# ***BHEL - AN OVERVIEW***

INTRODUCTION

In 1956 India took a major step towards the establishment of its heavy engineering industry when Bharat Heavy Electricals Limited, the first heavy electrical manufacturing unit of the country was set up at Bhopal. It progressed rapidly and three more factories went into production in 1956 .The aim of establishment BHEL was to meet the growing power requirement of the country.

BHEL has supplied 97% of the power generating equipment that was commissioned in India during 1979-80. BHEL has supplied generating equipment to various utilities capable of generating over 18000MW power. BHEL is one of the largest power plant equipment manufacturing firms in India and it ranks among the top ten manufacturers globally. BHEL has covered up many power stations over 40 countries worldwide.

BHEL has its head quarters at New Delhi. Its operations are spread over 11 manufacturing plants and number of engineering and service divisions located across the country. The service division includes a network of regional offices throughout India.

## BHEL’S UNITS IN INDIA

**S.No. PLACE UNITS (PLANTS)**

1. HARDWAR 2

2. BHOPAL 1

3. JHANSI 1

4. JAGDISHPUR 1

5. HYDERABAD 1

6. BANGALORE 3

7. RANIPET 1

8. RUDRAPUR 1

A BRIEF HISTORY

 The firstplant of what is today known as BHEL was established nearly 40 years ago at BHOPAL and was genesis of Heavy Electrical Equipment industry in India. BHEL is today the largest engineering enterprise of its kind in India, with a well recognized track record of performance making profits continuously since 1971-72. It achieved a sales turnover of Rs.1022 core in 1997-98. BHEL caters to core sectors of the Indian Economy via, Power, Industry, Transportation, Defense, etc.

 The wide network of BHEL’s 14 manufacturing divisions, 9 service centers & 4 power Sector Regional centers & about 150 project sites enables the service at competitive prices. Having attained ISO 9000 certification, BHEL is now embarking upon the Total Quality Management. The company’s inherent potential coupled with its strong performance over the years, has resulted in it being chosen as one of the “Navratna” PSEs, which are to be supported by the Government in their endeavor to become future global players.

Power Sector

Power sector comprises thermal, nuclear, gas & hydro power plant business. Today, BHEL supplied sets account for nearly 56,318 MW or 65% of the total installed capacity of 86,636 MW in as against nit till 1969-1970.

BHEL has proven turnkey capabilities for executing power projects from concept to commissioning. It posses the technology and capability to produce thermal power plant equipments up to 1000MW rating and gas turbine generator sets up to a unit rating of 240 MW. Cogeneration and combined cycle plants have been introduced to achieve higher plant efficiencies. To make efficient use of the high ash content coal available in India, BHEL supplies circulating fluidized bed boilers to thermal and combined cycle power plants. BHEL manufacturers 235 MW nuclear turbine generator sets and has commenced production of 500 MW nuclear turbine generator sets. Custom-made hydro sets of Francis, Pelt on and Kaplan types for different head-discharge combinations are also engineered and manufactured by BHEL is based upon contemporary technology comparable to the best in the world & is also internationally competitive.

Transmission

BHEL also supplies a wide range of transmission products and systems up to 400 KV Class. These include high voltage power and distribution transformers, instrument transformers, dry type transformers, SF6 switchgear, capacitors, and insulators etc. For economic transmission bulk power over long distances, High Voltage Direct Current (HVDC) systems are supplied. Series and Shunt Compensation Systems have also been developed and introduced to minimize transmission losses.

Transportation

A high percentage of trains operated by Indian Railways are equipped with BHEL’s traction and traction control equipment including the metro at Calcutta. The company supplies broad gauge electrical locomotives to Indian Railways and diesel shunting locomotives to various industries.5000/6000 hp AC/DC locomotives developed and manufactured by BHEL have been leased to Indian Railways. Battery powered road vehicles are also manufactured by the company.

International Operations

BHEL’s products, services and projects have been exported to over 50 countries ranging from United States in the west to New Zealand in far East. The cumulative capacity of power generating equipment supplied by BHEL outside India is over 3000MW. The company’s overseas presence includes projects in various countries. A few notable ones are : 150 MW (ISOI) gas turbine to Germany, utility boilers and open cycle gas turbine plants to Malaysia, Tripoli-west, power station in Libya executed on turnkey basis, thermal power plant equipment to Malta and Cyprus, Hydro generators to new Zealand and hydro power plant equipment to Thailand. BHEL has recently executed major gas-based power projects in Saudi Arabia and Oman, a Boiler contract in Egypt and several Transformer contracts in Malaysia and Greece.

MANUFACTUTING UNITS & PRODUCT PROFILE

**1. THERMAL SETS/THERMAL POWER PLANTS: (HARiDWAR)**

* Steam Turbines & generators up to 500/600/660 MW
* Capacity for utility & combined cycle applications, capability to manufacture steam turbines with supercritical steam parameters & machining generator up to 1000 MW unit size.
* Steam turbines for CFFP application

**2. GAS BASED POWER PLANTS: (HYDERABAD)**

* Gas turbines of up to 255 MW (ISO) rating
* Gas turbines based cogeneration & combined cycle systems for industry & utility applications.

**3. HYDRO SETS: (BHOPAL)**

* Custom-built conventional hydro-turbines of Kaplan, Francis and pelt on types with matching generators
* Pumps turbines with matching motor generators
* Mini/Micro hydro sets
* Spherical, butterfly and rotary valves & auxiliaries for hydro stations

**4. EQUIPMENT FOR NUCLEAR POWER PLANTS: (BHOPAL, TIRUCHY, HYDERABAD)**

* Turbines & generators
* Steam generators
* Heat exchangers

 **5. DG POWER PLANTS: (JHANSI)**

* HSD, natural gas/ biogas based diesel power plants etc. Unit rating 20 MW & voltage up to 11 KV, for emergency packing as well base operations on turnkey

**6. INDUSTRIAL SETS (HYDERABAD)**

* Industrial turbo sets of ratings from 1.5 to 120 MW.
* Gas turbines load matching generators ranging from 3 to 255 MW (ISO) rating
* Industrial steam turbines & gas turbines for drive applications & cogeneration applications.

