which is not purely resistive. The voltage and current will not be in phase i.e. if the voltage is inductive like motors, the current will lag the voltage and in case of capacitive load, current will be ahead of the voltage.

The lagging phenomenon produces leading power factor while leading phenomenon produces leading power factor.

The power factor is one of the important factor which plays vital role in the stability of electrical equipment including generators.

Rating of generator is normally specified in MVA/KVA i.e. product of voltage and current. But power rating considers the effect of load on current so power factor is also multiplied

The output power is obtained by using the equation -

$$P = VI \cos \emptyset$$

Where,
P- Power output in KW or MW
V- Voltage on the output terminals of generator, Volts
I- Current Flowing as load effect from the Generator, Amp
$\cos \emptyset$ - Power Factor as effect on Load

For Star connected generator the output power P,

$$P = \sqrt{3} VI \cos \emptyset$$

For 660MW generator power rating is,

Power P = 660MW
Voltage V = 22KV
Power Factor = 0.85 Lagging
No. of Phases = 3
Frequency F = 50Hz

The output is MCR i.e. maximum continuous rating which implies the guaranteed sustained load condition.

OPERATION OF TURBO GENERATOR

Turbo Generator

Whenever two or more turbo generators are connected in parallel for their correct operation, they must be share same amount of load. For above operation to be made successful certain precautions must be taken care of.

For operating the turbo generators, when they are connected to the same bus, they must be operated in same phase sequence, equal voltages and frequencies.

Following are the general steps which guide how alternators are synchronized and in which pattern they are connected to bus during operation.

Phase Sequence Check

The positive phase sequence i.e. A, B, C is the standard phase sequence for 3 phase systems. If the phase sequence gets disturbed during the parallel operation magnetic instabilities can occur leading to setting up of treacherous circulating currents.

Voltage Checking

The word *Synchronous* in synchronous generator itself suggest, the operating frequency of the generator must be in sync to the bus frequency to which it is connected. An AVR located at the switch panel controls the current fed to the rotor field winding to adjust the voltage produced, by limiting or allowing the flow of current as per requirement.

Frequency Checking

The generation frequency of a synchronous generator is directly proportional to operating rotational speed. By correct observation of grid frequency, the speed can be adjusted by adjusting the steam pressure in the turbine.

With the help of these fine adjustments we can achieve exact synchronization

Other than above crucial aspects following things must also be known for normal operation of generator

- Power rating for continuous operation of generator is 330/660MW.
- In various other operating conditions, the operational capacity of generator shall be insistent with – Generator Capability Curve.
- Generator cannot be allowed to operate with load in air-cooled mode.
- When the voltage of generator stator varying within the rating of 5% and power factor is at the rated value, its capacity shall keep unchanged.
- When the voltage of generator stator is higher or lower than 5% of rated value, the allowed current value of stator can be allowed to be lower or higher than 5% of rated value.
- Generator can operate with variable power factors, when power factor is reducing, the current of rotor shall not be greater than the rated current, and the apparent power is reduced. During increase it can't increase beyond rating.
- Sometimes Generator is operated in Overloading conditions. But other parameters must be same as at their rating.
- Increase/decrease rate of load of Generator shall be generally 5% of rated load per minute; however, under a state of emergency, it shall depend on the steam turbine.
- Generator can structurally operate stably under the condition of leading power factor being 0.95 and at the rated power.
- Generator can output rated power continuously at rated power continuously at rated power, rated voltage deviation of 5%, and rated frequency deviation of 3~5%.
- During normal operation of generators, hydrogen pressure in the unit must be higher than the pressure of cold water inside.
- If any hydrogen cooler is out of operation for some reason the generator can operate only 80% of full load.

- Due to some reason if hydrogen cooler stops functioning the generator can operate till 80% of full load.

TYPES OF GENERATOR

AC GENERATOR

- **Synchronous**

The Generator is running at synchronous speed while generating power.

For steam turbine generator synchronous speed is 3000RPM while for hydro it is variable depending on local conditions.

Brush Excitation

Rotor is connected with excitation source through carbon brushes. Regular maintenance is required to maintain the connectivity of brush.

Wear and tear has to be monitored through separate instrumentation. In 660MW power plant in Adani this system is used.

Brushless Excitation

It has an advantage over brush excitation system. The excitation source is connected with rotor with electro-magnetic non-contact type arrangement.

In this type separate pilot exciter is used to develop the field in the rotor. In 330MW Adani Power Plants this system is used.

- **Asynchronous**

The Generator is running is 3% slip speed more than the synchronous speed. For Example in wind turbine the synchronous speed is 1500RPM.

To generate power at full load the asynchronous generator runs at 1500+3% i.e. 1545RPM.

Excitation is given through the stator and the advantage is that no separate excitation source is necessary.

DC GENERATOR

It is less used in industrial applications. Rather, these are used for small purposes e.g. *Welding Machines*.

Standard steam turbine generators are designed with 2 poles to have a speed of 3000RPM. While salient pole generators are designed for more than 4 poles may be 12 or more than that depending upon requirement.

Generators at Mundra are fully enclosed and have cylindrical rotors. Stator windings are water-cooled and the iron cores of stators &rotors and rotor windings are hydrogen cooled.

Seal Oil system uses a single-flow sealing pad.

Excitation system adopts SCR-side self-shunt static excitation system mode. Excitation power is supplied directly from outlet of Generator, with excitation transformer, while excitation transformer, while excitation starting power is supplied from Station Auxiliary System.

GENERATOR CAPABILITY CURVE

The real and reactive power capability of a generator can be easily described with the help of generator capability curve. The curve is plotted on an apparent power (S) plane, on vertical axis Real power is plotted and Reactive power on horizontal axis. The capability curve is based on the phasor diagram of a synchronous generator.

