DESIGN AND INTERFACE OF GIS FOR AUGMENTING CAPACITY OF EXISTING AIS IN HIGHLY URBANIZED AREA

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the
Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

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May 2014

Undertaking For Originality of the Work

I, **Mr. Vijaysinh R. Shinol**, (**Roll No:12MEEE27**), give undertaking that the Major Project entitled **"Design and Interface of GIS for Augmenting Capacity of Existing AIS in Highly Urbanized Area"** submitted by me, towards the partial fulfillment of the requirement for the degree of Master of Technology in **Electrical Power Systems**, **Electrical Engineering**, under Institute of Technology, Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of Plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that **Mr. Vijaysinh R. Shinol** (Roll No. 12MEEE27), student of M.Tech in Electrical Engineering (Electrical Power Systems) of Institute of Technology, Nirma University, worked in Takalkar Power Engineers & Consultants Pvt. Ltd. (TPEC), Vadodara as a project student during the period of July 2013 to May 2014.

During this he carried out work pertaining to his thesis titled **"Design and Interface of GIS for Augmenting Capacity of Existing AIS in Highly Urbanized Area"**, under our guidance.

According to our assessment he has put in good amount of working days and has completed his work to our satisfaction. We understand that this work is towards the partial fulfillment of the syllabus for Master Degree in Electrical Engineering (Electrical Power Systems) of the Nirma University.

We wish him all the best for his all future assignments.

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- Vijay R. Shinol
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Abstract

Due to increase in power demand, load on substation is increased day by day. In urban substation many a time it is not possible to provide extension to existing air insulated substation due to non availability of space to accommodate additiona bays. In such case GIS extension is the only viable solution.

In GIS extension the cables are drawn from the existing bus and they are connected to GIS equipment. There after depending upon the requirement, the GIS equipment is either connected to step down transformer or step up transformer and feeders are taken out for connection to grid.

The extension of GIS from existing AIS substation need much engineering and also requires background of the equipment available in the market. Control and protection system of such expansion of GIS need critical review. Similarly operational configurations of GIS extension is different than those of independent AIS and GIS substation / switchgear also the Civil and structural work of such substation is a precise job.

The project work examines various aspects of such GIS extension for given voltage class and brings out detail engineering and construction feature of such substation.The study will include equipment specification, retrofitting in the existing AIS (if it is an extension) and interface between AIS and GIS.

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Abbreviations

AIS Air Insulated Substation
BPI Bus Post Insulator
CT Current Transformer
DSLP Direct Stroke Lightning Protection
EHV Extra High Voltage
GIS Gas Insulated Substation
HT High Tension
HV High Voltage
IDMT Inverse Definite Minimum Time
LA Lightning Arrestor
LT Low Tension
MTS Mixed Technology Switchgear
MV Medium Voltage
ONAN Oil Natural Air Natural
HIS Hybrid Insulated Substation
PT Potential Transformer
SCADA Supervisory Control And Data Acquisition
TRV Transient Recovery Voltage

Nomenclature

I_{pn} .... Primary Current
I_{sn} .... Secondary current
I_r .... Rated Current of the Protection IED
I_{fmax} .... Maximum Fault Current
R_{CT} .... C.T. Secondary Resistance
R_L .... Lead Resistance
R_b .... Relay Burden
V_{kmin} .... Min. Knee Point Voltage
ρ .... Resistivity of Soil
ρ_s .... Surface layer Resistivity
C_s .... Reflection factor
t_s .... Duration of Shock for Determining Allowable Body Current
R_g .... Spacing Factor For Mesh Voltage
D_f .... Decrement Factor For Determining IG
K_m .... Grid Resistance
L_x .... Length of Conductor in X Direction
L_y .... Length of Conductor in Y Direction
K_{ii} .... Corrective Weighted Factor
K_i .... Irregularity Factor
E_m .... Mesh Voltage
L_r .... Length of Ground Rod
E_s .... Step Voltage
K_s .... Geometrical Factor
L_R .... Total Length of Ground Rod
h_x .... Height of the Object to be Protected
h_a .... Active height of the Object to be Protected
r_x .... Radius of Protective Zone
Q .... Conduction heat flux
K .... Thermal conductivity
T_s .... Surface temperature
T_{sur} .... Surrounding temperature
T_∞ .... Fluid temperature
ε .... Emmisivity
β .... Volumetric thermal expansion coefficient
C_p .... Specific heat
μ .... Viscosity
ν .... Kinemetic viscosity
Gr_L .... Grashof number
P_r .... prandlt number
Nu_L .... Nuscelt number

Contents

Chapter 1

Introduction

1.1 Background

Substations form an important element of transmission and distribution network of electrical power system. Basically, these provide points for controlling the supply of power on different routes by means of various equipments such as transformers, compensating equipments, circuit breakers, isolators etc. The various circuits are linked together through these components to bus- bar system at the substation.