7. **POWER STATION ELECTRONICS EQUIPMENTS: (BANGALORE)**

* Microprocessor based distributed digital control systems
* Data acquisition systems
* Man machine interface
* Substation control with SCADA
* Static excitation equipment or automatic voltage regulator
* Electro hydraulic governor control
* Furnace safeguard supervisory systems

8. **SWITCH GEAR: (BHOPAL)**

* Switchgear of the various types for indoor and applications and voltage ratings up to 4 KV
* Minimum Oil Circuit Breaker ( 66 KV - 132 KV )
* SF6 Circuit Breaker ( 132 KV – 400 KV )
* Vacuum Circuit Breaker ( 3.3 KV – 33 KV
* Gas Insulated Switchgear ( 36 KV )

9. **TRANSFORMER: (BHOPAL)**

* Power transformer for voltage unto 400 KV.
* HVDC transformer and reactors of unto 400 KV rating.
* Series and Shunt reactors unto 400 KV rating
* Instrument transformers:
1. Current Transformer unto 400 KV
2. Electromagnetic Voltage Transformers unto 400 KV
3. Capacitor Voltage Transformer unto 400 KV Cast resin dry type transformer unto 10 MVA, 33KV

 **10. INSULATORS: (BANGALORE AND JAGDISHPUR)**

* High tension ceramic insulators
* Disc or suspension insulators for AC or DC applications ranging from 45 to 300KV electromechanical strength, for clean and polluted atmosphere.
* Pin insulators of up to 33 KV
* Post insulators suitable for applications of up to 6 units.
* Hollow porcelains of up to 400 KV
* Solid core insulators of 25 KV rating ( both porcelain and hybrid ) for railways
* Disc insulators for 800 KV AC and HVDC transmission lines ( BHEL is the first Indian manufacturer to supply such insulators )

**11. Capacitor**

* Power capacitors for industrial and power systems of up to 250 KVA rating for application up to 400 KV.
* Coupling or CVT capacitors for voltages up to 400 KV
* Low Tension Thyristor Switched Capacitor ( LTTSW )
* Series capacitors for transmission systems

**12. INDUSTRIAL ELECTRICAL MACHINES: (BHOPAL)**

* AC squirrel cage, slip ring, synchronous motors, industrial alternators and DC machines are manufactured as per range summarized below. Special purpose machines are manufactured on request.
* AC machines for safe area applications.

**13. CONTROL GEAR: (BHOPAL)**

* **INDUSTRIAL CONTROL GEAR:**
	+ Control Panels and cubicles for applications in steel, aluminum, cement, paper, rubber, mining, sugar and petrochemical industries.
	+ Liquid rotor starters for SIM of up to 2500 hp rating
	+ Liquid regulators for variable speed motors.
* **CONTACTORS:**
* LT air break type AC for voltages up to 660 KV
* LT air break type DC contactors for voltages up to 660 KV
* HT vacuum type AC for voltages up to 11 KV
* **TRACTION CONTROL GEAR:**
	+ Control gear equipment for railways and other traction applications
	+ Control and relay panels
	+ Control panels for voltages up to 400 KV and control desks for generating stations and EHV substation
	+ Control and relay boards
	+ Turbine gauge boards for thermal, gas, hydro and nuclear sets
	+ Turbine electrical control cubicles
	+ Transformer tap-changer panels
1. **SILICON RECTIFIERS: (BHOPAL)**
* Silicon power rectifiers with matching transformers for industrial applications.
* Aluminum or Copper, Zinc smelting for electrolysis in chemical industry and AC & DC traction applications.
1. **THYRISTOR EQUIPMENT: ( BHOPAL )**
* Thyrister Converter Equipment
* Thyrister Inverter Equipment
* Static AC variable speed drive systems
* Thyrister values for HVDC transmission up to 500 KV
1. **POWER DEVICES : ( BHOPAL )**
* High power capacity silicon diodes and thyristor devices and solar photovoltaic cells.

**17. TRANSPORTATION EQUIPMENT: (TIRUCHY)**

* AC electric locomotive
* AC DC dual voltage electric locomotive
* Diesel electric shunting locomotive
* Diesel hydraulic shunting locomotive
* OHE Recording cum test car
* Electric traction equipment ( for diesel or electric locos electric multiple units, diesel multiple units and urban transportation systems )
* Traction motors
* Transformers smoothing reactors
* Traction generators or Alternators
* Rectifiers
* Bogies
* Vacuum circuit breakers
* Auxiliary machines
* Microprocessor based electronic control equipment
* Power Converter and Invertors
* Static Invertors for auxiliary supply
* Loco control resistances i.e. field elevators dynamic braking resistances and inductive shunts.
* Traction Control Gear.
1. **VALVES AND PUMPS (TIRUCHY)**
2. **TELECOMMUNICATION (BANGALORE)**
3. **BUSDUCTS (BANGALORE)**
4. **COMPRESSORS ( HYDERABAD**
5. **OIL FIELD EQUIPMENT (HYDERABAD)**
6. **SYSTEMS AND SEVICES ( VARANASI AND MUMBAI )**

 **23. CASTINGS AND FORGING: (HARDWAR)**

* Sophisticated heavy castings and forgings of creep resistant alloy steels, stainless steel and other grades of alloy steels meeting stringent international specifications.
1. **SEAMLESS STEEL TUBES: (TIRUCHY)**
* Hot finished and cold drawn seamless steel tubes with a range varying from outer diameter of 19 to 133 mm and wall thickness of 2 to 12.5 mm, in carbon, steel and low alloy steels to suit ASTM / API and other international specifications.

 24. **Studded Tubes:**

* Extended surface tubes for high performance heat transfer applications
1. **Spiral Firmed Tubes:**
* Heat frequency resistance welded finned tubes for WHR systems, economizers and heat furnace.
1. **NON-CONVENTIONAL ENERGY SYSTEMS : ( GURGAON )**
* Wind electric generator of up to 250 KW rating.
* Solar PV system and power plant.
* Solar water heating systems.
* Solar lanterns.
* Battery provided road vehicles

# BHEL HARIDWAR

***An Overview***

At the foothills of the majestic Himalayas & on the banks of a holy Ganges in Ranipur near HARIDWAR is located **Heavy Electricals Equipment Plant** of **Bharat Heavy electrical ltd.**

BHEL, wholly owned by the government of India is an integrated engineering complex consisting of several plants in India, where about 70,000 workers are busy in design & manufacturing of a wide range of heavy electrical equipment. At present 70% of the country’s electrical energy is generated by the sets manufacturing by BHEL, Haridwar.

