Generator Termination Bus-bar Arrangement - Design requirements: Utility Perspective

D. K. Chaturvedi (NTPC)
Harshvardhan Senghani (NTPC)
K Venugopal (CS Electric)

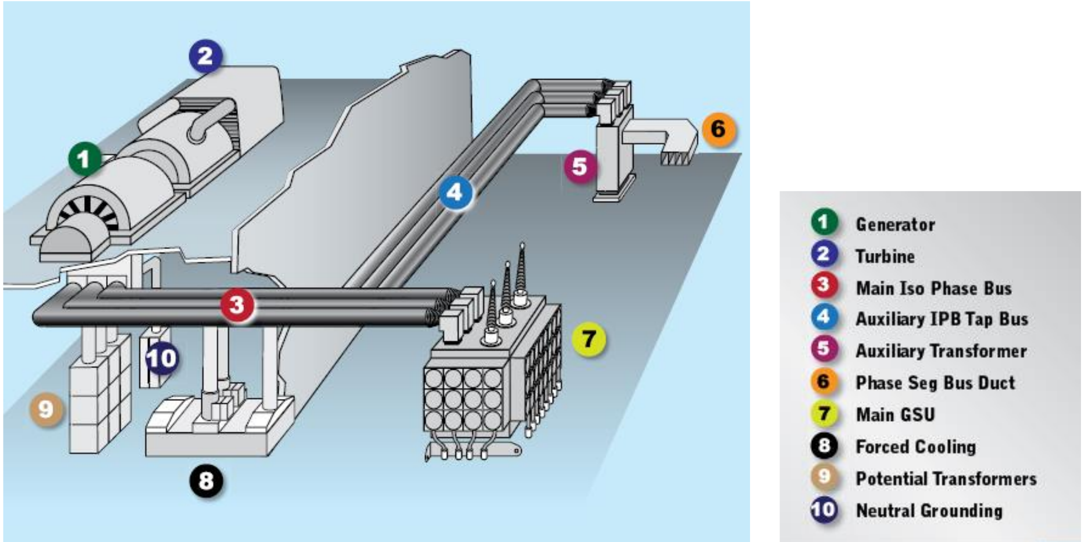
This paper appraise user on the termination arrangement design of large turbo generator. As the turbo generator size increases, generator termination design becomes critical due to limited space availability below the generator in Turbo Generator deck. The connection of bus-duct is partly have phase segregation and thus experiences very high forces on the bushing connections. As the generator size increases, a large number of flexible connections are required to carry continuous current in range of 20-25kA. In order to facilitate high conductivity bus-bar connection carrying 20kA to 25kA current, it is necessary to connect 36 to 48 flexible connections between the generator bushing stem and Isolated Phase bus-duct palms. The termination arrangements has to be designed to connect 36-48 numbers of flexible connections per phase to the generator bushing thus arising need of suitable connection piece assembly mounted on the generator bushing. This connection piece assembly has to be adequately sized to ensure termination of all flexible connections having a width of 50-80 mm. The design of this connection piece assembly should be such as to ensure sufficient air clearances between adjacent phases as well as between phase to earth to avoid any insulation failure caused by switching surge or lightning surge.

The Orientation of bushing as well as spacing between adjacent phases connections is critical. The adequacy of bushing design along with a) large additional static weight of connection plate or connector piece and also b) weight of connection flexibles in large numbers (36-48 numbers being terminated on the connection piece at generator bushing) has to be reviewed by expert.

It has been seen that each flexible connection occupies a width of 50 to 100 mm and thus needs adequate peripheral surface on generator bushing connection. As a practice many of the Generator manufacturers do not provide the connection arrangement and therefore never carryout detail analysis to establish adequacy of termination arrangement during a three phase short circuit fault right at the generator terminal. This detail analysis covering thermal, mechanical and electrical stress at generator termination arrangement, if not done properly could results in a major failure and severe damage to the generator stator winding. It would be appropriate that generator manufacturer provide bushing with suitable connector and do the necessary analysis establishing the suitability of bushing design to withstand stresses arising out of worst case failure.