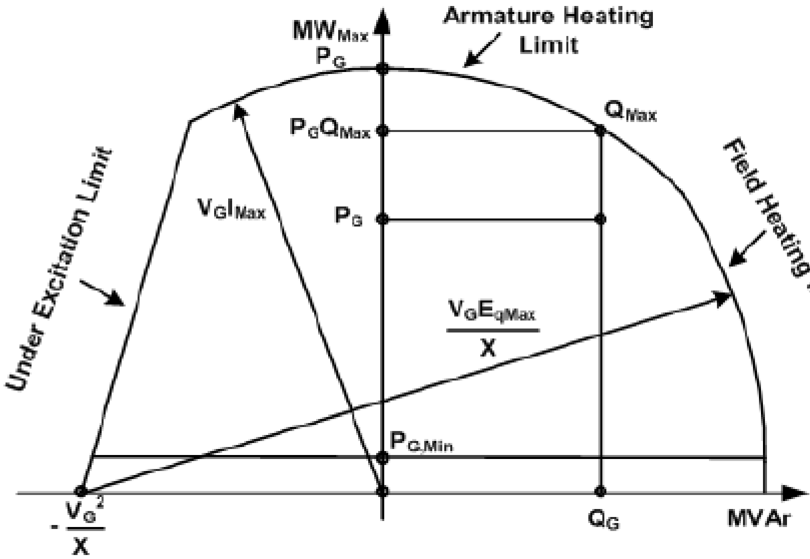


Figure 6.1 – Generator capability curve

The curve consists of three main sections

Under Excitation Limit

This portion represents reactive power coming into the machine with the constant MVA. This section reflects end-ring heating when the generator operates in under excited region. Also this portion of the curve indicates a minimum amount of current fed to rotor field winding to maintain smooth operation of generator.

Armature Heating Limit

This segment of the curve is in form of arc centered at origin. The radius of the arc represents the apparent power, represented by S (in MVA), the active power limitations of the arc primarily reflects thermal heating limitations intrinsic to stator windings.

Field heating limit

This portion of the curve is an arc centered on Q axis, the arc meets the positive Q axis having a constant MVA part of the curve and states the higher boundary of reactive power which the generator can produce. This arc also reveals current based heating, but for rotor winding.

EVACUATION OF GENERATED POWER

Generator can supply power in two different conditions:

- Stand-alone system – supplying power in isolation.
- Connected to a power grid as synchronized unit.

Large power stations are generally meant for supplying power through an interconnected grid, where many other generators and distribution systems are grid constituents.

When the generator is not synchronized with the system,

- Change in prime mover input will result into change in speed.
- Change in excitation will result into change generator terminal voltage.

When the generator is synchronized with the system,

- Change in prime mover input will result into change in MW.
- Change in excitation will result into change MVAR.

POWER EVACUATION ARRANGEMENT AT ADANI POWER, MUNDRA

The generator is connected to the 400kV switchyard through a step-up Generator Transformer (GT). Each 330MW unit consists of one Generator Transformer (GT), Two Unit auxiliary Transformers (UAT), and One Station Transformer (ST) which is shared between two units.

The power is evacuated through 8 * 400kV and 2 * HVDC lines. 400KV and 220kV system are connected by an Inter Connecting Transformer (ICT). Unit auxiliaries are taken from respective UATs of the concerned units and station auxiliaries are taken from Station Transformers.

GENERATOR MAINTENANCE

Maintenance during a shut down:

The maintenance of a generator basically depends on the number of hours of operation and its service life. For that we take into account three types of overhauls:

1. Minor or mo overhaul:

The objective of this overhaul is to be able to imagine as precisely as possible the state of a generator. This enables us to use minimum number of dismantling operations in order to allow the generator to be serviced until the next overhaul, and to be able to estimate the contents of the next intervention. It is rare that repair work or modifications are planned at the time mo.

2. Major or Mo overhaul:

The objective of this kind of overhauling process is to access the exact state of generator to authorize its maintenance till next major overhaul.

A major overhaul involves taking out the rotor. Specific maintenance operations or modifications resulting from previous observations and experience must be included in the major overhaul plan.

3. A ten year or TYO overhaul:

A ten-year overhaul of a generator is above all Mo completed by systematically replacing the parts which are highly stressed during or at the time of dismantling and previous reassembling operations. A TYO can equally be used to carry out improvements resulting from experience.

NOTE

The generator is only one component in the electrical energy production series. Therefore, maintenance cannot be done independently from other links.

Therefore, it must be checked that the generator overhaul program is sufficient to allow its operation without reaching the critical overhaul limit.

Theoretical overhauling process in different timelines:

Item	Operation description	mo	Mo2	TYO
A	Before shutdown of Unit			
	Checking of the operation data	✓	✓	✓
	Checking of the short circled rotors turns	✓	✓	✓
B	Before Disassembly			
	Insulation measurement of the bearing at exciter end	✓	✓	✓

	H2 leak detection using a gas leak detector at the exciter end	✓		
C	Disassembly operations			
	Outer oil deflectors	✓	✓	✓
	Bearing cover	✓	✓	✓
	Clamping collar	✓	✓	✓
	Journal bearing	✓	✓	✓
	Seal ring	✓	✓	✓
	Upper 1/2 bearing end shield		✓	✓
	Lower 1/2 bearing end shield		✓	✓
	Winding cover fan nozzle ring		✓	✓
	Inner oil deflectors		✓	✓
	Fan blades		✓	✓
	Rotor disassembly		✓	✓
	H_2 or gas coolers		✓	✓
	Draining of stator's water circuit		✓	✓
	Phase corrections		✓	✓
	Operation of neutral point		✓	✓
D	Stator checking tests			
	1. Magnetic core			
	Visual inspection		✓	✓
	Ring flux tests/ELC ID Test			✓
	2. Windings			
	Visual inspection		✓	✓
	Air tightness test		✓	✓
	Insulation resistance of the stator winding	✓	✓	✓
	Polarization index	✓	✓	✓
	Phase to phase partial discharge		✓	✓
	Phase to phase dissipation discharge			✓
	Insulation resistance-circuit in water	✓	✓	✓
	Radial wedging		✓	✓
	3. Frame - cooler compartments - terminal box			
	Visual inspection	✓	✓	✓
	Blowing of bottom point pipework	✓	✓	✓
	Visual inspection of foundation tie rods			✓
	US test of foundation tie rods			✓
	4. Coolers			
	Clearance of tube bundle and water boxes	✓	✓	✓
	Clearance of tube bundle at gas end		✓	✓
	Tightness test at water end		✓	✓
	Blowing-purging and draining of pipework	✓	✓	✓
E	Rotor checking Tests			
	Short circuit detectors		✓	✓
	Visual inspection		✓	✓