***PRODUCTS OF BHEL HARIDWAR***

**1. HEEP’S PRODUCT & CAPACITY RATINGS**

**PRODUCT CAPACITY RATING**

1. Thermal set/nuclear set 210 MW-660 MW

2. Generator different power stations acc. to requirement

3. Gas Turbine 60 MW- 200 MW

4. Heat Exchangers/Condenser Up to 800 MW

**2. CFFP’s PRODUCT & CAPACITY RATINGS:**

**PRODUCT CAPACITY RATING**

a) Steam steel castings like steam 6000 Tones

Chest, turbine cylinders, stray rings,

Runner blades etc.

b) Special steel forgings like steam turbine 3250 Tones

 Rotors, rotor discs, hydro turbine shaft.

***BLOCKS IN HEEP***

* BLOCK-1 Turbo Generators, AC Machines
* BLOCK-2 Fabrication (Steam, Hydro & gas Turbine)
* BLOCK-3 Gas & Steam Turbine
* BLOCK-4 CIM(Coil & Insulation Manufacturing) & ACG (Apparatus control Gear)
* BLOCK-5 Heat exchangers, Forging and Fabrication
* BLOCK-6 Stamping
* BLOCK-7 Wooden Packing works
* BLOCK-8 Fabrication, seamless tubes and heat exchanger

***FACILITIES AND INFRASTRUCTURE***

Modernization and regular up gradation / up gradation of facilities and other infrastructure is a continuous endeavor at HEEP, BHEL. After initial setting up of the plant during the year 1964-72, in collaboration with the Soviet Union, the plant facilities and infrastructures have since been continuously upgraded under various investment projects vise, Stamping Unit Project, LSTG Project, Motor Project, Governing Components Project, TG Facilities Modernization, TG Facilities Augmentation, Quality Facilities Augmentation, EDP projects, Gas Turbine Project, Facilities have also been added and establishments have been created for new projects in Defense and Aviation Project. Additionally, R &D facilities have also been created under Generators Research Institute, Pollution Control Research Institute, HTL modernization and other such schemes.

Today the Plant has unique manufacturing and testing facilities, computerized numerically controlled machine-tools, Blade shop, heavy duty lathes, milling machines, boring machines, machining centers and many more. The Over Speed Vacuum Balancing Tunnel created for rotors up to 1300 MW (32T, 6.9 M – dia bladed rotor, 6 rpm up to 4500 rpm) is one of the 8 of its kind in the entire world.

The total spectrum of sophisticated, unique and other facilities at HEEP, Hardwar are the state-of-the-art in manufacturing processes and can be utilized for a variety of products' manufacture.

***HUMAN RESOURCE DEVELOPMENT CENTRE***

**INTRODUCTION**

 HRDC Workshop caters to the needs of skill training of various trainees at HRDC. These trainees include Engineering Trainees & ACT Apprentices amongst others. Any other type of trainees who are to be given imported training can be given skill training in areas of machining, turning, fitting, welding, electrical, carpentry & electronics. In a year, about 500 ACT Apprentices are given training on various machines.

**VARIOUS SECTIONS OF HRDC**

There are 7 different sections in HRDC in which facilities exist for training.

(i) **Turning Section** – has facilities for practical training of Turner Apprentices & trainees. There are 18 Lathes, which include HMT lathes H22, LB 17, LM 001, Russian lathe No. 163, Kirloskar lather D 1 and one CNC Trainmaster T-70 of HMT make.

(ii) **Fitting Section –** has facilities for training in the area of fitting e.g. 36 bench vices for fitting work.

(iii) **Machining Section –** has 24 milling machines for skill training, 1 shaper, 1 slotter and 10 grinding machines. A CNC machining center also exists for training in CNC operations.

(iv) **Welding Section –** has facilities to give practical training in gas welding and electric welding. The section has transformer, MG set, rectifier & an electrode oven.

(v) **Electrical Section –** has facilities for providing practical training in electrician field. Areas in which practical training is given are laying of house wiring, joints making & motor winding.

(vi) **Carpentry Section –** facilities for providing practical training in the field of carpentry. It has various wood working machines, like surface planer lathe, thickness planer, circular saw, pedestal grinder & drilling machines.

(vii) **Electronics Trade –** In this section practical training is given in making circuits & repair work of TVs, tape recorders, amplifiers etc.

***POLLUTION CONTROL RESEARCH INSTITUTE***

To provide directional thrust to environmental control / protection activities, a Pollution Control Research Institute has been set up by BHEL at HEEP, Hardwar with the assistance of United Nations Development Programme (UNDP).

The main objective of the Institute is to develop technologies for pollution control in the areas of air, water noise and solid waste to obviate unintended side effects of economic growth. The Institute is concentrating on research and development activities related to environment protection against pollution emanating from industries. PCRI provides consultancy services related to pragmatic approaches / methods to maintain pollution within permissible limits. The other objectives include development of methods for recovery and recycling of industrial wastes.

Most modern facilities for monitoring and analysis in the area of air, water, noise and solid waste are available at the Institute. It has full-fledged computer facilities for prediction and forecasting pollution impact. It also has workshop and other support services.

The laboratories of Pollution Control Research Institute have been recognized by Ministry of Environment and Forests, Govt. of India; Department of Science and Technology, Govt. of India; Madhya Pradesh Pradushan Nivaran Mandal; UP State Pollution control Board; Bihar State Pollution Control Board; Punjab State Council for Technology; Haryana State Pollution Control Board; Karanataka State Pollution Control Board.

***AVIATION PRODUCTS***

**MANUFACTURING FACILITIES**

**1. LIGHT TRAINER AIRCRAFT PROJECT**

In 1991, BHEL Entered into Aviation Sector as part of its diversification efforts and has taken up manufacturing of two-seater light trainer aircraft "SWATI". The aircraft was designed and developed indigenously by R&D Wing of Directorate General of Civil Aviation, India. Requisite organizational facilities and services infrastructure has been developed in Sector X at BHEL, Hardwar.

"SWATI" is a general purpose aircraft powered by 116 HP horizontally opposed piston engine with fixed pitch propeller and has wide range of applications like flying training, sports, touring, surveillance, photography, courier & personal use.

**2. WORKSHOP & FACILITIES:**

2.1 **General:**

Hangar / Manufacturing Workshop consisting of one bay of size 45x90 meters with expansion provision on eastern side have been developed at Aviation Project Site in Sector X.