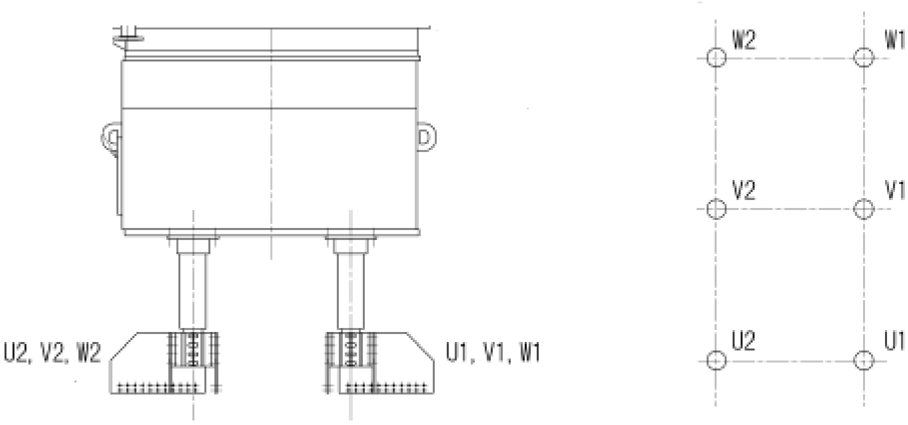
It has been seen that various manufacturers have not only different orientation of phase bushing connection but also generally not provide complete solution for bus-bar connection with generator bushing. It is very important to understand effect of clearances between phases and effect of short circuit forces during any three phases to ground fault. This paper elaborates a few cases, where solutions to take care of electrical and mechanical stress experience by the bushing during a transient condition have been worked out.

Unit size of 660/ 800 MW and above are quite common now-a-days. These large generators have star connected windings and star point is formed outside the generator. Corresponding to each phase winding two terminals are taken out of the generator frame. 6 terminal bushing are available outside the generator frame of these 3 form the star point at neutral end and the output is taken from other 3 line terminals. Typical installation is as shown in figure (1).

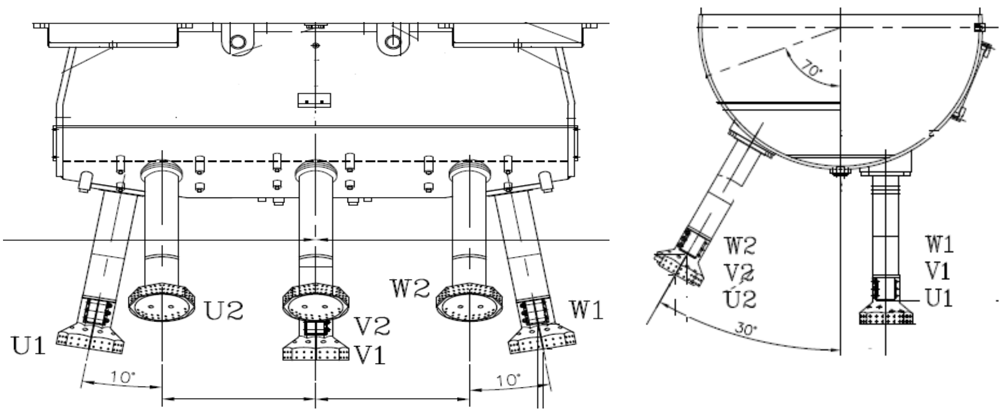


(1)

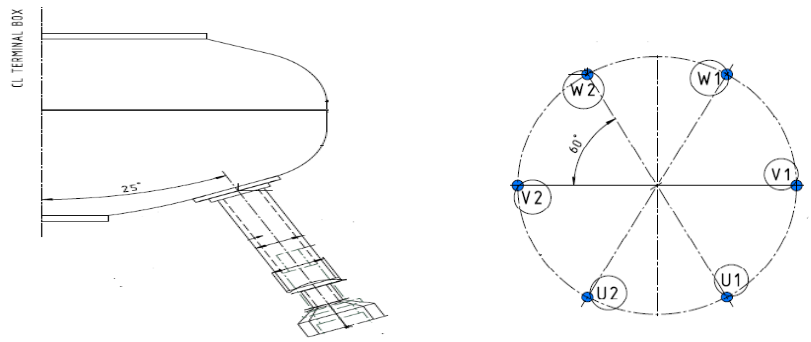
Relative position of the terminals on generator frame is as per manufacturer's standard design. It is desirable that line end and neutral end terminals are located as far as possible to have the ease of making connection of isolated phase bus to the generator. Typical arrangement of generator terminal bushing for large turbo-generator of size 660 MW and above from different international manufacturer's viz. Alstom, Toshiba, Hitachi, Siemens, BHEL etc. is as shown in figure (2).



