Experiences during construction & commissioning of Electrical power generation and evacuation systems in PFBR.

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Abstract

BHAVINI, a public sector unit under Department of Atomic Energy, is responsible for construction, commissioning and operation of fast reactors in India. Prototype Fast Breeder Reactor (PFBR) capacity of 500 MWe which is in advanced stage of commissioning is the forerunner for the second stage of India's three stage nuclear programme.

Starting from detailed engineering, manufacture installation, integration, till commissioning and operation of all the electrical and control & instrumentation systems, there were many challenges and surprises which have been addressed one by one in a systematic manner. This paper brings out major experiences during construction, commissioning of electrical power Generation and evacuation system in PFBR.

The emergency electric power supply (Class IE) system in Nuclear Power Plant is generally categorized into three types based on the power requirements of the loads.

1. AC power supply to Auxiliaries, which can tolerate short interruption upto 3 minutes is classified as Class-III AC Emergency power supply. Under normal condition, this power supply is drawn from Class IV system and in case of class IV power supply failure, emergency diesel generators provide the back up.
2. No break AC power supply to auxiliaries derived from class-III buses through rectifier/charger and inverter with a battery backup at the input of inverter is called class-II power supply.
3. No break DC power supply to auxiliaries derived from Class-III buses through rectifier/charger with a battery backup provided at the output of the rectifier / charger is called Class-I power supply.

Introduction:

The major experiences during construction & commissioning of electrical power generation and evacuation systems in PFBR are broadly classified under the following heads:

1. 230 kV SF6 Gas Insulated Switchyard
2. 21 kV, 19 kA Generator Circuit breaker
3. 6.6 kV 4500V KVA Emergency Diesel Generator Sets.
4. Primary Sodium Pump – VFD system
5. 415V MCC, HCC panels
6. Electrical Pre-heating system along with associated insulation monitoring device.

1. 230 kV SF6 Gas Insulated Switchyard

An indoor SF6 Gas insulated Switchyard is provided at PFBR to safeguard and increase the reliability of electrical equipment against saline atmosphere. The Generator Transformer (GT) and Unit Auxiliary Transformer (UAT) are protected from the direct sea winds by the tall Turbine Building. Station transformer (ST) located adjacent to the Switchyard. The switching scheme for high voltage substation is double main bus scheme with double circuit breaker in the feeder of GT and a single circuit breaker provided in the transmission line/ connections.

A 230 kV substation with six numbers of transmission lines directly connected to PFBR and one tie line connected through 230 kV underground cable to Madras Atomic Power Station (MAPS) of capacity of 2 X 220 MWe. The transmission system is designed to withstand the outage of two circuits of 230 kV system without the necessity for load shedding / rescheduling of generation.

The major experiences during erection, commissioning of 230 kV Switchyard are given below:

1.1 800 mtrs. Of 230 kV XLPE insulated Lead sheathed cable laid underground in a buried trench between PFBR and MAPS to draw start up power requirement. There is no testing equipment / facility for carrying out AC High voltage test of the insulation for the imported 230 kV cable as per IEC 62067. Testing requirement and the methodology of testing were discussed with Central Power Research Institute (CPRI) and MAPS to avoid inadvertent tripping of the 220 MWe Nuclear Power Plant during energization of cable. Accordingly, required the pre-commissioning checks for a EHV cable of length 800 mtrs. were carried out at site successfully through CPRI testing equipment and cable got qualified before actual energization of cable.

1.2 As part of pre-commissioning checks on 230 kV Gas Insulated Switchyard, High voltage test of 380kV for 1min, 304kV for 3min and partial discharge measurement at 170kV by UHF method were carried out successfully for all the SF6 Gas compartments as per IEC 62271 by arranging the specially mobilized testing equipment / facility for the same from M/s. Alstom, France.

1.3 During regulatory inspection, physical independency of the double circuit 230 kV (6 Nos.) transmission lines was debated in view of common beam for all the 6 bays. The detailed analysis was carried out through STAAD/PRO software for conforming integrity of the structural members of the towers and beams connecting the two bays of the switchyard. As the weakest link in the transmission line namely tension insulator clamp at the terminal tower will fail first, thereby switchyard gantry structure is safe and stable under different load combinations and does not have any safety implication.