"Sub-station is integral parts of a power system and form important links between the generating station, transmission systems, distribution systems and the load points."

Construction of any substation from 33 kV to 765 kV is a precise job. There are many inputs required for electrical, mechanical and civil design of the substation.

- **Electrical Design**
  Electrical design relates to the MVA capacity of the substation, selection of switchyard equipment like power transformer, circuit breaker, bus post insulator, current transformer, potential transformer, capacitive voltage transformer, lightning arrester, carrier communication equipment, control and relay panels, capacitors bank, SCADA system etc.

- **Mechanical Design** Mechanical design relates to fabrication of various structures, air conditioning, fire protection etc.
- **Civil Design**
  Civil design relates to roads, water supply scheme, storm water disposal scheme, water harvesting, structure foundation, control room, cable trenches, office building, stores building, drainage, transformer/reactor foundations, road, security cabin etc.

1.2 Recent Trends

When the space is a constraint, compact substation has to be designed and constructed which includes Gas Insulated Switchgear (GIS). GIS is a compact substation. Now a day a combination of GIS and AIS are gaining more popularity, particularly in the densely populated urban areas where acquisition of additional land is not possible.

Due to increase in power demand, load on substation is increased. In urban substation many a time it is not possible to provide extension to existing air insulated substation due to non availability of space to accommodate additional bays. In such case GIS extension is the only viable solution. Also in hilly area where the availability of space is main constraint, Gas Insulated substation has to be designed and constructed.

GIS concept could be a very healthy and cost effective solution to the utility from operational/ maintenance point of view, during the life of a substation. No doubt that the equipment installation cost of GIS is more than the conventional AIS substation.

1.3 Objective of Project

In this Project, main objective is to identify various aspects of GIS extension for augmenting the capacity of existing AIS substation in an urbanised area. Design a GIS for given voltage class on the basis of actual application. The study includes equipment specification, design/engineering like earthing, lightning protection system,cable schedule, interface between AIS and GIS, preparation of Substation design drawings and calculations.

1.4 Scope of Work

The work fulfills objective in following steps:

- Identify factor leading to Gas Insulated Substation extension.
- Study of present load, load growth for next five year and availability of space.
- Electrical design of GIS including equipment specification.
- Detail engineering like earthing, CT sizing, lightning system, busbar sizing, illumination design, station auxiliary supply, battery sizing, cable schedule etc.
- Substation design drawings and calculations are prepared.
- Interface between AIS and GIS.

1.5 Problem Identification and Project Planning

1.5.1 Problem Identification

The power demand in the country is increasing exponentially. The urban and sub-urban areas have very high density of consumers and in addition each consumer consumes power in big quantity. The space availability in urban and suburban areas is very less. With the result expansion of existing substation becomes very difficult.

Creating load centre away from the populated area does not solve the purpose as it will be difficult to secure right of way (ROW) for an over head transmission line or even to EHV cables. Hence it would need construction feeders or link cables over a longer distance. Besides this, it would also cause voltage drop.

Most of the substation in urban areas are connected to each other to form a ring main. Any extension in the substation capacity therefore needs providing Gas Insulated Substation (switchgear) in the existing air insulated substation.

Such substation comprise number of incoming line bays, transformer bays and feeder bays as AIS. Cables are laid from the AIS bus up to the point of GIS. The secondary feeder of GIS is connected to a transformer or taken out as a HT feeder to other remote substation as per the requirement. The utility in the metropolitan city like Mumbai, Delhi, Kolkata, Chennai etc. have started deploying such GIS extension. Even the utility of gujarat state (GETCO) has started augmenting the capacity of existing substation using GIS.

In this project, I have worked on case study of a substation at Borivali Aarey in Mumbai. The space available is very less and it is difficult to extend one AIS bay in available area. Extension in the substation capacity is therefore possible with GIS.