2- (a)



2-(b)

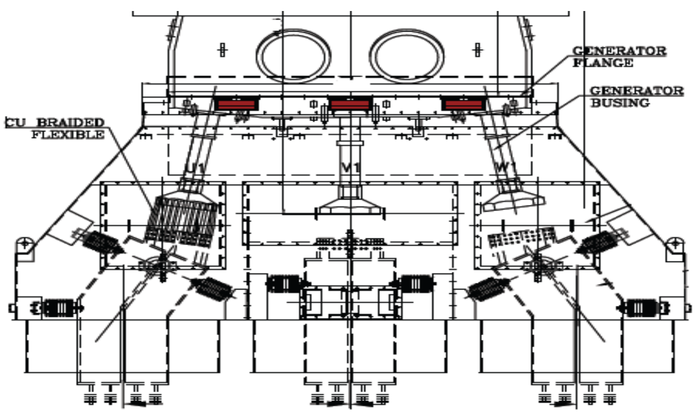


2-(c)

There has been extensive development of generator connection designs since their introduction because of larger generating sets and the consequential increase in load and fault currents. Typically value of the rated load current for 660 MW turbo generator is 22 KA and IPB main run fault level is 450 KA peak. Phase to earth faults produce fault current which is restricted by the neutral grounding equipment. However, there is always the possibility of an earth fault developing into a phase to phase fault which causes much greater damage; it is therefore preferred to use isolated phase bus system.

The principal function of the Generator Terminal Connections is to connect the Generator to its associated generator transformer though IPB and unit electrical system through Unit transformer via Tap of Busduct. The rating of the main connections installation is established on the basis of temperature rise above a specified ambient at rated current and its ability to withstand both three-phase short-circuit and earth fault conditions anywhere on the generator voltage system without damage. These requirements introduce some complication in the system design in order to achieve high integrity. The forces caused by short-circuit and earth fault currents are very complex. The forces produced differ greatly, depending on whether the fault is three-phase or single-phase, the three-phase fault being more onerous.

The circulating enclosure current in IPB creates its own surrounding magnetic field which must be in antiphase to that produced by the conductor, thus the magnetic field still exists within the enclosure but is cancelled outside it. Since the enclosure has resistance, the resultant external magnetic field around to each conductor is about 10% of that which would occur if there was no metallic enclosure. Since the external magnetic field has been reduced, it follows that the forces between conductors are also reduced by a similar proportion, as will be the forces between enclosures that exist due to the current flowing in them. However, end effects occur where the conductor is connected to its associated piece of plant/equipment and is, for practical reasons, unshielded. Therefore magnetic fields at these points are much stronger and forces greater. Typical termination arrangement of IPB on generator terminals is shown in figure (3) where it can be seen that IPB enclosure terminates on generator terminal box and IPB conductor to bushing connection piece assembly connection is unshielded.



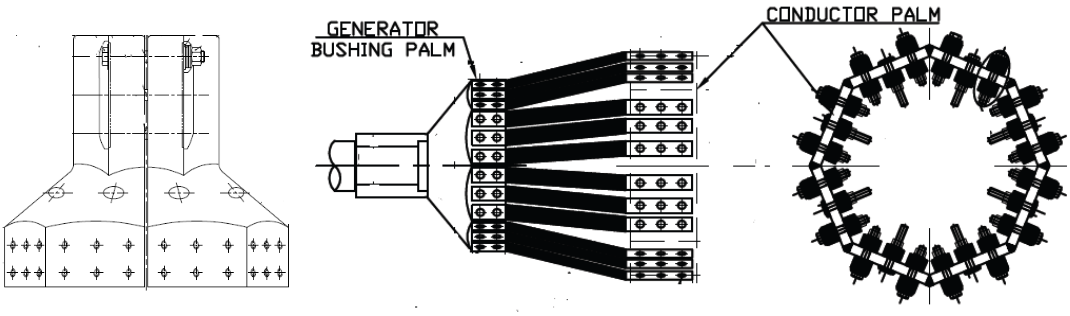
(3)

Enclosures are therefore connected to auxiliary equipment viz. Generator/transformer via rubber bellows which maintain the physical protection of the conductor but isolate the enclosures electrically from the equipment. The short-circuiting of the enclosures is done as close to the end of their run as possible. The external magnetic fields produced by the conductor currents can link with conducting loops in the adjacent steelwork, producing circulating currents and heat. This is a problem to be considered by the designer since excessive heat, in addition to being an unnecessary system loss, can cause unacceptable expansion and can be a hazard to personnel if the steelwork is touched.