* 1. **Manufacturing:**

Following major components, sub-assemblies & assemblies are manufactured in different sections:

* Fuselage
* Landing Gear
* Engine Mount
* Fuel Tank
* Pair of Wings
* Pin, Bush, Axle, Stud, etc.
* Lever, Brackets, Controls, etc.
* Fin, Rudder, Tailplane, Elevator, etc.
	1. **Facilities:**

i) **Fabrication / Welding Section**

Equipped with TIG welding machines, this section is meant for fabrication of fuselage, engine mount, landing gear and welding of lugs, brackets and other items on fuselage.

ii) **Wing Manufacturing Section**

This section is located in WWM shop (Block-VII) of HEEP, as all the required wood working facilities are available in that Shop.

iii) **Machine Shop**

The Shop is equipped with medium capacity center lathes, milling machines and drilling machine. Small components like pins, bush, axle, wing to wing attachment fitting etc. are routed through this Section.

iv) **C.M. Section (Chrome Moly-Steel Section)**

Components of CM steel like lugs, brackets, levers, control system etc. are manufactured in this Section. This section is equipped with fitter tables, vices, hand shear machine, screw press etc.

v) **Alclad Section**

All components / sub-assemblies made of Alclad material like Fin, Rudder, Tailplane, Elevator, Cowling etc. are manufactured in this Section. This Section is equipped with fitter tables, vices, compressed air, Hand shear machine, Sheet folding machine, 160 T Hydraulic press, 25 T Crank press etc. Fuel tank is manufactured in Sheet Metal Shop of ACM (Block-IV).

vi) **FRP Section**

FRP Components like fairing, nose cap upper & lower, drag reduction items etc. are made in this Section.

vii) **Assembly Section**

Trial Assembly / Final assembly of components on fuseldge is carried out in this Section like mounting of fin, rudder, tailplane, engine, fuel tank, controls, instruments etc.

viii) **Test Flying Facilities**

To establish performance characteristics of aircraft before delivery to the customer, an airstrip of size 23M in width and 914 M in length has been developed in Sector IX near the Project Site.

***CENTRAL PLANT STORES***

**General**

Materials from suppliers, sub-contractors, other unitsand ancillaries enter the factory premises from eastern gate.

**Material Receipt**

The materials are unloaded at receipt area, identified in the Central Plant Stores and subsequently shifted to respective custody areas after inspection. In case of heavy materials, receipt areas are adjacent to custody areas.

**Material Issue**

All the materials are received by Central Plant Stores and issued to users / manufacturing blocks. Manufacturing blocks have their own sub-stores to receive material from Central Plant Stores and further issue it to the shop / sections concerned.

**Stores Custodies**

The locations, where various types of material are stored by Central Plant Stores, have been classified as custody-I, II, III, IV & V.

# ELECTRICAL MACHINES BLOCK (BLOCK — I)

***Introduction***

1. Block-I is designed to manufacture Turbo Generators.

2. The block consists of 4 bays- Bay-I (36\*482 meters), Bay-II (36\*360 meters) and Bay-III and Bay-IV (Of size 24\*360 meters each).

3. For handling and transporting the various components over-head crane facilities are available, depending upon the products manufactured in each Bay. There are also a number of self-propelled electrically driven transfer trolleys for the inter-bay movement of components/assemblies.

4. Testing facilities for Turbogenerator are available in Bay-II.

5. There is a special test bed area for testing of T.G. of capacity of 500

MW Unit sizes.

***MANUFACTURING PROCESS***

Fabricated components are received in respective machine sections from Fabrication blocks (Block — II, V, VI, VIII), while castings and forgings are received from sister unit CFFP and other indigenous and foreign sources for Turbo Generators. Stampings are received from stampings manufacture block, block—VI and coils, bars, insulating details and sheet metal components are received from coils and insulation manufacture and apparatus and control gear box (block — IV).

*1. Turbo Generators –*

* Making of blanks is done for checking the availability ofmachining allowances.
* Machining of the major components is carried out in Bay - I & Bay- II and other small components in Bay - III and Bay - IV. Theboring and facing of stators are done on CNC horizontal boringmachine using a rotary table. The shaft is turned on lathe havingswift 2500 mm and the rotor slots are milled on a special rotor slotmilling machines.
* In case of large size Turbo Generators core bars are welded tostator frame with the help of telescopic centering device. Thecentering of core bar is done very precisely. Punchings areassembled manually and cores are heated and pressed in number ofstages depending on the core length.
* Stator winding is done by placing stator on rotating installation. After laying of lower and upper bars, these are connected at theends, with the help of ferrule and then soldered by resistancesoldering.
* Rotor winding assembly is carried out on special installation wherecoils are assembled in rotor slots. The pressing of overhangportionis carried out on special ring type hydraulic press, whereas slotportion is pressed manually with the help of rotor wedges. Coilsare wedged with special press after laying and curing. The dynamic balancing of rotors is carried out on the over speed balancing installation. 500 MW Turbo Generators are balanced in vacuum balancing tunnel.
* General assembly of Turbo Generators is done in the test bed. Rotor is inserted in the stator and assembly of end shields, bearingsetc. are carried out to make generators ready for testing.Prior totest run the complete generator is hydraulically tested for leakages.Turbo Generators are tested as per standard practices and customer requirements.

***TURBO GENERATOR***

*500 MW Turbo generators at a glance -*

2-Pole machine with the following features:-

* Direct cooling of stator winding with water.
* Direct hydrogen cooling for rotor.
* Micalastic insulation system
* Spring mounted core housing for effective transmission of vibrations.
* Brushless Excitation system.
* Vertical hydrogen coolers

**Salient technical data–**

* Rated output : 588 MVA , 500 MW
* Terminal voltage : 21 KV
* Rated stator current : 16 KA
* Rated frequency : 50 Hz
* Rated power factor : 0.85 Lag
* Efficiency : 98.55%

**Important dimensions & weights –**

* Heaviest lift of generator stator : 255 Tons
* Rotor weight : 68 Tons
* Overall stator dimensions [LxBxH] : 8.83Mx4.lMx4.02M
* Rotor dimensions : 1.15M dia x 12.11 M length
* Total weight of turbo generator : 428 Tons

**Unique installations–**

Heavy Electrical Equipment Plant, Haridwar is one of the best equipped and most modern plants of its kind in the world today. Some of the unique manufacturing and testing facilities in the plant are:

***TG Test Bed–***

New LSTG [Large Scale Turbo Generator] Test Bed has been put up with indigenous know- how in record time for testing Turbo generators of ratings 500 MW and above up to 1000 MW. It caters to the most advanced requirement of testing by employing on-line computer for dataanalysis.