2. 21kV 19KA Generator Circuit Breaker

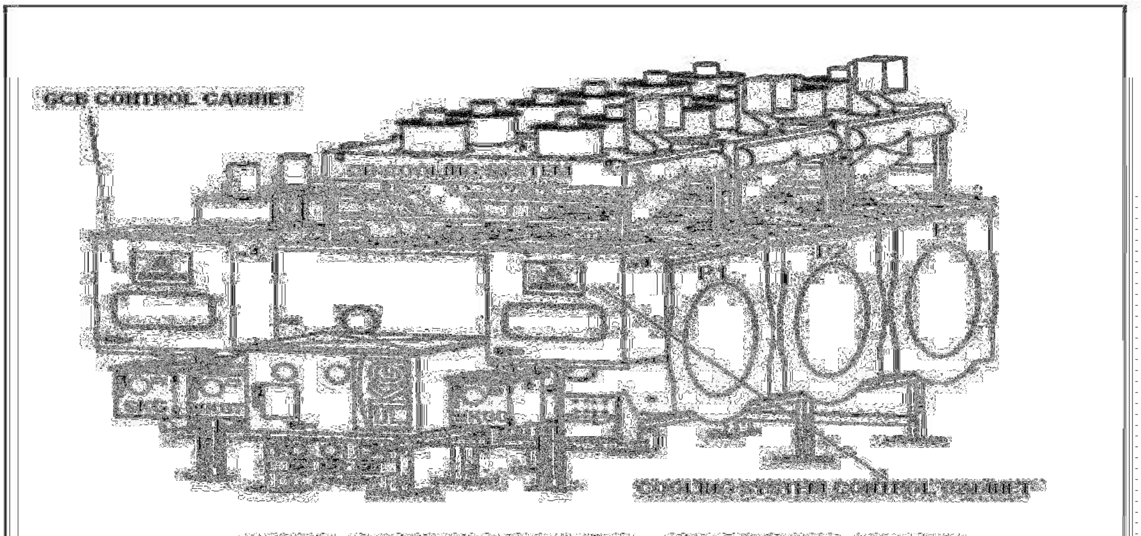
2.1 Description of system

Generator circuit breaker (GCB) of rating 21kV 19KA located between the Generator and the Generator Transformer consists of three metallic sheath enclosed phase segregated units called poles with forced ventilation/cooling system and dry SF6 gas as an arc quenching medium. All the three poles are mounted on a common chassis.

Each pole of the GCB Unit is integrated with the following components:

1. Circuit breaker (FKG)
2. Series isolator / disconnector switch (SKG)
3. Generator side Earth switch (MKGG)
4. Generator Transformer side Earth switch (MKGT)
5. Protective / Surge Capacitors (CD1 and CD2)
6. SF6 pressure monitoring density-meter.

7. Ventilation system consists of 4 no's Centrifugal fans and 2 no's of Axial fans.



GENERATOR CIRCUIT BREAKER (GCB)

2.2 Site Modification during erection & commissioning:

The platform of height 2215 mm constructed at PFBR for erection of Generator circuit breaker during construction stage was suitable for AREVA Make FKG-1XP model, whereas the Model of GCB supplied to site is AREVA, FKG-1XV. Due to additional platform area requirement for taking up erection of GCB model no FKG1XV-Areva make and to integrate with 21kV Isolated Phase Bus Duct (IPBD) running from Turbo generator to GT & UAT 1 & 2, structural modification/ extension & strengthening works carried out on existing platform at PFBR-BHAVINI site.

i.e.

- The existing GCB platform was raised by 430 mm in height in-order to match the centre line of IPBD to GCB centre line i.e. 39.7M.
- The Existing platform also extended by 1085 mm in Length in-order to accommodate centralized control cubicle, earth switch panels etc. along-with operating space for the supplied GCB model no FKG1XV-Areva make.