Simplified mathematical analysis of currents, fields and forces experienced by main connection design is possible. However, mathematical analysis does to not give exact analysis of the forces under condition of short circuit. The major design concern arising from fault considerations is mechanical strength. The designer must provide a suitable support arrangement for the termination arrangement to ensure that the final: structure is of adequate strength to withstand the forces that are exerted on the system during fault conditions.

It is pertinent to note here that usually generator manufacturer and busduct supplier are separate. Busduct supplier ensures the adequacy of the busducts wrt thermal limits as per specifications and short circuit forces and also usually the busducts are type tested establishing the design requirements. However, the complete analysis of the termination arrangement is not carried out wrt design requirements of the connection plate/piece assembly, clearances between phases and phase to earth, weight transfer to bushing due to connection plate/piece assembly and flexibles and adequacy of the complete termination arrangement wrt static and dynamic loading which will be experienced during the fault condition. Any support given to the connections should be independent of the machine to prevent the transmission of vibration. Early design coordination at the interface connection onto the machine is necessary to solve the problems associated with terminal spacing and ensure that the specified impulse-withstand level can be achieved.

Of the several busduct termination arrangement used in various NTPC power generating stations one case is where generator manufacturer has provided the octagonal connection piece assembly as shown in figure 4 for connecting the busduct flexibles.

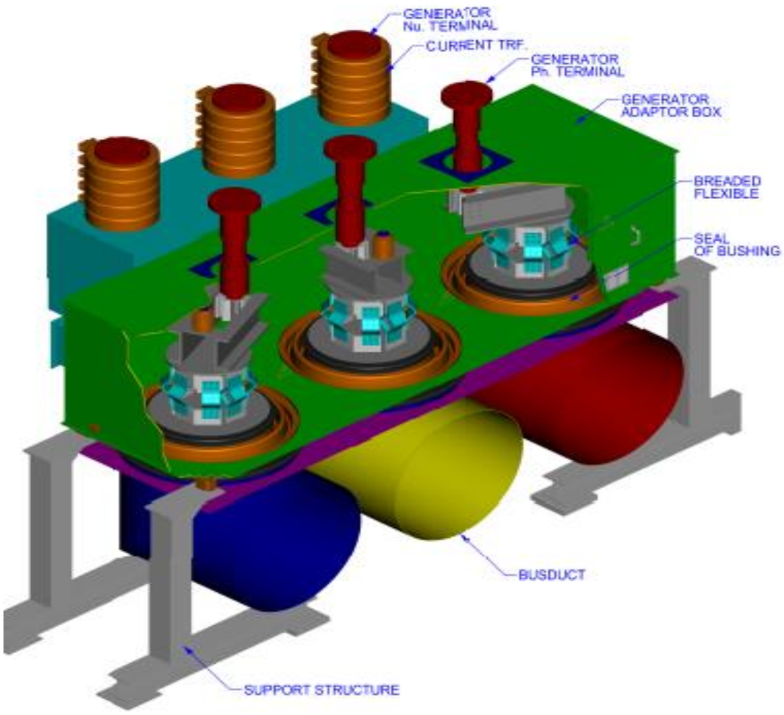


(4)