***Other major facilities are as follows –***

* Major facilities like stator core pit equipped with telescopic hydraulic lift, micalastic plant for the manufacture of stator bars, thermal shocks test equipment, rotor slot milling machine etc. have been specially developed by BHEL.
* 12 MW/10.8 MW, 6.6 KV, 3000 RPM AC non salient pole, synchronous motor has been used for driving the 500 MW Turbogenerator at the TEST Bed. The motor has special features to suit the requirement of TG testing (500 MW and above). This is the largest 2- pole (3000 rpm).

***Over speed Balancing vacuum tunnel –***

For balancing and over speeding large flexible Turbo generators rotors in vacuum for ratings up to 1,000 MW, an over speed and balancing tunnel has been constructed indigenously. This facility is suitable for all types of rigid and flexible rotors and also high speed rotors for low and high speed balancing, testing at operational speed and for over speeding.

*Generator transportation –*

* Transport through300 Tons 24-Axle carrier beam railway wagon specially designed indigenously and manufactured at Haridwar.
* The wagon has been used successfully for transporting one generator -from Calcutta Port to Singrauli STPP.

***CONSTRUCTIONAL FEATURES OF STATOR BODY***

***1) Stator Frame –***

Stator body is a totally enclosed gas tight fabricated structure made up of high quality mild steel and austenitic steel. It is suitably ribbed with annular rings in inner walls to ensure high rigidity and strength .The arrangement, location and shape of inner walls is determined by the cooling circuit for the flow of the gas and required mechanical strength and stiffness. The natural frequency of the stator body is well away from any of exiting frequencies. Inner and sidewalls are suitably blanked to house for longitudinal hydrogen gas coolers inside the stator body.

***2) Pipe Connection –***

To attain a good aesthetic look, the water connection to gas cooler is done by routing stainless steel pipes; inside the stator body; which emanates from bottom and emerges out of the sidewalls.

These stainless steel pipes serve as inlet and outlet for gas coolers.

From sidewall these are connected to gas coolers by the means of eight U-tubes outside the stator body. For filling the generator with hydrogen, a perforated manifold is provided at the top inside the stator body.

***3) Terminal Box –***

The bearings and end of three phases of stator winding are brought out to the slip-ring end of the stator body through 9 terminals brushing in the terminal box. The terminal box is a welded construction of (non magnetic) austenitic steel plates. This material eliminates stray losses due to eddy currents, which may results in excessive heating.

***4) Testing Of Stator Body –***

On completion of manufacture of stator body, it is subjected to a hydraulic pressure of 8 kg/cm for 30 minutes for ensuring that it will be capable of withstanding all expansion pressure, which might arise on account of hydrogen air mixture explosion. Complete stator body is then subjected to gas tightness test by filling in compressed air.

***CONSTRUCTIONAL FEATURES STATOR CORE***

***1) Core –***

It consists of thin laminations. Each lamination made of number of individual segments. Segments are stamped out with accurately finished die from the sheets of cold rolled high quality silicon steel.

Before insulation on with varnish each segment is carefully debarred. Core is stacked with lamination segments. Segments are assembled in an interleaved manner from layer to layer for uniform permeability. Stampings are held in a position by 20 core bars having dovetail section. Insulating paper pressboards are also put between the layer of stamping to provide additional insulation and to localize short circuit.

Stampings are hydraulically compressed during the stacking procedure at different stages. Between two packets one layer of ventilating segments is provided. Steel spacers are spot welded on stamping. These spacers from ventilating ducts where the cold hydrogen from gas coolers enter the core radialy inwards there by taking away the heat generated due to eddy current losses. The pressed core is held in pressed condition by means of two massive non-magnetic steel castings of press ring. The press ring is bolted to the ends of core bars. The pressure of the pressure ring is transmitted to stator core stamping through press fringes of non-magnetic steel and duralumin placed adjacent to press ring.

To avoid-heating of press ring due to end leakage flow two rings made of copper sheet are used on flux shield. The ring screens the flux by short-circuiting. To monitor the formation of hot spots resistance transducer are placed along the bottom of slots. To ensure that core losses are within limits and there are no hot spots present in the core. The core loss test is done after completion of core assembly.

***2) Core Suspension –***

The elastic suspension of core consist of longitudinal bar type spring called core bars. Twenty core bars are welded to inner walls of stator body with help of brackets. These are made up of spring steel having a rectangular cross section and dove-tail cut at tap, similar type of dovetail is also stamped on to stamping and fit into that of core bar dovetail. Thus offering a hold point for stamping core bars have longitudinal slits which acts as inertial slots and help in damping the vibrations. The core bars are designed to maintain the movement of stator core with in satisfactory limits.

***CONSTRUCTIONAL FEATURES OF STATOR WINDING***

***1) General –***

The stator has a three phase, double layer, short pitched and bar type of windings having two parallel paths. Each slots accommodated two bars. The slot lower bars and slot upper are displaced from each other by one winding pitch and connected together by bus bars inside the stator frame in conformity with the connection diagram.

***2) Conductor Construction –***

Each bar consists of solid as well as hollow conductor with cooling water passing through the latter. Alternate arrangement hollow and solid conductors ensure an optimum solution for increasing current and to reduce losses. The conductors of small rectangular cross section are provided with glass lapped strand insulation.

A separator insulates the individual layers from each other. The transposition provides for mutual neutralization of voltage induced in the individual strands due to the slots cross field and end winding field. The current flowing through the conductor is uniformly distributed over the entire bar cross section reduced. To ensure that strands are firmly bonded together and give dimensionally stability in slot portion, a layer of glass tape is wrapped over the complete stack. Bar insulation is done with epoxy mica thermosetting insulation. This insulation is void free and posses better mechanical properties. This type of insulation is more reliable for high voltage. This insulation shows only a small increase in dielectric dissipation factor with increasing test voltage. The bar insulation is cured in an electrically heated process and thus epoxy resin fill all voids and eliminate air inclusions.

**➢ *Method of Insulation –***

Bar is tapped with several layers of thermosetting epoxy tape. This is applied continuously and half overlapped to the slot portion. The voltage of machine determines the thickness of insulation. The tapped bar is then pressed and cured in electrical heated press mould for certain fixed temperature and time.