	Blade liquid penetrate test		✓	✓
	Visual inspection of blades		✓	✓
	Rotor tightness		✓	✓
	Geometrical checking of the shaft seal supporting surface		✓	✓
	Visual inspection of shaft seal and journal bearing supporting surface	✓	✓	✓
	Rotor insulation resistance	✓	✓	✓
	Visual inspection of the turbine coupling		✓	✓
	Visual inspection of the rotor windings		✓	✓
	Visual inspection of the exciter coupling		✓	✓

Table 8.1 – Theoretical overhauling process chart

Generator Overhaul (Planning for unit-4)			
Sr.	**Process**	**Starting Date**	**Ending Date**
1	Removal and Inspection of Hydrogen Coolers	26-May	29-May
2	CRO Measurement, Decouple LPT and generator, Alignment measurement	29-May	30-May
3	Exciter Rotor and Stator removal	30-May	31-May
4	Disassembly of outer end shield bearing 7 and 8, H2 seal, oil deflector, fan blades, oil piping	31-May	02-Jun
5	Generator fan blade removal, rotor air gap measurement, gasket, guiding plate and shoe positioning	02-Jun	04-Jun
6	Pulling out Generator Rotor for inspection	04-Jun	04-Jun
7	Generator power terminal inspection and tightness	04-Jun	05-Jun
8	Testing (Electrical and others) of stator and rotor	05-Jun	10-Jun
9	NDT of fan blades and seal rings	05-Jun	08-Jun
10	Generator Rotor Insertion	10-Jun	10-Jun
11	Assembly of Bearing 7 and 8 bottom half, fan, nozzle ring, fan blades, bottom end shield, H2 shield	21-Jun	22-Jun
12	Alignment of LPT- Generator and coupling	21-Jun	21-Jun
13	Assembly of Bearing 7 and 8 top half, H2 seal box up, exciter, stator box up	22-Jun	23-Jun
14	Final box up	23-Jun	23-Jun

Table 8.2 - Practical plan followed by Adani Power, Mundra for Generator overhaul

GENERATOR OVERHAUL PROCESS

Overhauling is one the most crucial process conducted on a machine to determine its healthiness and when it is operated for a long time or occurrence of any fault. It's necessary to carry out overhauling process regularly in order to ensure the operation of machine meets its specifications.

DETAILED OVERHAULING PROCESS (STEP BY STEP)

- **GENERATOR ROTOR REMOVAL**

1. Replacing H2 Gas with an inert gas for the safe removal of hydrogen coolers.
2. De-coupling the Generator / Turbine and exciter, removal of exciter from the bed.
3. Replace the shaft seal at outer covers.
4. Measure air gap between the stator and rotor at 4 points diametrically opposite at right angle. This should be done for both turbine and exciter end.
5. Open bearing cover check for clearances and abnormality, if any, on the bearing surface.
6. Decouple the generator and record alignment readings.
7. Remove bearings after ensuring that stator is not jammed by threading out of rotor by inserting packing material.
8. Remove and place the rotor on the stand specialty provided for.
9. Check the rotor for any sign of overheating, mechanical abrasion, loose wedges, etc., and clean it with compressed air and cloth.
10. Check the rotor end rings for any damage or check by ultrasonic inspection method.
11. Check fan blades and hubs for erosion and cracks.
12. Check that balancing weight are secured firmly.
13. Measure field and insulation resistance of the rotor and compare it with design data.
14. Clean the rotor and apply finish coat as recommended by the manufacturer. Dry up the rotor.

GENERATOR STATOR

1. Clean stator windings, ventilating ducts with dry compressed air.
2. Inspect for defects like
   - 2.1. Discoloration of winding (for hot spots)
   - 2.2. Loose missing slot wedges
   - 2.3. Inter coil spacers on overhangs
   - 2.4. Broken overhaul coil bindings for end supports
   - 2.5. Protective coatings on the core steps at slot ends
3. Replace any broken wedges as required.

GENERATOR ASSEMBLY

1. Insert rotor inside the stator carefully. Put packing material in the air gap between stator and rotor for protection and assemble all removed parts. Fix the exciter in bed. Assemble bearing pedestal.
2. Ensure that the bearing has been cleaned, necessary scrapping has been done to remove any uneven surface. Bearing insulation should be taken care, wherever provided assemble the bearings.
3. Alignment and coupling of the generator with Turbine and exciter with Generator. Check air gap and ensure it matches with original gap.
4. Check the pedestal pipe flange insulation and also the same for pipe connection and bolt. Replace if necessary. Box up the bearing.
5. Fix inner and outer end covers.
6. Filling up of gases in coolers.

TESTING PROCESSES

Testing processes are the backbone of overhauling process. Test carried out on equipment's provides us with valuable parameters which can help to judge the healthiness of the equipment and allow us to prepare a checklist for any replacement in near future

ADVANTAGES

- Provides data for optimization of operation
- Reduction in replacement cost.
- Ensures process capability and develops checklist.
- Increases confidence levels during longer operations.

Both the electrical tests and the visual inspections are major pillars of generator testing, for ensuring proper generator performance. It also helps you evaluate the condition of equipment in order to determine if replacement or modernization projects are necessary.

MAJOR TESTS CONDUCTED

- **Stator**

  Stator Core

  - ELCID test

  Stator Windings

  - IR & PI
  - Wedge knocking test
  - Partial discharge
  - Winding DC resistance
  - Capacitance test also known as Tan δ test

- **Rotor**

  Rotor Windings

  - IR
  - Winding DC resistance
  - AC Impedance Test
  - RSO (earth fault /inter- turn short)

  Rotor Core

  - Air Ventilation Test

DETAILS OF PROCESS

- **General Visual Inspection**

Typical visual inspections include identification of discoloration, cracking and other physical anomalies.

- **Stator core**

ELCID Test or Flux, Loop Test

The stator core of the electric generator is formed from large number of thin iron sheets (laminations), insulated one from another in order to diminish losses due to eddy currents. They have a teeth like structure.