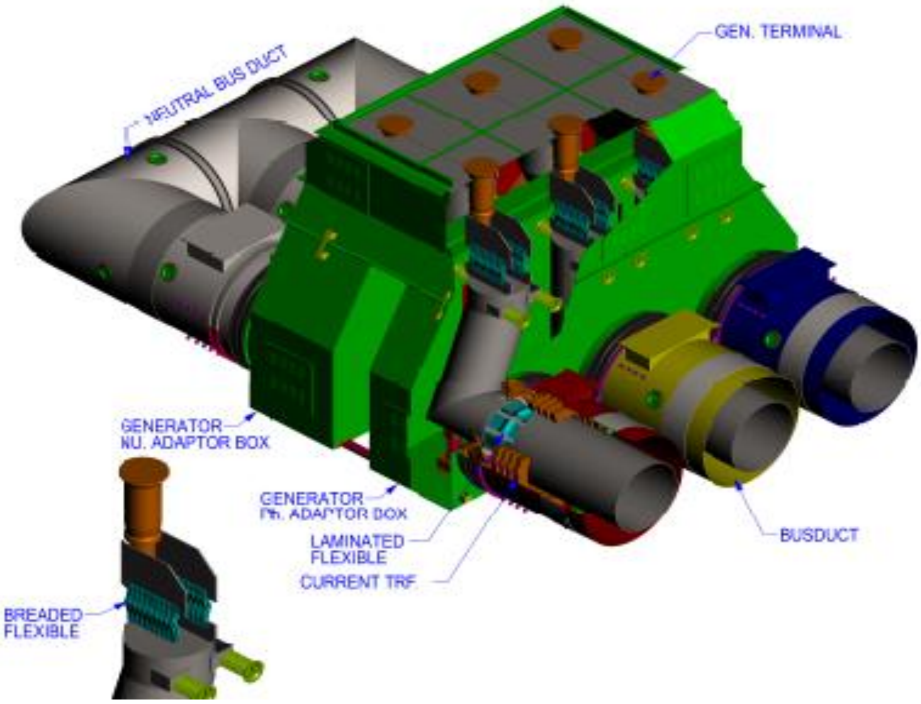
In such cases octagonal palm is constructed on IPB conductor end for connecting the adequate number of copper braided flexible to generator terminal. The mating surface of the generator terminal as well as the copper flexible connections are silver coated with a thickness of 10 microns to facilitate low contact resistance. Properly designed bolted bus bar connections provide satisfactory service. Bolting is used as connections may be periodically broken during maintenance activity.

Careful selection of the braids is necessary to ensure that there is adequate current-carrying capacity and that they are capable of operating continuously at the maximum specified temperature. Consideration should be given to: (a) The length of braid compared to ensure that there is adequate flexibility (b) The number, size and position of the fixing holes on the crimped ferrule at flexible ends (which affects the clamping pressure on the joint and hence its current-carrying capability) (c) The ambient air temperature within the terminal enclosure

Complete termination arrangement is housed in generator terminal adaptor box as shown in Figure (5)



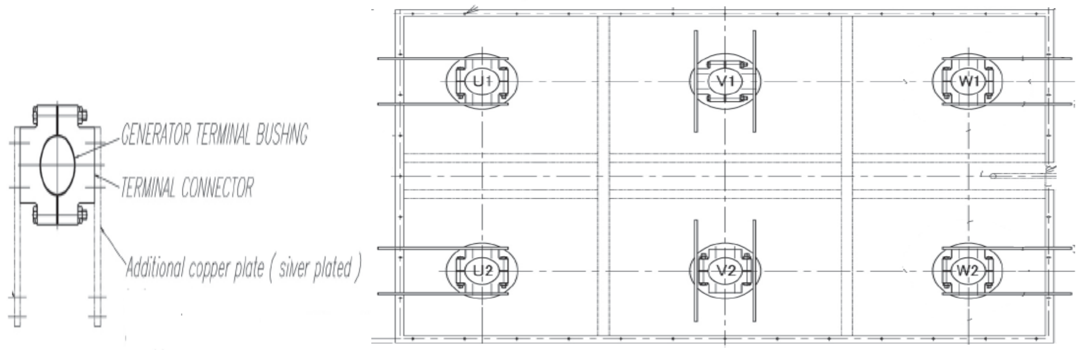
5- (a) Generator Connection with adaptor Box for Line side only (Neutrals are shorted at Generator terminals itself)



5-(b) Generator Connection with Terminal adaptor Box for Line side/ Neutral side

Further it is recommended that necessary arrangement is done in the adaptor box for the hydrogen escape for hydrogen cooled generators in order to avoid explosions in the event of hydrogen leakage from generator. Suitable skirting/covering provided on the upper most end of the adaptor boxes to prevent any entry of insects and to also allow escape of hydrogen.

One other termination arrangement is where copper plates are used as connection surface for busduct flexibles (Figure 6).