1.5.2 Project Planning

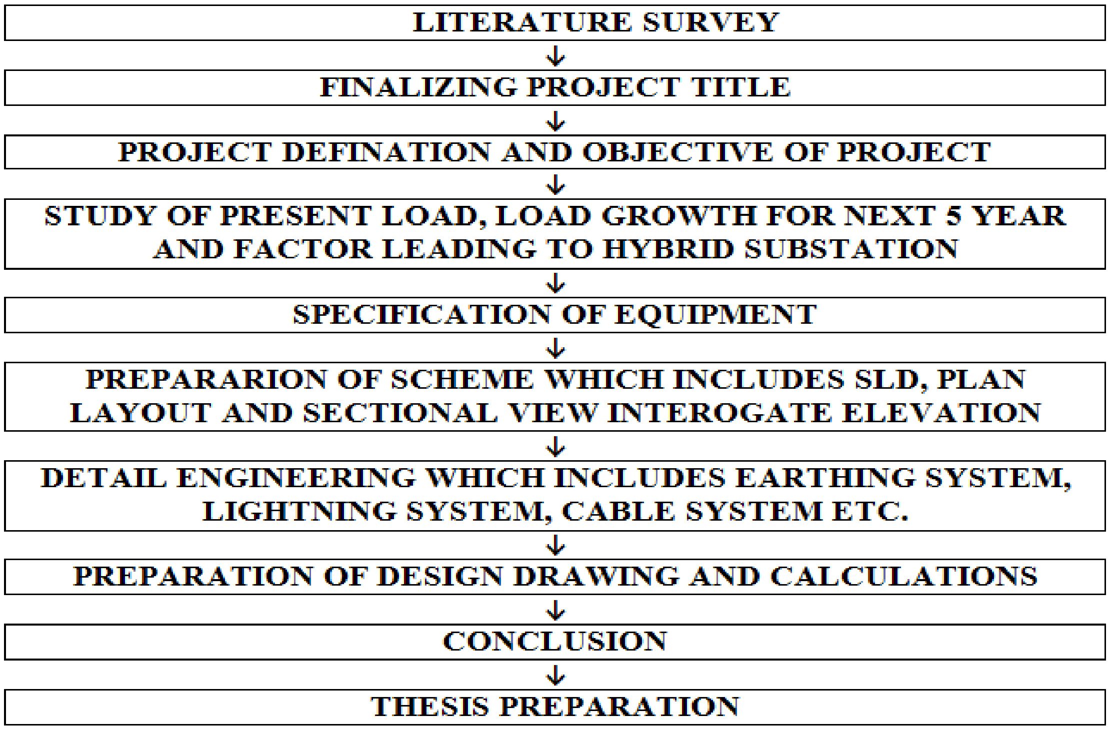


Figure 1.1: Project Planning

1.6 Thesis Organization

Chapter 1 introduces the background and design of substation, the recent trends in switchgear technology, Objective of project, scope of work, problem identification and project planning.

Chapter 2 gives literature survey on experiences with space saving solutions and different technology used in compact substation.

Chapter 3 explains load growth study and factor leading to GIS extension. It also explain advantages and disadvantages of GIS.

Chapter 4 determines brief of equipments and give ratings selected for the proposed gas insulated substation.

Chapter 5 includes step by step design for proposed gas insulated substation. It also includes main design calculations like Earthing, CT Sizing, DSLP Busbar Sizing and Battery sizing. It also includes the simulation result of busbar.

Chapter 6 includes conclusion and future scope of project work.

Appendix A includes detail earthing design calculation.

Appendix B includes illumination design of GIS room with simulation results.

Chapter 2

Literature Survey

Paper 1 briefs about the cost-effectiveness of integration of substations and lines into the geographic service area. Besides building new substations, the upgrading of existing substations has important considerations. Decisions between replacement or refurbishment are not the only options, also using existing substation footprints for new & more compact equipment is another approach. In recent years there has been increasing emphasis placed on reducing environmental impact of construction of substations. Options include new aesthetic solutions, better integration into the environment or placing entire substations underground.

While paper reports on experiences with such space saving solutions, becoming more a common practice of utilities, paper also presents a number of interesting examples of integration of substations and lines into its geographic service area and afford augmentation. Such projects follow typically the evaluation of life-cycle cost, performance, behavior and environmental impacts. Last but not least a sensitivity analysis is required to address the different aspects of the individual parameters of each utility and application.