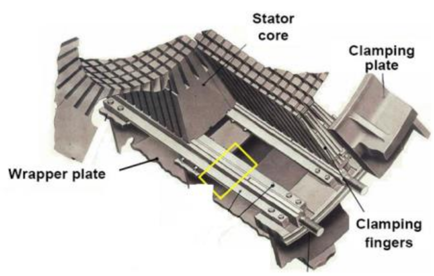


Figure 10.1- Internal construction of generator stator *Figure 10.2- Teeth like structure of laminations*

The stator core of the generator operates under a constant load and ages as the result of mechanical, thermal, and electrical stresses. These stress deteriorate the condition of insulation. Damaging of insulation can lead to generation of eddy currents which produces heat, which can eventually heat up nearby insulation leading to to complete failure of the machine.

These fault currents shown in red create eddy current which causes localized heating creating hot spots.

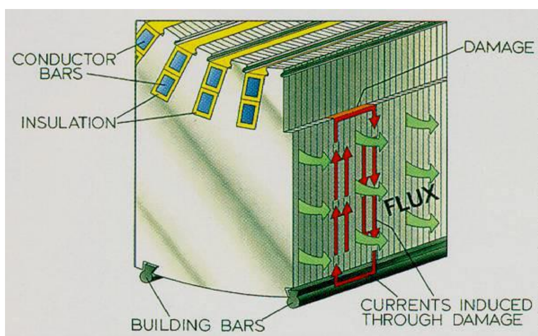


Figure 10.3-Fault currents

Method

- Exciting the stator core by a magnetic induction of about 4 % of the rated magnetic induction
- Detection of the iron faults by means of the electromagnetic effect, using a “Chattock magnetic potentiometer”. Commonly known as Pick Up coil
- This test is completely based on **Ampere Circuital Law.**
- If we move around following a contour via the far edges of the teeth, the voltage which is produced by EMF generated by Fault current increase or decrease the measured voltage depending on direction of contour and current.

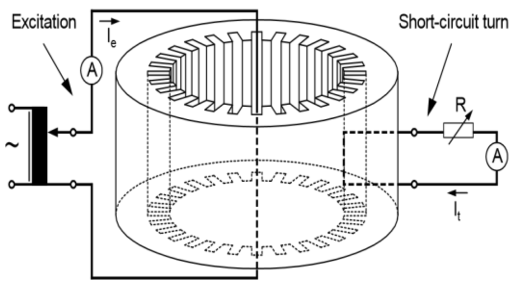


Figure 10.4-Exciting the stator core

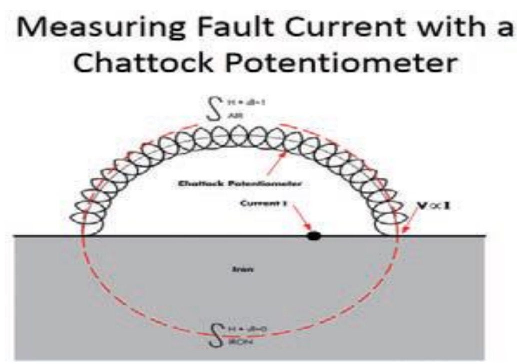


Figure 10.5-Applying Ampere Circuital Law

Results

- Due to fault current EMF gets generated which increases the measured voltage, which can be shown as spikes in the generated graphs.
- Typically, in case of no fault voltage remains between ± 20mV but due to fault it rises to 100mV.

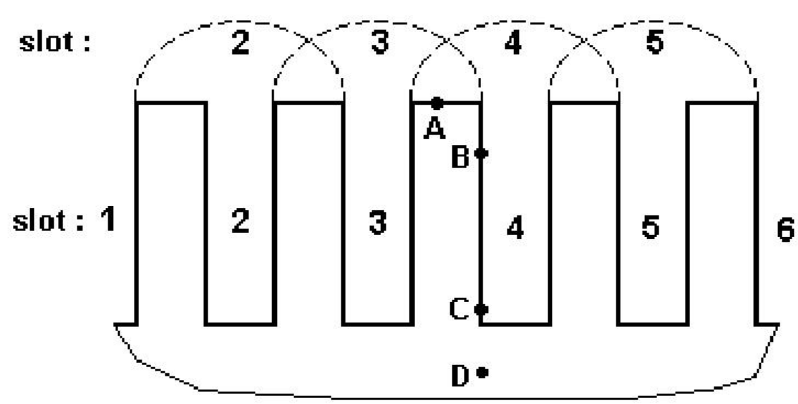


Figure 10.6-Example of stator core for analysis

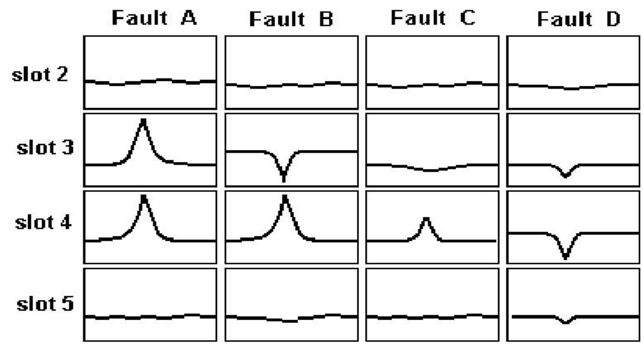


Figure 10.7-Final graph generated after processing of above stator sample

- **Stator windings**

IR & PI

Both Insulation Resistance Value Test (IR Value Test) and Polarization Index Value Test (PI Value Test) are conducted on HV machine to determine service condition of the insulation of stator windings. Contamination deteriorates the HV windings. It is done to measure dryness and cleanliness of insulation.

Procedure

A DC voltage is applied across conductor and the ground. This DC voltage drives a current through the insulation which is equal to.

$$Z = V/I$$

Where,
Z – Insulation Resistance
V – Applied Voltage
I – Current through the insulator

Megger [7] is used to do this test.

Due to dielectric in nature insulators inherit capacitive properties. Whenever any voltage is applied capacitive charging takes place. When it loads up capacitive component ends and resistive remains. That's why IR test is done at least for 1 minute because of charging effects.