**➢ *Corona Prevention –***

To prevent corona discharges between insulation and wall of slots, the insulation in slot portion is coated with semiconductor varnish. The various test for manufacture the bar are performed which are as follows–

* Inter turn insulation test on stuck after consolidation to ensure absence of inter short.
* Each bar is subjected to hydraulic test to ensure the strength of all joints.
* Flow test is performed on each bar to ensure that there is no reduction in cross section area of the ducts of the hollow conductor.
* Leakage test by means of air pressure is performed to ensure gas tightness of all joints.
* High voltage to prove soundness of insulation.
* Dielectric loss factor measurement to establish void free insulation.

**➢ *Laying Of Stator Winding –***

The stator winding is placed in open rectangular slots of the stator core, which are uniformly distributed on the circumference. A semi conducting spacer is placed in bottom of slots to avoid any damage to bar due to any projection. Driving in semi conducting filler strips compensates any manufacturing tolerances. After laying top bar, slot wedges are inserted. Below slots wedges, high strength glass texolite spacers are put to have proper tightness. In between top and bottom bars, spacers are also put.

**➢ *Ending Winding –***

In the end winding, the bars are arranged close to each other. Any gaps due to design or manufacturing considerations are fitted with curable prepag with spacer in between. The prepag material is also placed between the brackets and binding rings. Lower and upper layers are fixed with epoxy glass ring made in segment and flexible spacer put in between two layers. Bus bars are connected to bring out the three phases and six neutrals. Bus bars are also hollow from inside. These bus bars are connected with terminal bushing. Both are water-cooled. Brazing the two lugs properly makes connection.

***CONSTRUCTIONAL FEATURES OF ROTOR***

The rotor comprises of following component:

1) Rotor shaft

2) Rotor winding

3) Rotor wedges and other locating parts for winding

4) Retaining ring

5) Fans

6) Field lead connections

***1) Rotor Shaft –***The rotor shaft is a single piece solid forging manufactured from a vacuum casting. Approximately 60 % of the rotor body circumference is with longitudinal slots, which hold the field winding. The rotor shaft is a long forging measuring more than 9m in length and slightly more than one meter in diameter.

The main constituents of the steel are chromium, molybdenum, nickel and vanadium. The shaft and body are forged integral to each other by drop forging process. Following tests are done: -

* Mechanical test
* Chemical analysis
* Magnetic permeability test
* Micro structure analysis
* Ultrasonic examination
* Boroscope examination

On 2/3 of its circumference approximately the rotor body is provided with longitudinal slot to accommodate field winding. The slot pitch is selected in such a way that two solid poles displaced by 180o C are obtained. For high accuracy the rotor is subjected to 20% over speeding for two minutes. The solid poles are provided with additional slots in short lengths of two different configurations.

One type of slots served as an outlet for hydrogen which has cooled the overhang winding and other type used to accommodate finger of damper segments acting as damper winding.

***2) Rotor Winding***

After preliminary turning, longitudinal slots are milled on sophisticated horizontal slot milling machine. The slot house the field winding consists of several coils inserted into the longitudinal slots of rotor body*–*

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*2.1.Copper Conductor –*

The conductors are made of hard drawn silver bearing copper. The rectangular cross section copper conductors have ventilating ducts on the two sides thus providing a channel for hydrogen flow. Two individual conductors placed-one over the other are bent to obtain half turns. Further these half turns are brazed in series to form coil on the rotor model.

*2.2.Insulation –*

The individual turns are insulated from each other by layer of glass prepag strips on turn of copper and baked under pressure and temperature to give a monolithic inter turn insulation. The coils are insulated from rotor body by U-shaped glass laminate module slot through made from glass cloth impregnated with epoxy varnish. At the bottom of slot D-shaped liners are put to provide a plane seating surfaces for conductors and to facilitate easy flow of gas from one side to another. These liners are made from molding material. The overhang winding is separated by glass laminated blocks called liners. The overhang winding are insulated from retaining rings segments having L-shape and made of glass cloth impregnated by epoxy resin.

*2.3.Cooling Of Winding –*

The rotor winding are cooled by means of direct cooling method of gap pick-up method. In this type of cooling the hydrogen in the gap is sucked through the elliptical holes serving as scoop on the rotor wedges and is directed to flow along lateral vent ducts on rotor cooper coils to bottom of the coils. The gas then passes into the corresponding ducts on the other side and flows outwards and thrown into the gap in outlet zones.

In this cooling method the temperature rise becomes independent of length of rotor. The overhang portion of the winding is cooled by axial two systems and sectionalized into small parallel paths to minimize temperature rise.

Cold gas enters the overhang from under the retaining rings through special chamber in the end shields and ducts under the fan hub and gets released into the air gap at rotor barrel ends.

*1) Rotor Wedges –*

For protection against the effect of centrifugal force the winding is secured in the slots by slot wedge. The wedges are made from duralumin, an alloy of copper, magnesium and aluminum having high good electrical conductivity and high mechanical strength. The wedges at the ends of slot are made from an alloy of chromium and copper. These are connected with damper segments under the retaining ring for short circuit induced shaft current. Ventilation slot wedges are used to cover the ventilation canals in the rotor so that hydrogen for overhang portion flows in a closed channel.

*2) Retaining Ring –*

The overhang portion of field winding is held by non-magnetic steel forging of retaining ring against centrifugal forces. They are shrinking fitted to end of the rotor body barrel at one end; while at the other side of the retaining ring does not make contact with the shaft.The centering rings are shrinking fitted at the free end of retaining ring that serves to reinforce the retaining ring, securing, end winding in axial direction at the same time. To reduce stray losses, the retaining rings are made of non-magnetic, austenitic steel and cold worked, resulting in high mechanical strength.

*3) Fans –*

Two single stage axial flow propeller type fans circulate the generator cooling gas. The fans are shrinking fitted on either sides of rotor body.

Fans hubs are made of alloy steel forging with three peripheral grooves milled on it. Fan blades, which are precision casting with special alloy, are machined in the tail portion so that they fit into the groove of the fan hub.

*4) Field Lead Connections –*

*Slip Rings –*

The slip ring consists of helical grooved alloy steel rings shrunk on the body shaft and insulated from it. The slip rings are provided with inclined holes for self-ventilation. The helical grooves cut on the outer surfaces of the slip rings improve brush performance by breaking the pressurized air pockets that would otherwise get formed between the brush and slip rings.