The erection, final alignment & pre-commissioning checks on "Generator Circuit breaker", Model No-FKG1-XV of AREVA make supplied by BHEL was completed within +/- 1mm of evenness at 8.5 M el in TB area. The measurement of timing for breaker operation for each pole during pre-commissioning checks carried out successfully and found to be well within the limit specified by manufacturer.

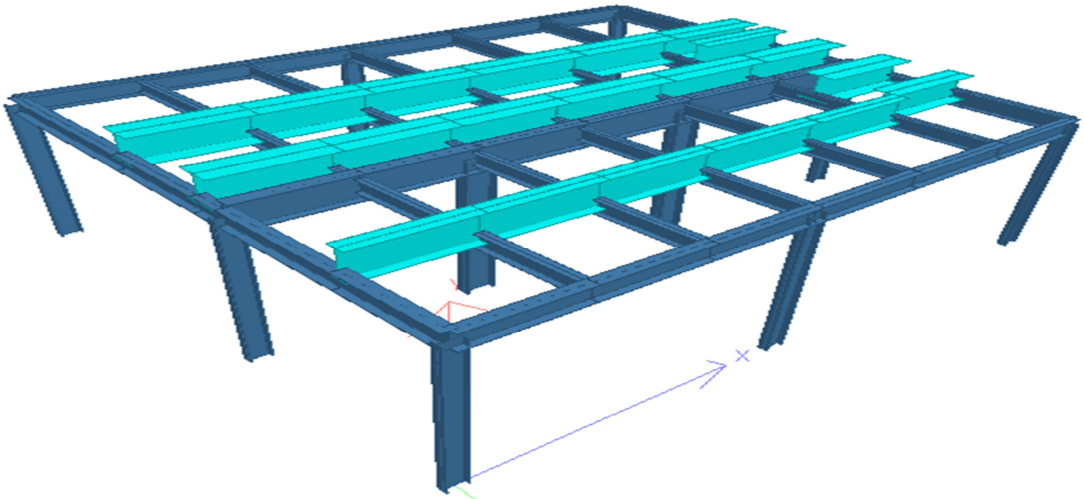
In-order to arrest the anticipated vibration of the platform during GCB operation, the existing platform was also strengthened by providing additional structural support after carrying out detailed analysis for structural integrity.

The existing GCB supporting structure platform was analyzed with given equipment load. The structural analysis and design reviews were carried out by using STAAD-Pro as per final inputs. Additional support structures were added for strengthening the same.

The Stad/pro model are generated as per the given sketches, the sketches are attached.

2.3.2 STAAD MODEL & 3D MODEL:

MODELLING VIEW



Dark Blue Structure: Existing platform Suitable for FKG-1XP model, GCB.

Sky Blue Structure: Additional supports provided for increasing the platform by 430mm & for extending the platform by 1095 mm for erection & positioning of FKG-1XV model, GCB of AREVA make.

3 6.6kV 4500kVA of Emergency Diesel Generator

3.1 Description of Emergency Diesel Generators: (EDG)

EDGs are critical safety component of Nuclear power plants because they provide electrical power necessary to activate and control reactor cooling and safety systems in the event of a Loss of Off-site Power event, and to prevent a critical Station Blackout (SBO) scenario.

500 MWe, PFBR has four number of Diesel Generator sets to provide power supply to safety and safety related systems through 6.6 KV Class III power supply system. Rating of each DG set is 6.6 KV, 3 phases, 50 Hz, 3600 KWs, 0.8 PF, 4500 KVA, 1000 rpm and are designed to meet the requirements of IEEE 387. The Class III power supply system is provided with two independent divisions located in Electrical Building-1 and Electrical Building-2 respectively. The two DG sets of a division are located in two different DG building. Diesel Generators are provided as on-site sources of AC power to feed the Class III supply system only for supplying the loads which cannot tolerate interruption in AC power supply for more than a few minutes following the loss of the Class IV (Offsite Power Supply) from the grid.
In the event of loss of the Class IV power supply, all the 4 DGs would start automatically through Emergency Transfer System (EMTR) and each one would feed its associated 6.6 kV bus section. The DG set takes approximately 10 seconds to start and can be fully loaded in another 10 seconds. The power supply to class III will be available within 20 seconds.