Since the resistive value of an electrical insulator also varies with temperature, an additional test called PI Value test is introduced to resolve this issue.

When a voltage is applied across an insulator, a tiny leakage current flows in order of mA from line through insulator towards ground.

The outflow current contains four constituents -

- Capacitive component

  Due to DC voltage across insulator and its dielectric behavior, initial charging takes place between lines to ground. Current declines exponentially. The above mentioned current exits only for 10 seconds but takes about 60 seconds to get out totally.

- Resistive or conductive component

  This conductive current flows because of resistive nature of insulator and don't find any changes in values during the test.

- Surface leakage component

  Because of contamination and dust, this small component flows through shallow surface of the conductor.

- Polarization component

  Due to presence of contaminant molecules dielectrics sometimes become polar. Because of the applied electric field the polar molecules inside the insulator try to align themselves in the direction of field.

Because in the course of 10 minutes the molecules aligns themselves in coherence to electric field, to remove the effect of polarizing we take megger results for about 10 minutes.

As 1 minute get passed the IR value which is relieved from capacitive component. When the megger values are measured for 10 minutes for the insulator, the result shows nearly a collection of 12 values, which are free from capacitive and polarization component of the leakage current.

PI is calculated as the ratio of values measured from megger for 10 versus the one taken for 1 minute.

Finally, PI test can be evaluated as -

$$I = I_C + I_R + I_S + I_P$$

$$R_1 = V / (I_R + I_S + I_P)$$

$$R_{10} = V / (I_R + I_S)$$

$$PI = (R_{10}/R_1) = 1 + I_P/(I_R + I_S)$$

Where,
I – Total initial current
I – Total initial current

I_C – Capacitive current
I_R – Resistive current
I_S – Surface leakage current
I_P – Polarization current of the insulator
R_1 – Megger reading after 1 minute
R_{10} – Megger reading after 10 minutes
V – Source voltage
PI – Polarization Index

Larger values of I_R or I_S or both tells about condition of the insulation. Leakage current which is resistive in nature must be small for good insulators.
The Polarization Index is always anticipated for values more than 2, problem arises when the value is less than 1.5.

Wedge Knocking Test

Intermittent checking of stator wedges in the slot must be performed to test their tautness. The rotor must be removed for testing. The type of sound produced by the stator wedges when they are stuck sharply by a hard blunt object indicates the tautness of the wedge inside the slot. Tight wedge is indicated by a dull sound and hollow confirms the presence of a slack wedge. When between two extremes a ring appears, it is sure of becoming unfastened in future. This criterion is used to assess the tightness of the stator winding when using the method of wedge tapping.

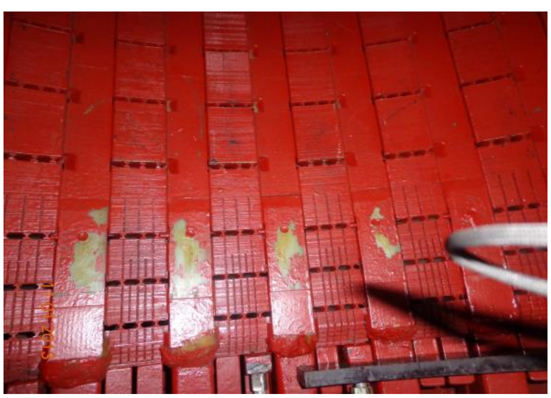


Figure 10.8 – Wearing off of paint in Stator Winding

Figure 10.9 – Performing wedge knocking test

Tan δ / Power *Factor* and Capacitance Tes*t*

Whenever a pure insulator is connected across conducting line and earth, it exhibits properties of a capacitor. If the capacitor is pure, current flowing through the capacitor leads the voltage by 90 degrees.
Because of the prolonged usage of the insulator, moisture and dust particles contaminate it.
This contamination becomes a conductive path for various leakage currents.

Procedure
Firstly, the insulation to be tested must be isolated from the supply. After isolating from the main supply a very low frequency is fed across the equipment Initially normal voltage is applied, if the results are promising i.e. the tan delta value is not much higher than the applied voltage is increased to 1.5 to 2 times of normal voltage. A loss angle analyzer is connected to collect the data which is then fed to a computer to process and graph it.

Why Low frequency is applied?

If the applied frequency is higher, the capacitive reactance which is inversely proportional to frequency gets reduced thereby increasing the capacitive component of current to a large extent. The resistive component is nearly fixed because it consists of only leakage currents due to contamination. Resistive component too depends on applied voltage and conductivity of insulator.

At very high frequency, the capacitive current becomes very large which increases the amplitude of vector sum of capacitive and resistive current components.

Also to do the test we need a high power endurance device to measure high apparent power developed during measurement of tan delta angle.

Therefore, power requirement of tan delta test would become very high which is not in any case practical.

In addition to above, there's a second reason too for keeping the input frequency low during the test.

The inverse relationship of tan delta with frequency explains at lower frequency it becomes easier to measure the value of tan delta.

Dissipation factor, tan delta $\propto 1/f$.

Hence, at low frequency, the tan delta number is high, the measurement becomes easier.

$$Dissipation\ Factor = \frac{I_R}{I_C} = \frac{1}{2\pi f C R}$$

Where,
I_C – Capacitive current
I_R – Resistive current
f – Frequency
C – Capacitance
R – Resistance

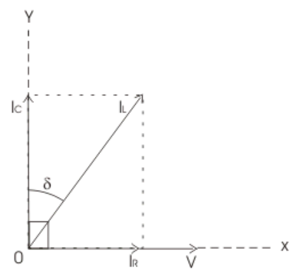


Figure 10.10 – Phasor Diagram Capacitive Current to Resistive Current

Analysis of Data Collected

Generally, two ways are there to determine the condition of insulation after data from tan delta Test is collected

By comparing the results from previous test data, we can determine the state of healthiness of insulation.

By comparing, the latest data of all insulations with one another to make a checklist in order to prepare for future replacements.