Paper reflects that, it is often required to extend or replace installed substations within their existing location or footprint by GIS extension, combining air insulated and gas insulated technology. For air insulated bus-bars with disconnecting switches in combination with mixed technology switchgear (MTS), the capability of the switches

and their behavior during bus-bar operations must be considered. The given rated transfer current values may not be sufficient if an existing AIS substation using air insulated bus-bars operates in combination with GIS bays.
Paper 2 reflects example of MTS. Mixed technology switchgear can thus be made up one of the following combinations:

- AIS in compact or combined design
- GIS in combined design
- Hybrid Insulated Substation in compact or combined design
  - Conventional switchgear
    Switchgear of which bays only include conventional components
  - Compact switchgear
    Switchgear of which at least one or more bays are compact bays, i.e. in which at least some components share common support structures and cannot be placed individually.
  - Combined switchgear
    Switchgear of which at least one or more bays are combined bays, i.e. in which at least some components are multifunctional.

Paper 3 presents the advantages of modular construction of GIS. The recent past has witnessed a growing demand for compact solutions for indoor as well as outdoor applications. It has been noted that in addition to their small space requirement, many compact solutions offer standardized as well as interchangeable switchgear modules catering to the clients needs for flexibility. The fact that different kinds of available solutions like the HIS are delivered as pre-fabricated modules, reduces the overall erection and installation time to an extent in comparison to a conventional (AIS) substation, where individual components have to be procured, handled, installed, commissioned and maintained separately. Another advantage of pre-fabrication is

the reduced risk of faulty installation at site.
In case of refurbishments or extensions, usually the lack of space makes it difficult to use the conventional (air-insulated) equipment. The above mentioned MTS characteristics permit the use of the new modules in GIS technology as well as in conventional installations. The overall cost of a substation using GIS components are comparable in investment cost but significantly lower in operating cost when the TDL concept is considered consequently. This paper also discusses about some example of GIS extension in ring main configuration.
Paper 4 discusses about Design Experience of 230/115/69kV Substation Refurbishment Extension Project in Philippine Grid Network. This paper describes some issues considered during design of this project, such as transformer power capacity growth, main equipment dismantling and new secondary system integration into existing system.

- **Review and modification work caused from TR power capacity growth**
  The 100MVA transformer at the Cabanatuan substation under Luzon expansion project was replaced with one of 300MVA capacity. The increase of capacity, lead to the increase in weight of transformer, foundation size and rated current.

- **Layout modification considering insulation clearance**
  The space for surge arrester installation on transformer high voltage side was reduced due to increase in transformer size. In order to make enough clearance for transformer installation, we reviewed installation of 3 phase surge arrester on the transformer main tank.

- **Structural Analysis of Gantry Structure**
  The bus conductor of transformer secondary side was changed from single conductor to two bundle conductor due to growth of transformer capacity.

The subject of the paper 5 is the discussion of various executed GIS extensions and the subsequent erection and commissioning. It is based on the evaluation of over 30 years of experience with a high number of GIS in operation. Gas insulated switchgear (GIS) is often built to its final extent in several stages. The motives for upgrades and extensions are principally economical if well planned and are related to the expected or future network growth. Typical extensions are additional bays, bus section disconnectors, double cable terminations etc. Transmission system growth may lead to higher requirements with regard to short circuit current and/or nominal current ratings after the initial GIS installation. For planned extensions, the mid and long range forecasts and expectations regarding the following are decisive:

- Growth of population and/or growth of industrial, commercial activities in a certain region, resulting in increase of consumption of electrical energy.
- New industrial, economical areas and zones need for new energy supply points.
- added generating points, increasing the output of generating stations
- improved redundancy, availability of the energy supply
- Layout and concept changes of the high voltage network.

In case of substations, when space is really limited as in crowded city centres or at high altitude mountain locations, underground GIS substations, need very precise initial planning. Modular construction, small flexible GIS, with HV cable connections, power transformers, heat exchangers, etc. are allowing for hidden underground substations.