Various auxiliaries system such as lubrication oil, Fuel oil, starting air, Jacket water, Fresh air supply and exhaust gas system with turbo charger etc. are provided for each of DG. Thus each DG set is a standalone system.

Diesel generator is designed to operate without failure during Operation Basis Earthquake and after safe shutdown earthquake conditions.

3.2 Challenges in commissioning of DG sets:

3.2.1 Pre-Operational Tests on DG-1 (IEEE-387 Clause No. 7.3)

The following Pre-Operational Tests were carried out on DG-1 successfully.

1. Endurance and load test (IEEE-387 Clause No. 7.5.9)
2. Largest load and Design load rejection test (IEEE-387 Clause No. 7.5.7 & 7.5.8)
3. Hot restart test (IEEE-387 Clause No. 7.5.10)
4. Loss of offsite power test (LOOP) (IEEE-387 Clause No. 7.5.4)
5. Other tests such as DG's capability to operate in isochronous mode and reliability test for 25 valid starts.

3.2.2 Major experiences during commissioning of DG sets :

3.2.2.1 DG -1 hunting at the time of synchronization

During the commissioning phase of DG's, It was observed that every time during synchronization, there were severe engine hunting sound. This was observed even during the smooth synchronization time with no much sudden deviation in Grid frequency. The issue was analysed thoroughly and the problem was identified.

Problem was with the RAISE/LOW SPEED command going parallel from both Mechanical Governor EGB & Electronic Governor. Due to this both the governors are in action simultaneously and hence there is problem of Hunting.

In consultation with manufacturer of DG set, the RAISE/LOW Scheme for Mechanical governor was modified by introducing Electronic Governor Major Alarm contact in series with the governor motor connections.

So, only when Electronic governor fails and Major shutdown occurs due to both the speed sensors failure, the contact generated in Engine control panel will allow Speed Raise/Lower Motor of mechanical Governor to act. In normal conditions mechanical governor will not interfere.

The Electronic Governor to Mechanical Governor Smooth take over, in the event of Electronic Governor Actuator removal was checked and performance was satisfactory & stabilization of speed was observed by taking trials multiple times.

3.2.2.2 DG-1 Starting Issue:

During initial commissioning of DG's, it was observed that on few instances, particularly while operating from remote control room, DG could not start on start command. It was thoroughly investigated and was found that the start solenoid valves didn't pick up on start command due to voltage drop on DC supply. Moreover the coil also has high pickup voltage in the range of 85% - 110%. The coils of all solenoids with the pickup requirement of 70%-110% and drop out voltages of >10 %< 50% were provided in-consultation with the manufacturer of DG set and the DG were tested for several starts before conducting 25 starts reliability tests and found to be satisfactory.

3.2.2.3 Spurious Diode Failure Trips on DG:

During initial commissioning tests, DG#3 was synchronized to Grid from MCR to initial power level of 1.8 MW (50% Of DG Capacity), When we reached 2.4 MW, DG Breaker got opened on 86 (Lockout Relay). Subsequently DG#3 was synchronized to Grid from local panel, Again when we approached 2.4 MW; DG breaker opened on "DETECTION DIODE

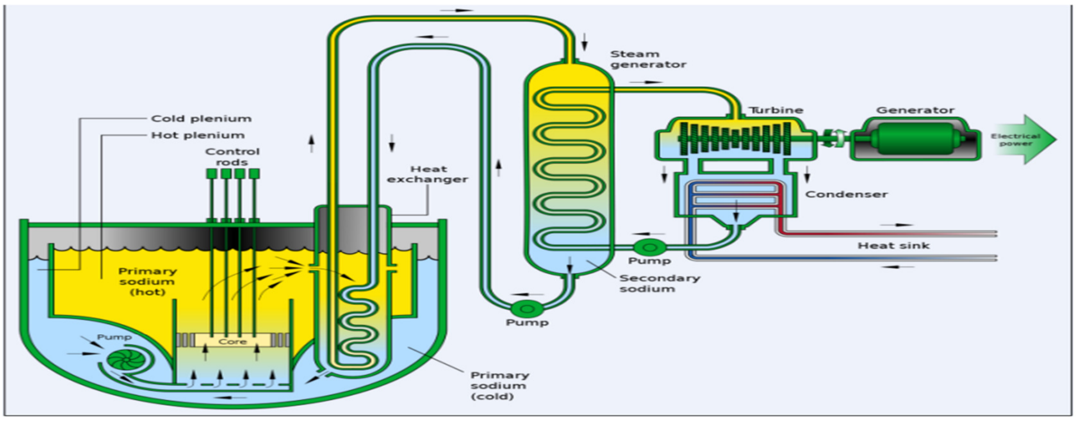
FAILURE" Alarm in AVR Cubicle. Ripples are recorded in Basier EDM 200 Module to a high level when the power in the range of 1 MW to 2MW.