AC* Impedance *Test

On an ideal scenario the AC Impedance test must be done when the machine is functioning at synchronous speed as because of action of centrifugal forces on moving conductors, shorted turns appear.

During shutdown, when generator is out of operation. Ideally machine is not in any contact which makes the fault resistance very high. Impedance measurement gives a more accurate picture rather than resistance measurements.

A presence of single shorted turn induces a backward current which opposes the Magneto Motive Force of the intact coil, which results in a drastic decrement in the reactance.

The impedance which is being measured shows a sudden change when a turn is shorted in the process of run-up or run down. Nearly for verification of shorted turns a minimum of 5 percent sudden change must be reported.

The highest field current which is to be supplied in the test must be considerably smaller than the required current for stator voltage at open circuit. The voltage applied should not exceed the rated no-load stator voltage.

For performing the AC impedance test the field windings must be accessible via the help of collector rings as low power AC must be supplied, during the course of the test. A 120-V, 1-phase, 60-Hz ac power is supplied.

The parameters voltage, current and shaft speed are to be measured. The power supply which is provided during the test must not be grounded as it can lead to damage of rotor if the winding comes across any ground fault.

Procedure

1. With proper calibration of the instrument the supply is connected to field winding. The supply which is to be connected must be ungrounded.

2. With the help of local speed indicator measure the speed and find its relationship with impedance.

3. The field winding must be adjusted to such a value that it must allow a maximum possible current of 75 percent of rated open-circuit current of stator.

4. When the stator windings are disengaged from the main power supply try increasing and decreasing the speed of the machine. Measure the parameters such as current, voltage and speed starting at zero and increasing in intervals of 100 RPM till the rated speed is not achieved. If continuous measurements needed to be done a Multichannel Strip Chart Recorder can be used.

The calculated values of the impedance ($Z = V/I$) can be graphed versus the change in speed. If there is an unexpected change in the impedance of 5 percent or a slow change of 10 percent marks a very strong chance of finding a shorted turn at that place. The mentioned test seems not much subtle as the two formerly termed. An important point to note down is solidly short turns seldom produces any change in impedance.

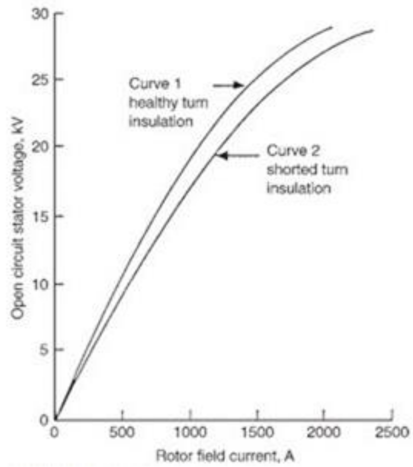


Figure 10.11 – Detecting shortened rotor winding turns

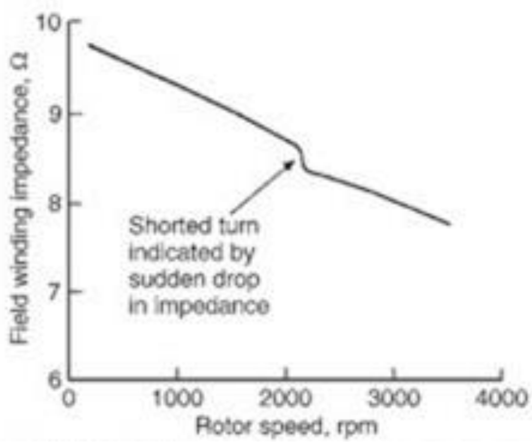


Figure 10.12 – Detecting shortened rotor turns by impedance matching

RSO Test

The RSO test is used to find out the presence and location of shorted turns in the rotor windings. This test is performed when the machine is offline i.e. when the rotor is taken out of the stator frame, as to perform the test we need to attach the magnetic probes to the end of field windings

There are basically two type of shorts found in the rotor windings, namely ground short and winding short. In case of ground shorts, the insulation between the copper winding and the rotor frame get depleted and in case of winding shorts the insulation between two consecutive windings gets depleted. These cases are shown in the figure (transverse view of a rotor winding slot)

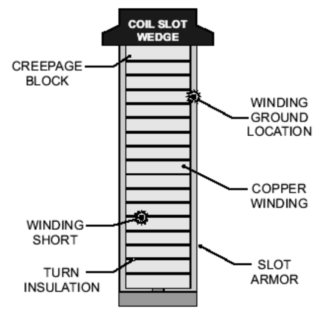


Figure 10.13-Transverse section of rotor slot

Disadvantages of shorted turn in rotor windings

• The resistance created at the shortened junction would dissipate huge amount of energy in form of heat as in our case field excitation current is 2495 A so even 1 ohm of resistance would lead to production of 2.495 Kw heat energy which would be sufficient to damage the nearby insulation.

• The shorted turns cause magnetic flux density imbalance due to which the rotor vibrations increase while machine is operating

Procedure and connections

The RSO test is the modified version of TDR (Time Domain Reflectometry) which was used by communication engineers to find distortion in telephonic transmission lines, the defects were indicated in form of inverted reflected wave generated due to the imperfection in line, but in case of rotor windings by using traditional TDR test we get multiple reflections due to sudden turnings at the coil's rectangular edges, hence engineers came up with RSO test. The RSO test relies on the fact that rotor windings are symmetrical.

A device TDR100 is used to conduct the test, it has an inbuilt low voltage high frequency wave generator which is used to send the input signals at both ends of the field winding and observe the output signal from the other end of the field winding at a time. In oscilloscope we actually measure the input signal wave superimposed with inverted output signal.