(6) Termination arrangement with copper plates as connection surface

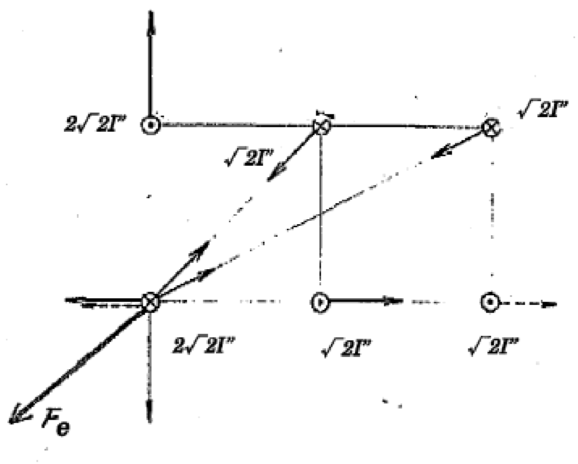
In this case it is important to ensure at design stage the correct clearances between phases and phase to earth as the copper terminal plates are not connected identically to each phase bushing terminal connector. Adequacy of the generator bushing wrt enduring the electromagnetic forces during sudden short circuit fault was checked mathematically.

Simplified analysis is presented below:

Step (1): Peak short circuit current calculated as per

$$Is = \sqrt{2}\left\{(I''-I')e^{-\frac{t}{T''}} + (I'-I)e^{-\frac{t}{T'}} + I\right\}\cos(\omega t-\alpha) - \sqrt{2}I''\cos(\alpha)e^{-\frac{t}{T_{dc}}}$$

Step (2): Electromagnetic force/Bending moment on bushing is calculated



Calculation model of Bushing alignment

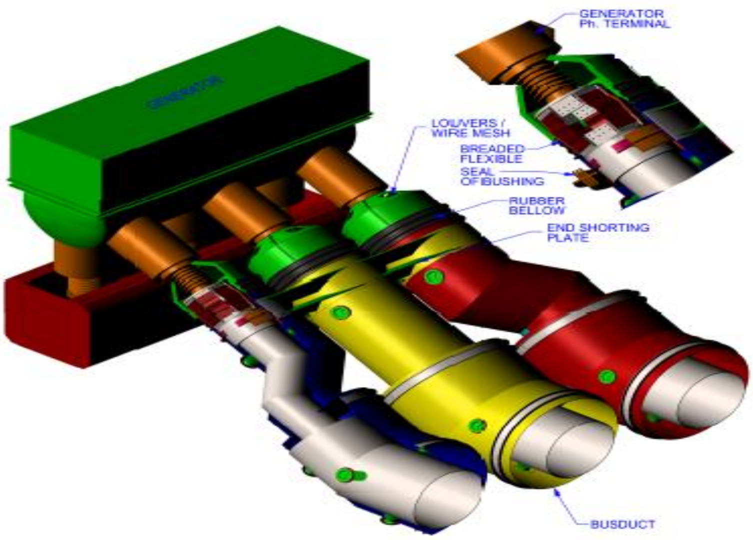
Step (3): Bending moment due to copper plates calculated

Step (4): Effective bending moment experienced by the generator bushing checked wrt selected bushing design allowable maximum bending moment