On through investigation, it was found that ripple settings in the Basler EDM 100 Module were not done appropriate to this DG. The module was calibrated to the field current of the DG and the problem was resolved.

4. VFD Drives for Primary Sodium Pump

4.1 General description

The Primary sodium pump is a vertical, single stage, top suction, free surface pump with bottom sodium lubricated hydrostatic bearing and top thrust bearing. The pump impeller takes suction from the **cold sodium pool (670 K)** of the main vessel and discharges into an axial diffuser. High pressure sodium then passes to the delivery pipe, which connects the pump to the dia grid plenum (pump-pipe-connector) of the reactor. The sodium then traverses the fuel sub-assemblies and hot sodium from reactor core passes to the Intermediate Heat Exchanger located inside the main vessel and isolated from the pump. Sodium from outlet of Intermediate Heat Exchanger finally mixes with cold sodium pool of main vessel, thus completing a closed circuit.



4.2 Variable Speed Drive Power Supply System:

There are two Primary Sodium Pumps in the reactor for core cooling purposes. These sodium pumps are operated by Variable speed Drives. The normal rated speed operation of PSP Pump with drive is 590 rpm. Both the Pumps are in service during normal Operating conditions. These Drives are cooled by water system. VSD's are capable of operating at speeds of interval +/-1 rpm. The Pump is required to be operated at various speeds for Reactor Power control and Core Cooling Requirements, which is met by the VSD operation of PSP Pumps

4.3 Electrical Architecture of Variable Speed Drive System

The Primary Sodium Pumps 1&2 are fed from class-III Bus HVBeb52-100A and HVBeb52-200A respectively. However, the PSP Pumps are operated through VSD Drives only in class-IV Supply Available condition and is not the part of class-III Emergency loads. PSP's are not envisaged to be started from rest using DG sets due to provisions of pony motor and the pump running under loss of offsite supply.
On loss of Class IV supply, PSP's coast down to 20% speed from 100% speed due to flywheel action in 32 sec and the speed reduces to 15% in 45 sec. The PSP's are provided

with hydrostatic bearings and the PSP's are required to be operated at least at 15% speed to prevent damage to bearing.

The Variable Speed AC Drive Motor with integral flywheel is connected to the primary sodium pumps. The flywheel is designed to supply the adequate energy for achieving the flow coast down from the operating speed to half the speed in 8s (flow halving time).

There is a 45KW Squirrel Cage Induction Pony Motor with the rated speed of 1500 rpm and operating Speed of 98 rpm (with Reduction Gear), which engages with PSP motor shaft when the speed of Main PSP Motor coasts down and reduces to 98 rpm, this is done through a overrun clutch. The over-run mechanical clutch disconnects the pony motor from the main drive motor when the speed of the main drive motor is greater than 17% of the rated speed.

The VSD drives of PSP are 4942KW Vector controlled Variable speed Drive. Two separate controls are provided namely torque component and Flux component which are physically decoupled.