*Field Lead –*

The slip rings are connected to the field winding through semi flexible copper leads and current-carrying bolts placed in the shaft. The radial holes with current carrying bolts in the rotor shafts are effectively sealed to prevent the escape of hydrogen. A field lead bar, which has similar construction as, does the connection between current carrying bolt and field winding that of semi flexible copper leads (they are insulated by glass cloth impregnated with epoxy resin for low resistance and ease of assembly).

**COOLING SYSTEM**

Heat losses arising in generator interior are dissipated to secondary coolant (raw water, condensate etc.) through hydrogen and Primary water. Direct cooling essentially eliminates hot spots and differential temperature between adjacent components, which could result in mechanical stresses, particularly to the copper conductors, insulation, rotor body and stator core.

***Hydrogen Cooling Circuit:***

The hydrogen is circulated in the generator interior in a closed circuit by one multistage axial flow fan arranged on the rotor at the turbine end. Hot gases is drawn by the fan from the air gap and delivered to the coolers where it is recooled and then divided into three flow paths after each cooler:

*Flow path I:*

Flow path I is directed into the rotor at the turbine end below the fan hub for cooling of the turbine end half of the rotor.

*Flow path II:*

Flow path II is directed from the cooler to the individual frame compartments for cooling of the stator core.

*Flow path III:*

Flow path III is directed to the stator end winding space at the exciter end through guide ducts in the frame of cooling of the exciter end half of the rotor and of the core end portion. The three flow paths miss the air gaps. The gas is then returned to the coolers via the axial flow fan. The cooling water flow through the hydrogen coolers should automatically control to maintain a uniform generator temperature level for various loads and cold-water temperature.

***Cooling Of Rotors:***

For direct cooling of rotor winding cold gas is directed to the rotor end wedges at the turbine and exciter ends. The rotor winding is symmetrical relative to generator centerline and pole axis. Each coil quarter is divided into two cooling zones consists of the rotor end winding and the second one of the winding portion between the rotor body end and the midpoint of the rotor. Cold gas is directed to each cooling zone through separate openings directly before the rotor body end. The hydrogen flows through each individual conductor is closed cooling ducts. The heat removing capacity is selected such that approximately identical temperature is obtained for all conductors. The gas of the first cooling zone is discharged from the coils at the pole center into a collecting compartment within the pole area below the end winding from the hot gases passes into air gap through the pole face slots at the end of the rotor body. The hot gas of the second cooling zone is discharged into the air gap at the mid length of the rotor body through radial openings in the hollow conductors and wedges.

***Cooling of stator core:***

For cooling of the stator core, cold gas is passes to the individual frame compartment via separate cooling gas ducts. From these frames compartment the gas then flow into the air gap through slots and the core where it absorbs the heat from the core. To dissipate the higher losses in core ends the cooling gas section. To ensure effective cooling. These ventilating ducts are supplied from end winding space.

Another flow path is directed from the stator end winding space paste the clamping fingers between the pressure plate and core section into the air gap along either side of flux shield. All the flows mix in the air gap and cool the rotor body and stator bore surfaces. The air gap is then returned to the coolers via the axial flow fan. To ensure that the cold gas directed to the exciter end cannot be directly discharged into the air gap. An air gap choke is arranged with in the stator end winding cover and the rotor retaining rings at the exciter end.

***Primary Cooling Water Circuit in the Generators:***

The treated water used for cooling of the stator winding, phase connectors and bushings is designated as primary water in order to distinguish it from the secondary coolant (raw water, compensator etc.). The primary water is circulated in a closed circuit and dissipates the absorbed heat to the secondary cooling in the primary water cooler. The pump is supplied with in primary water cooler. The pump is supplied with in the primary water tank and delivers the water to the generator via the following flow paths:

*Flow path I:*

Flow path I cools the stator winding. This flow path passes through water manifold on the exciter end of the generator and from there to the stator bars via insulated bar is connected to the manifold by a separate hose. Inside the bars the cooling water flows through hollow strands. At the turbine end, the water is passed through the similar hoses to another water manifold and then return to the primary water tank. Since a single pass water flow through the stator is used, only a minimum temperature rise is obtained for both the coolant and the bars. Relatively movements due to the different thermal expansions between the top and the bottom bars are thus minimized.

*Flow Path II:*

Flow path II cools the phase connectors and the bushings. The bushing and the phase connectors consist of the thick walled copper tubes through which the cooling water is circulated. The six bushings and phase connectors arranged in a circle around the stator winding are hydraulically interconnected so that three parallel flow paths are obtained. The primary water enters three bushings and exits from the three remaining bushings. The secondary water flow through the primary water cooler should be controlled automatically to maintain a uniform generator temperature level for various loads and cold-water temperatures.

**EXCITATION SYSTEM**

In large synchronous machines, the field winding is always provided on the rotor, because it has certain advantages they are:

* It is economical to have armature winding on the stator and field winding on the rotor.
* Stationary armature windings can be insulated satisfactorily for higher voltages, allowing the construction of high voltage synchronous machines.
* Stationary armature winding can be cooled more efficiently.
* Low power field winding on the rotor gives a lighter rotor and therefore low centrifugal forces. In view of this, higher rotor speeds are permissible, thus increasing the synchronous machine output for given dimensions.

***Design features***

The excitation system has a revolving field with permanent magnet poles. The three-phase ac output of this exciter is fed to the field of the main exciter via a stationary regulator & rectifier unit.

Three-phase ac induced in the rotor of the main exciter is rectified by the rotating Rectifier Bridge & supplied to the field winding of the generator rotor through the dc lead in the rotor shaft. A common shaft carries the rectifier wheels, the rotor of the main exciter & PMG rotor. The shaft is rigidly coupled to the generator rotor. The generator & exciter rotors are supported on total three bearings.

***Three Phase Pilot Exciter***

It is a six-pole revolving field unit. The frame accommodates the laminated core with the three-phase winding. Each pole consists of separate permanent magnets that are housed in a non-magnetic metallic enclosure.

***Three Phase main exciter***

The three phase main exciter is a six-pole armature-revolving unit. The field winding is arranged on the laminated magnetic poles. At the pole shoe, bars are provided which are connected to form a damper winding.

Between the two poles, a quadrature-axis coil is provided for inductive measurement of the field current. After completing the winding & insulation etc., the complete rotor is shrunk on the shaft.