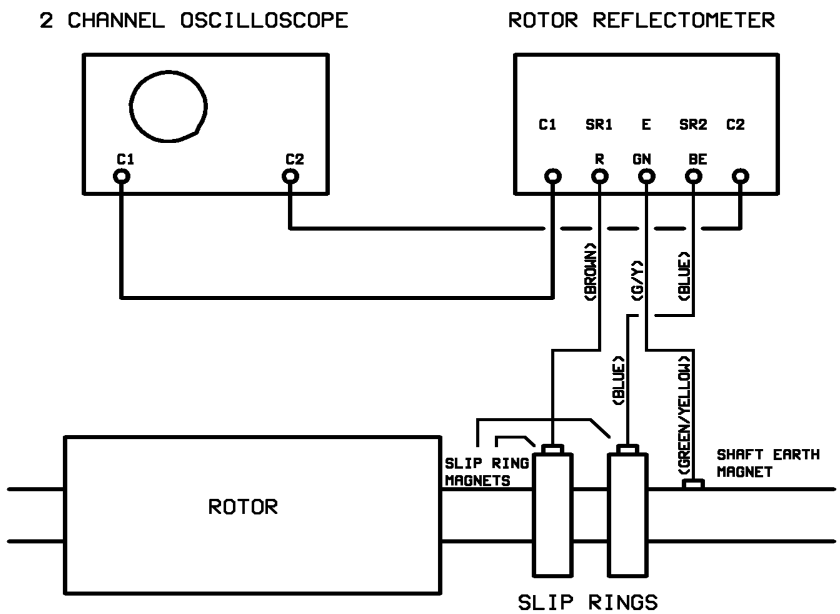
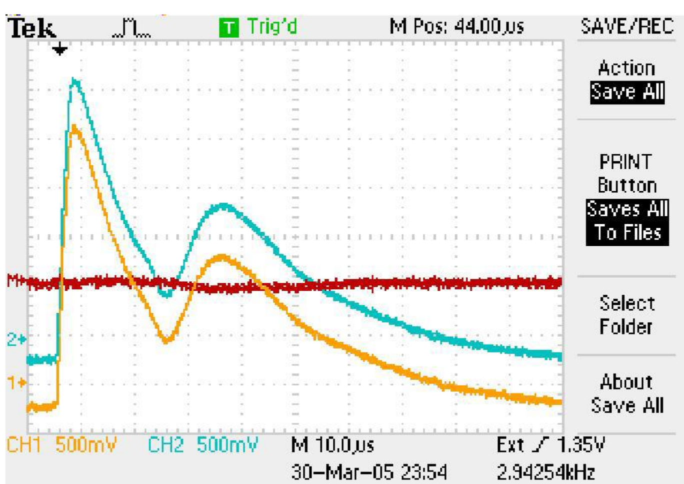


Figure 10.14 – Apparatus connection for RSO test



Where,

Blue => Input Signal

Yellow => Output Signal

Red => Input Signal – (inverted) Output Signal

Figure 10.15 – Sample reading of a RSO test

The results are interpreted as follows –

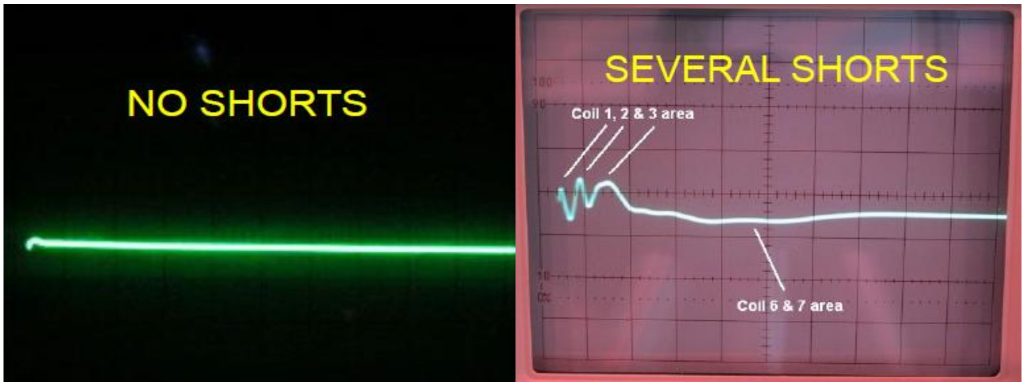


Figure 10.16 – Interpreting the results of RSO test

In all the examples taken, the resultant output signal is plotted on the oscilloscope. In case of multiple Shorts in the Winding, depending on the location of the "kinks" on the line, rough localization of the shorts (coil and pole) is possible.

Air Ventilation Test

Figure 10.17 – Flushing of air via blower

Figure 10.18 – Current carrying bolt

Air ventilation test is done to test whether the caging is properly intact and there's no leakage on sideways of the stator and holes on the caging flush the coolant properly because trapped hydrogen acts like a bomb.

Blowers are used to flush air between caging and rotor core. Also near the current carrying bolt shown in above figure pressure is measured.

If the pressure measured drops significantly there must be a leakage in caging.

Parameters	**Values**
Power Rating	3 KW
Pressure	969 Pa
Speed	2900 RPM

Table 10.1 – Blower Specifications

COMPARISON WITH OTHER POWER PLANTS

NATIONAL THERMAL POWER CORPORATION LIMITED

Figure 11.1 – NTPC Logo

ABOUT THE COMPANY

National Thermal Power Corporation Limited (NTPC Ltd.) is an Indian public sector undertaking, engaged in electricity generation. It is a "*Government Company*" under the *Companies Act 1956*. Its core business is generation and sale of electricity to state-owned power distribution companies and State Electricity Boards in India.

It is the largest power producer in India. It has a mammoth capacity of 51,410 MW. It contributes to over a quarter of the total power generation in India. It currently produces roughly **25 billion** monthly units of electricity. *Forbes* ranked NTPC **300th** in its annual *Forbes Global 2000 (2016).*

COMPANY AT A GLANCE

Founded:	*7 November 1975*
Headquarters:	*NTPC Bhawan, Lodhi Road, New Delhi, India*
Key personalities:	*Gurdeep Singh (MD and Chairman)*
Key Products:	*Electricity generation and distribution*

VINDHYACHAL THERMAL POWER STATION (NTPC)

The Vindhyachal Thermal Power Station is a coal-fired power station of NTPC and located in Singrauli district in Madhya Pradesh. It is the largest power station in India. It has a gigantic capacity of 4760MW. Water for the plant is sourced from the discharge canal of Singrauli Super Thermal Power Station and the coal is sourced from the Nigahi mines.