4.4. Experiences during commissioning:

4.4.1 Glitch in Encoder Issue:

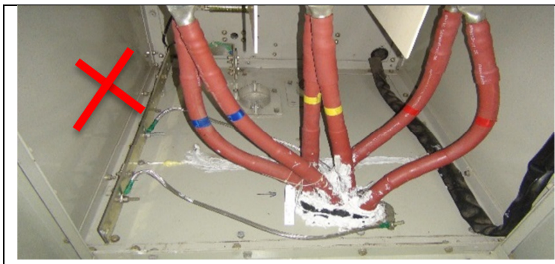
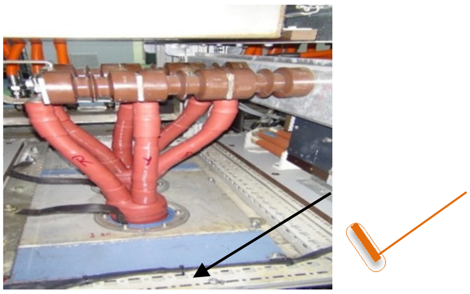
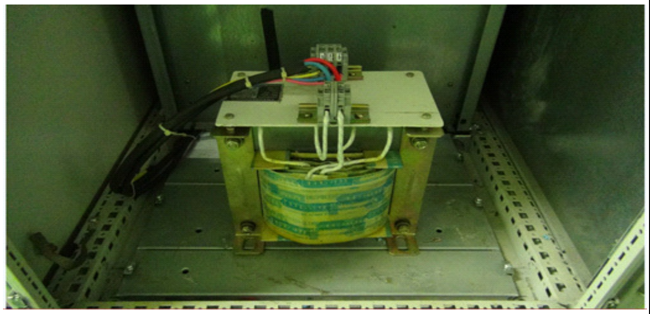
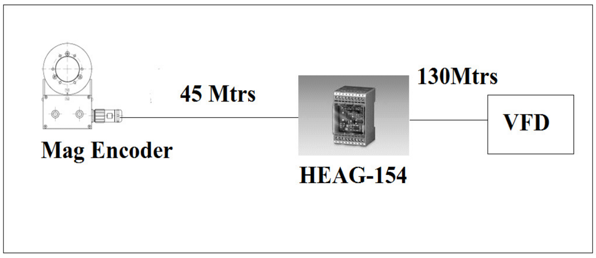
The Closed loop speed control of drive is implemented by connecting 2 Nos. of redundant Magnetic incremental encoders MHGE 200 at the PSP motor shaft and the signal is wired to VSD Cabinet. The length of cables between the Motor encoder and Drive cabinet is around 188mtrs. which resulted in poor signal strength from encoder and the drive tripped due to 'Glitch in Encoder' FAULT. The signal from encoders were verified by checking K1, K1', K2, K2' Signals from both the encoders. The signal strength was improved by introducing Signal Repeaters at a distance in between the Drive and motor.

4.4.2 EMI Interferences in VSD System:

PSP Pump is operated by 3600kw VSD Drive and SSP Pump by 2700KW VSD Drive. There are 2 no. of PSP's and 2 no. of SSP's in the plant. The Commissioning of VSD System was started for the first time with PSP-1 Drive Panel along with the supplier M/s BHEL and M/s INGETEAM. During commissioning of VSD Drive, VSD was successfully pre-charged to 5600Vdc, but subsequently a spurious fault was appearing frequently every time VSD was brought to RFR (Ready for Run) condition. However on starting the Motor, Firing pulses were injected for a very short duration and the drive was observed tripping on "Semiconductor Error".

Later the Drives of PSP-2, SSP-1 and SSP-2 were also subsequently tested, each of it had shown similar behaviour. Based on the commissioning experiences of M/s Ingeteam, it was suspected that the Drive was picking up external noise from nearby environment. BHEL along with M/s INGETEAM advised a set of modifications to avoid the electromagnetic interferences on the system.

The following modifications were carried out on the installation of the system to avoid the EMI issues on the drive.