***Rectifier wheels***

The silicon diode is the main component of the rectifier wheels, which are arranged in a three-phase bridge circuit. With each diode, a fuse is provided which serves to cut off the diode from the circuit if it fails. For suppression of the momentary voltage peaks arising from commutation, R-C blocks are provided in each bridge in parallel with each set of diodes.

The rings, which form the positive & negative side of the bridge, are insulated from the rectifier wheel which in turn is shrunk on the shaft. The three phase connections between armature & diodes are obtained via copper conductors arranged on the shaft circumference between the rectifier wheels & the main exciter armature.

***Voltage regulator***

The voltage regulator is intended for the excitation and control of generators equipped with alternator exciters employing rotating uncontrolled rectifiers. The main parts of the regulator equipment are two closed-loop control systems including a separate gate control set and thyistor set each, field discharge circuit, an open loop control system for exchanging signal between the regulator equipment and the control room, and the power supply circuits.

***Voltage regulation***

The active and reactive power ranges of the generator have required a wide excitation setting range. The voltage regulator in the restricted sense, i.e. the control amplifiers for the generator voltage controls via the gate control set the thyristors so as they provide quick correction of the generator voltage on changing generator load. For this purpose the gate control set changes the firing angle of the thyristors as a function of the output voltage of the voltage regulator. The main quantities acting on the input of the voltage regulator are the set point and the actual value of the generator voltage. The set point is divided into a basic set point (e.g. 90% rated voltage) and an additional value (e.g. 0 to 20%), which can be adjusted from the control room. In this case the setting range is 90 to 110%. With operation at the respective limits of the capability curve, further, influencing variable are supplied by the under and over excitation limiters.

To partly compensate the voltage drop at the unit transformer, a signal proportional to the reactive current can be added to the input, the controlled voltage level then rising together with the reactive current (overexcited) thereby increasing the generator degree of activity in compensating system voltage functions. Further, signals can be added if necessary via free inputs.

**BRUSHLESS EXCITOR STATOR**

The various schemes, for supplying D.C. excitation to the field winding to large turbo generators are given below:

* The Pilot Exciter and the main exciter are driven by the turbo generators main shaft. The pilot Exciter, which is a small D.C. shunt generator, feeds the field winding of main exciter is given to the field winding of the main alternator, through slip-rings and brushes. The function of the regulator is to keep the alternator terminal voltage constant at a particular value.
* In this second scheme it consists of main A.C. exciter and stationary solid-state rectifier. The A.C. main exciter, which is coupled to shaft of generator, has rotating field and stationary armature. The armature output from the A.C. exciter has a frequency of about 400 Hz. This output is given to the stationary solid-state controlled rectifier. After rectification, the power is fed to the main generator field, through slip rings and brushes.
* In third scheme the A.C exciter, coupled to the shaft that drives the main generator, has stationary field and rotating 3-phase armature. The 3-phase power from the A.C exciter is fed, along the main shaft, to the rotating silicon-diode rectifiers mounted on the same shaft. The output from these rectifiers is also given, along the main shaft, to the man generator field, without any slip rings and brushes. In the other words, the power flows along the wires mounted on the main shaft, from the A.C. exciter to the silicon diode rectifiers and then to the main generator field. Since the scheme does not require any sliding contacts and brushes, this arrangement of exciting the turbo generators has come to be called as *Brush less Excitation system*.

For large turbo generators of 500 MW excitation systems, the direct cooling required by the rotating field winding increases considerably (up to 10 kA or so). In such cases, the brush gear design becomes more complicated and reliability of turbo generator operation decreases. The only promising solution of feeding the field winding of large turbo generator is the brush less excitation system. In view of its many advantages, the brush less excitation system is employed in almost all large turbo generators being designed and manufactured now days. Here are some merits of Brush less Exciters.

* Eliminates slip rings, brush gear, field breaker and excitation bus/cables.
* Eliminates all the problems associated with transfer of current via sliding contacts.
* Simple, reliable and ideally suited for large sets.
* Minimum operation and maintenance cost.
* Self-generating excitation unaffected by system faults or disturbances of shaft mounted pilot exciter.

**ELECTRICAL GENERATOR PROTECTION –**

Generator may be endangered by short circuit, ground fault, over voltage, under excitation and excessive thermal stresses. The following protective equipment is recommended

1. Differential protection
2. Stator ground fault protection
3. Rotor ground fault protection
4. Under excitation protection
5. Over current protection
6. Load unbalance protection
7. Rise in voltage protection
8. Under-frequency protection
9. Reverse power protection
10. Over voltage protection

***SALIENT DESIGN FEATURES –***

*1) Air Cooled Turbo Generators Up To 200 MW Range (Type.- TARI)*

* Stator core and rotor winding direct air cooled
* Indirect cooling of stator winding
* Horizontally split casing design of stator
* Vertically side mounted coolers in a separate housing
* Moralistic bar type insulation system
* Separately assembled stator core and winding for reducing the manufacturing cycle
* Brush less/static excitation system

*2) Hydrogen & Water-Cooled Turbo Generators Of 200-235 MW range (Type: THW)*

* Stator winding directly water cooled
* Rotor winding directly hydrogen cooled by gap pick up method
* Resiliently mounted stator core on flexible core bars
* Thermo reactive resin rich insulation for stator winding
* Top ripple springs in stator slots
* Enclosed type slip rings with forced ventilation
* Ring/thrust type shaft seal
* Two axial fans for systematic ventilation and four hydrogen coolers
* Static excitation

*3) Hydrogen Cooled Turbo Generators Of 140-260 MW range (Type:THRI)*

* Stator core and winding directly hydrogen cooled
* Indirect cooling of stator winding
* Rigid core bar mounting
* Micalastic insulation system
* End shield mounted bearings
* Top ripple springs in stator slots
* Ring type shaft seals
* Symmetrical ventilation
* Brush less/ static excitation
* Integral coupling of rotor

*4) Hydrogen & Water-Cooled Turbo Generators Of 500 MW range (Type: THW)*

* Stator winding directly water cooled
* Rotor winding direct hydrogen cooled (axial)
* Leaf spring suspension of stator core
* Micalastic insulation system
* End shield mounted bearings
* Support ring for stator over hang
* Magnetic shunt to trap end leakage flux
* Ring type shaft seals with double flow
* Multistage compressor and vertical coolers on turbine end
* Brush less/static excitation
* Integral coupling of rotor