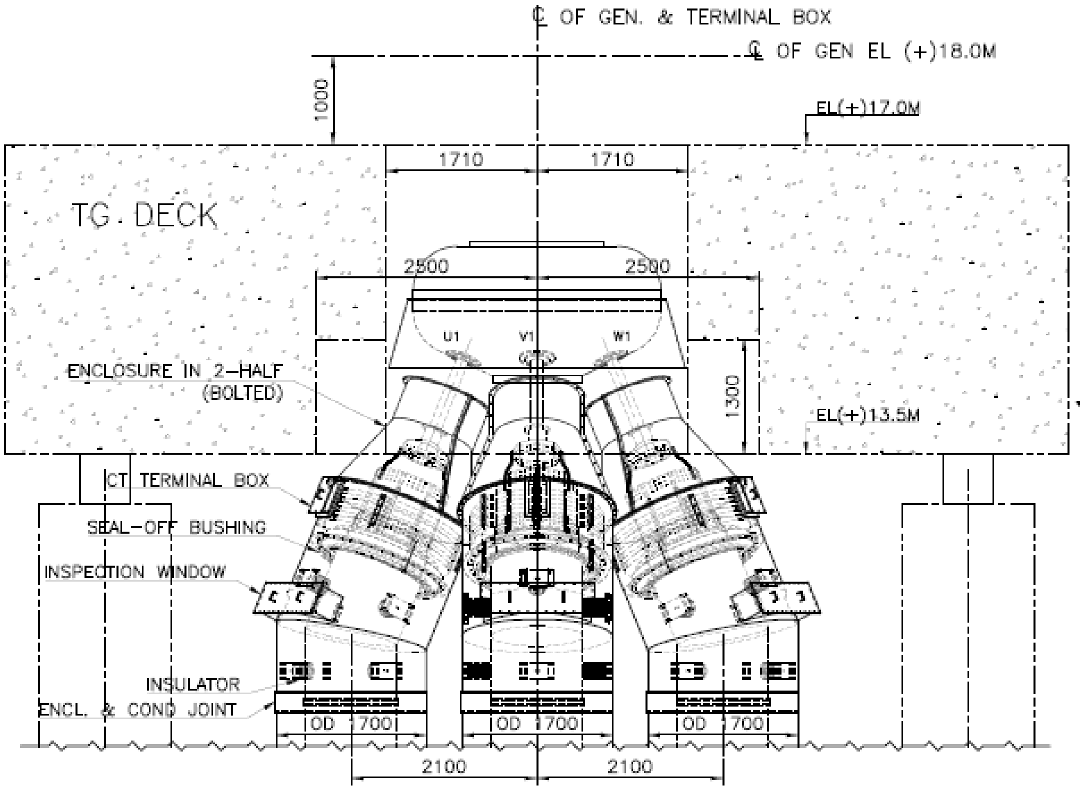
Other critical aspect is to manage the termination arrangement in limited space available below the TG deck between the TG columns. The obvious obstructions which require to be negotiated while taking out line end connections from generator terminals are, for example, the generator foundations, generator/turbine auxiliary equipment, access ways, etc. Other practical issues to be resolved at the generator terminal connections are heat dissipation due to confined space, access for stator cooling pipework, etc. The stray magnetic fields surrounding the main connections can give rise to inductive heating of adjacent steelwork. It is not only structural steel-work which may cause problems, but also piping and pipe hangers, gas and air ducts as well as stairs and handrails. Heating of such components could ignite adjacent flammable material, be a danger to personnel, cause structural stresses due to restrained expansion, and of course, incur additional running costs due to the losses. Care is taken well in advance for routing of the oil piping so as to allow access of maintenance and avoid fouling of the same with busduct adaptor box. Bolted access doors when provided on the terminal box is duly connected with the adaptor box thru properly sized copper earthing flexible to avoid any heating of access doors bolts. All hardware used in the assembly of generator terminal connections is non-magnetic. An adequate structural support is required for the enclosure to withstand the resultant static and dynamic loadings that the system will experience during fault. Electromagnetic vibration should receive careful study since buses with short spans and relatively rigid supports may have natural frequencies that coincide with the natural frequency or a harmonic of the current.

Current transformers (CTs) used in Protection system, tariff metering, etc. are located in Line side and Neutral side IPB runs or on Generator bushings. The design of the CTs must be such that they do not reduce the electrical impulse-withstand level or the power frequency withstand level of the installation. Adequate support and bracing of the CTs is required as a typical assembly is heavy; a neutral CT assembly may weigh 600-700 kg and a line CT assembly 400-500 kg. Sufficient ventilation must be provided to ensure that the heat produced in the windings does not cause unacceptable temperature rises. Any forces exerted on the CTs during fault conditions will be limited to those attempting to centralize them around the neutral line of the enclosure. These are not significant if the CTs are mounted concentrically. There will be little, if any, axial force exerted on the CTs and this is easily contained by the mountings.

Where space is restricted, it may be necessary to consider the use of specially designed sections of IPB having reduced conductor and enclosure dimensions as shown in Figure (7). Typical dimensions are also shown to bring out the criticality of the design wrt space limitation.



7-(a)



7-(b)

Conclusion:

Utility experience wrt design of generator termination arrangement is discussed in detail in the paper. Key aspects viz. short circuit forces on bushing connections, design of connection piece assembly, Orientation of bushing connection plates/piece and HV clearances that need to be taken care in the design are brought out to ensure the adequacy of the termination arrangement. It is suggested that user must ensure complete solution for the IPB termination arrangement on generator is designed with careful analysis by collaborative effort from generator manufacturer and busduct supplier. Improper termination connection design may result into the catastrophic failure during the generator operation.