	**HV cable glanding modified to Roxtec Glands:** ROXTEC Glands gives excellent protection for disturbances conducted by the armour or screen. Roxtec modules are used for shielding purposes giving protection up to 40GHz and more for **radiated interference**
	**All Control Cable glanding modified to ROXTEC Glands:** Roxtec Type gland provides all cables routed through a single entry plate and not spread around an enclosure. This single entry point minimizes the risk of circulating ground currents as all cables are earthed in the same point where the Roxtec frame serves as earthing bar enclosing all the cables
	Un grounded Power supply was provided to VFD for both High Voltage and Control Voltage. ➢ Secondary side Star winding of Converter Transformer neutral was ungrounded. ➢ 230V AC Control supply to VFD MCU and control cards was derived from separate isolation transformer.[Though Station UPS is having ungrounded Neutral , any effect due to Load side earthing (IMD not commissioned during that stage), should not affect the UPS power supply to VFD]
	Encoder Cabling in site was done through a twisted pair cable; however 2V Drop was observed in Encoder supply; Due to that there was significant signal loss. The distance between encoder and drive is 200 Mtrs; A Repeater unit HEAG154 was installed at 70 Mtrs from Motor at Local control panel in RCB-55.0Mtr elevation.

After carrying out all the above modifications, the spurious fault signal "Semiconductor Error" was found not generated in VSD Panel. These modifications infact has improved the performance and reliability of the VSD System.

5. 415V MCC, HCC panels:

5.1 Description of system

The PFBR plant consists of 274 Nos. of LT panels of 415V AC, 415/220V No break AC, 48V DC & 220V DC panels for supplying power supply to the connected loads of Class-IV, III, II & I category of normal, emergency, safety, safety & safety related and lighting loads etc.

Heater loads of rating varying from 0.4KW to 60KW required for pre-heating of primary & secondary sodium system equipment & pipe lines, component handling system equipment, de-contamination vessels, failed fuel location modules etc. of the PFBR-BHAVINI Station are fed from Heater Control Centres. The total no of heaters & their power supply requirements for various configuration to match heater power requirement are quite large in PFBR.

PFBR consists of 104 Nos of MCCs, 37 Nos of HCCs, 34 Nos of HITs, and 18 Nos of ISBs, 46 Nos SDBs & 35 Nos of MDBs located in Main Plant building at different elevations / locations & floors. MCCs pertaining to PFBR are 415V 3-ph & 3 wire, draw-out, bottom entry & compartmentalized type normally.

HCCs pertaining to PFBR are 3-ph 4-wire, draw-out, bottom entry, compartmentalized type. HCC panels are fed from HIT panels. In PFBR, The HCC bus voltages are 415V L-L, 220V L-L, 110V L-L and 63V L-L. The BUS configurations of HCC panels are 3-ph-4w system with ungrounded neutral. The HIT panel consists of one 3-Ph delta/ star transformer. The LV side of HIT transformer is connected to incomer of HCC panel.

The bus voltages of HCC panels in PFBR is 415V L-L, 220V L-L and 110V L-L based on the power rating of the heater loads/ wattage requirement. The voltages have been assigned considering surface area & length of pipe lines etc. The required voltages are obtained from the step down transformers available in the associated HIT panels.

5.2 Modification during detailed engineering, erection & commissioning:

274 Nos. of panels were erected in Main Plant buildings at different locations and elevation after working out optimum equipment layout drawings. Based on the actual dimension of panels, the space requirement for different panels in the room, working clearance around the panels, maintainability, segregation requirement (i.e.) physical separation and functional isolation to protect the division criteria were considered to fulfil design criteria for all class IE power supply system. A minimum of two independent divisions were provided so that each division shall have necessary reliability, capacity, capability to permit the system it serves to fulfil their safety functions. During detailed engineering stage itself, through review was carried out with respect to site floor opening availability, technical requirement, non-availability of floor opening, conversion of dual bus voltage HCC, conversion of MCC panels to cater 1_ph loads etc. and optimum GA drawing and panel layout drawing worked out and approved to take up manufacture.

5.2.1 Erection of panel in back-to back fashion:

The cut-out / floor opening at site was available at a distance of 500 mm separated by beam. In-order to erect the bottom entry panels in the existing cut out, the entire single front panel was split in to two sections & positioned in back to back fashion in close proximity & separated by a distance equal to beam depth (typically-500 mm). Both sections were physically interconnected by using horizontal top mounted bus-duct.