CAPACITY

Stage	*Unit Number*	*Capacity (MW)*	*Date of Commissioning*
1st	1	210	1987 October
1st	2	210	1988 July
1st	3	210	1989 February
1st	4	210	1989 December
1st	5	210	1990 March
1st	6	210	1991 February
2nd	7	500	1999 March
2nd	8	500	2000 February
3rd	9	500	2006 July
3rd	10	500	2007 March
4th	11	500	2012 June
4th	12	500	2013 April
5th	13	500	2015 August
Total	Thirteen	**4760**	

Table 11.1 – Details of power production distribution

The Russians assisted in the installation of the 210 MW units.

BHEL manufactured the 500 MW units.

International Assistance is taken from USSR for Stage I.

World Bank assistance is taken under the Time Slice loan for Stage II.

CONCLUSION

Maintenance and overhauling is one the most crucial process to be carried out after a long term continuous operation. Maintenance is necessary to reduce the sunk cost of the plant operation, also to increase the lifetime of plant. Tests during maintenance provide us with valuable data of numerous operational parameters of various equipments which have whole sole responsibility of proper and coherent functioning of the power plant. Testing is always done to simulate similar conditions which closely resemble the operating conditions.

Maintenance has to be done on a regular basis by company to maintain its efficiency of operations and in order to ensure that a machine has to be deliverable good and should not possess any unnecessary losses while working and shall run efficiently. It is necessary to ensure that all functional requirements are fulfilled, and to estimate the performance of generator.

The comprehensive training at Adani Power, Mundra assisted us in enhancing our knowledge and awareness pertaining to Generator operation to a great extent. It was once in a life time opportunity to see such large equipment during maintenance and work in a unit which has a *World Record* under its belt.

We envisaged the whole power generation system of a coal based thermal power plant. Besides this we gained knowledge about how various equipment work in coherence to produce such a humongous amount of electricity.

In a nutshell, the training at Adani Power, Mundra proved to be an integral part in quenching our thirst for knowledge in this field. It was surely an enriching experience to learn about the strategies involved in the construction, operation, maintenance of a generator of this scale.

FUTURE SCOPE

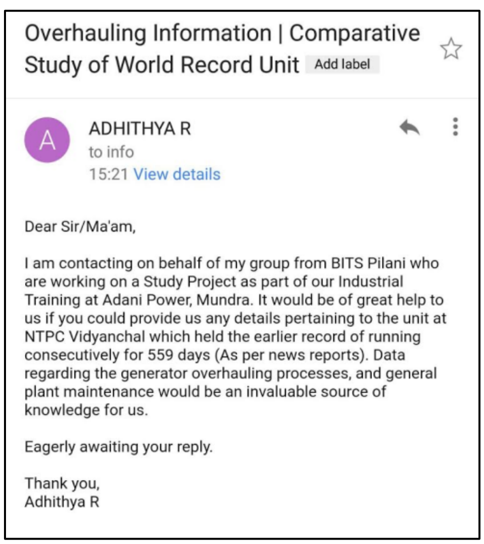
REDUCING THE ERRORS INVOLVED IN THE TESTS

- Errors are an unavoidable part of any practical process or experiment which rely on the output data
- Errors can be mainly classified into two types – A) Error in precision, B) Error in accuracy
- Precision errors arise from the constraints pertaining to the measuring apparatus. The best we can do to avoid such errors is to use high quality measuring devices and also decrease the number of such devices involved in a test wherever possible
- Discrepancies in accuracy may arise due to several reasons – The environment, the skill of the performer and other factors which can be classified as random errors. These errors can be minimized by repeating the tests multiple times and checking for concurrency

Currently, all the tests here carried out only once. Thus, there might be wrong deductions based on their results leading to severe damage to the machinery and will cause dent in their resources. Hence, we feel that there is a need for redundancy in the tests.

SUSTAINED LONG RUNS OF UNITS ON A REGULAR BASIS

- A very important and matter of curiosity was why all units of the plant could not operate for elongated stretches
- We decided to conduct an elaborate comparative study regarding the factors which inhibited this from happening
- Articles regarding the company's policies to maintain '5S' standards in all avenues helped us to understand that pre-planning and following the guidelines strictly was extremely important to achieve this feat
- We also contacted other power plants to extend our study, but, we were unsuccessful in our attempt to do so



Overhauling Information | Comparative Study of World Record Unit Add label

A ADHITHYA R
to info
15:21 View details

Dear Sir/Ma'am,

I am contacting on behalf of my group from BITS Pilani who are working on a Study Project as part of our Industrial Training at Adani Power, Mundra. It would be of great help to us if you could provide us any details pertaining to the unit at NTPC Vidyanchal which held the earlier record of running consecutively for 559 days (As per news reports). Data regarding the generator overhauling processes, and general plant maintenance would be an invaluable source of knowledge for us.

Eagerly awaiting your reply.

Thank you,
Adhithya R

AVOID OUTSOURCING OF OVERHAULING PROCESS

During this major overhaul of Unit 4, we noticed that all the maintenance and overhauling procedure was outsourced to BHEL Engineers. Also, various tests related to other machinery were not conducted using the facilities available in the plant. One such example is the Dissolved Gas Analysis test for Transformers. The coolant oil samples were collected from the plant and sent to an external laboratory in spite of having a Chemistry Department in the company which was capable enough to do so.

It would be a great addition to this power plant to have an independent working maintenance team which can further have sub sections dealing with different equipments working unanimously to eliminate the need for outsourcing. This will save the company a lot of money, and boast an incomparable array of employees with an elevated skill set.

PRODUCTION OF ELECTRICITY USING THE PIEZOELECTRIC EFFECT

Electric polarization in a substance (crystals such as Quartz) results from the application of mechanical stress. The reverse phenomenon also follows, i.e., if an electric current is passed through these substances, they change their shape by vibrating back and forth.

In a microphone, the sound energy (longitudinal pressure waves) are converted into electrical energy. The pressure waves from noise are used to make the crystal move back and forth, generating corresponding electrical signals.

Similar application can be done in the power plant. The noise produced by various machines such as the BFP, Turbine, etc. can be used to generate electricity with the help of piezoelectric materials.

LIST OF ILLUSTRATIONS

FIGURES

TABLES

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