5.2.2 Dual bus-voltage HCC:

The required voltage level for pre-heating circuits of Na lines & tanks are 415V, 220V, 110V &63V Line to Line due to different sizes of heater lengths as per the erected size / diameter of the pipe lines. In-order to cater required power supply at required voltage level, some of the HCCs was converted to dual voltage sections by introducing a step down transformer. By using dual voltage HCC in same floor, the requirement of additional HCC panels could be reduced thereby available space was utilized in optimum manner.

5.2.3 3ph-3Wire & 3 ph-4 wire MCC for 3-Ph loads and single phase loads:

The specified voltage level for all electrical drive loads in PFBR is 415V, 3-Ph 3 wire in balanced configuration. Some of the actuators for critical safety related equipment were supplied with 1-ph actuator motors for special application. For operation of the electrical actuator single phase power supply is required in MCCs. Therefore the MCCs are designed with a Dyn11 transformer of adequate capacity to accommodate inside the panel to drive neutral for the required loads.

5.2.4 Conversion of bottom entry panel to top entry panel.

The MCCs erected for PFBR are single / double front with bottom entry type based on cut-out / floor opening availability. Some places, the floor opening is not available as per the requirement of panel due to revision of lay-out or due to fouling of other heavy equipment in the panel rooms. In these areas, the panels were converted to top entry type instead of bottom entry as there is no feasibility for floor cutting etc. for cable termination / glanding.

6. Electrical Preheating system:

The electrical Preheating system is required to raise the temperature of primary and secondary sodium system pipe lines or equipment from ambient temperature to the required temperature in the given duration and also to maintain the pipe line / equipment at required temperature. Mineral insulated stainless steel sheathed heating cables are used for electrical preheating of sodium pipes and vessels in PFBR. Number of heating cables are connected in series or parallel and are grouped depending upon the pipeline / tank heater power requirement and the operating modes. The Primary & secondary sodium circuits line heaters are provided with ungrounded power supply so that heater failures resulting in grounding of heating element with associated pipeline / tank would not result in flow of fault current to the pipeline / tank and possible sodium fire hazard can be avoided.

To provide ungrounded power supply to heaters from station 415V grounded power supply, Dry type isolation transformers are provided whose secondary neutral is ungrounded and provide 4 wire supply distribution. Insulation monitoring devices (IMD) are provided for supervision and measurement of insulation resistance, detection and location of earth fault. A low frequency signal is injected by the IMD. The requirement of major components XM300C injector XLI300 interface device and EGX Ethernet Gateway of IMD worked out in detail based on site conditions and optimum configuration for achieving reliable insulation monitoring & communication of fault location for ungrounded network. IMDs increase personnel and equipment safety and availability.

During pre-commissioning checks of Na purification circuits, the adequacy of existing heater power in the As built piping circuit due to site changes, thermal power requirement for the pipelines, valves, components, uniformity of heat developed over the piping circuit found to be inadequate. The selection of heater ratings for the particular Na (sodium) pipe length varying from 200mm to 20 Mtrs. and diameter varying from 50mm to 600mm was a challenging job. Also the sequential heating of critical sodium circuits especially small dia. pipeline for proper draining and reheating of Na lines was posing herculean task, for selection of heater and associated power supply distribution by considering site conditions and the process requirement. In order to achieve the required heater power in all the sodium circuits detailed analysis was carried out and modification such as augmentation / change of Heater Isolation Transformer capacity, up-gradation of HCC feeder cables sizes, switchgear feeder ratings, operation of heater up to maximum designed capacity by proper regrouping of heater, increase of insulation thickness for the pipelines, replacement/ addition of heater, independent heater provision for valves were worked out and implemented at site.

CONCULSION:

Being the first of its kind project with high technology, various challenges cropped up during detailed engineering, construction and commissioning of electrical equipment of PFBR were analysed and interface issues were meticulously addressed for smoother commissioning activities. These rich experiences gained over the years helped in optimum utilisation of inhouse engineering skills for the analysis and commissioning activities. Unrelenting efforts in resolving such issues forms a solid feedback and gives us confidence to accept new challenges to work out engineering details for proposed two Fast Breeder Reactors of 600 MWe capacity with new design.