Chapter 3

Need of GIS Extension

3.1 Study of Load Growth

The pace of growth in industrial and commercial activities coupled with penetration of technology and I.T. in the day-to-day life of the common man, is expected to result in a high growth in power demand. Therefore, it is essential that Power Sector growth has to commensurate with the overall economic growth of the nation. The 12^{th} Five Year Plan for the Power sector being check by the Planning Commission aim at addition of 1 lakh MW of installed capacity.
As per the report 6 of planning commission Working Group, capacity addition requirement during the 12^{th} Plan is 75,785 MW. The source wise break up of 12^{th} Plan capacity addition program is given as under

Table 3.1: Capacity Addition Requirement

	Hydro(MW)	**Thermal(MW)**	**Nuclear(MW)**	**Total(MW)**
Central	5632	11426	2800	19858
State	1456	12340	0	13796
Private	2116	40015	0	42131
Total	9204	63781	2800	75785

Table 3.2: Year Wise Capacity Addition

Year	**Central(MW)**	**State(MW)**	**Private(MW)**	**Total(MW)**
2007-08	3240.00	5273.00	750.00	9263.00
2008-09	750.00	1821.20	882.50	3453.70
2009-10	2180.00	3118.00	4287.00	9585.00
2010-11	4280.00	2979.00	5121.50	12160.50
2011-12	4770.00	3761.20	11970.50	20501.70
			Total	54963.90

Table 3.3: Growth of Transmission Sector

Substation	**Central(MVA)**	**State(MVA)**	**Private(MVA)**	**Total(MVA)**
765kV	24000	1000	-	25000
400kV	77225	73172	630	151027
220kV	6436	215771	1567	223774
500kV HVDC	9500	1700	0	11200

Table 3.4: Forecasted Load of Mumbai

Year	**Total Required Load(MW)**
2010-11	3191
2011-12	3342
2012-13	3571
2013-14	3817
2014-15	4174

So, above load growth 7 needs to be considered while planning for Mumbai power system grid.

3.2 Factor Leading to GIS Extension

- Growth of population and/or growth of industrial, commercial activities in a certain region, resulting in increase of consumption of electric energy.
- New industrial, economical areas and zones need for new energy supply points.
- Added generating points, increasing the output of generating stations.
- Improved redundancy, availability of the energy supply.
- Layout and concept changes of the high voltage network.
- The substation capacity expansion by compaction of space occupied by AIS equipment is therefore possible with the use of GIS extension.

3.3 Advantages

- Space saving up to 50-60 percentage can be achieved compared to an AIS station in low voltage system.
- It has high reliability due to usage of GIS components technology.
- Installation is fast and easy.
- It allows flexibility in design and layout.
- Optimum use of land.
- The substation capacity expansion by compaction of space occupied by AIS equipment is therefore possible with the use of gas insulated substation.

- GIS solutions combine five functions of traditional AIS substation, namely circuit breaker, disconnector, earth switch current transformer and voltage transformer into one SF6 encapsulated module.
- Gas insulated Substation can be used for longer times without any periodical inspections.

3.4 Disadvantages

- Initial cost of Gas insulated substation is high.
- Excessive damage in case of internal fault.
- Diagnosis of internal fault and rectifying takes very long time (high outage time).
- SF_6 is green house gas, itś global warming potential is 25000 times more than CO_2.

3.5 Application of GIS Extension

- Non availability of sufficient space.
- Difficult climatic conditions at site.
- Urban site (high rise building).
- New industrial, economical areas and zones.
- More populated area.

Chapter 4

Selection of Proposed GIS Equipment

Deciding substation equipments and their ratings is important task of substation design. Selection of voltage level plays an important role in designing substation and its equipments. Major parameter considered in selection of voltage level depends on amount of power to be transferred. Gas Insulated substation designed in this project is extended from existing Air Insulated substation. Currently load of 400 MVA at 220 kV voltage level is supplied through Air Insulated Substation. Due to increase in load demand and availability of space constraint 125 MVA at 220 kV is supplied through Gas insulated substation which is an extension of one bay from Air insulated sub station.

4.1 System Parameters

- Nominal System Voltage(kV):- 220
- Highest Operating Voltage(kV):- 245
- Rated Frequency(Hz):- 50
- Grounding:- Effectively Earthed

- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and Between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460
  Switching surge withstand voltage:- -
- Rated Short Time Withstand Current(kA for 1 Sec.):- 40
- Rated Peak Withstand Current(kA):- 100
- Guaranteed maximum gas losses for complete installation as well as for all individual sections:- As per IEC 62271-203

4.2 GIS Equipments

4.2.1 Busbar

Main conductors are Aluminium or Copper alloy tubes as per manufacturers design philosophy and its dimensions depends upon mechanical strength.The rated current and short time withstand current is tested for current carrying capacity. The conductors are provided with silver plated finger contact assembly mounted on support insulator. These sliding contacts allow tubular conductors to expand axially with temperature rise without additional stress on support insulators. The shape of support insulator for tubular conductor normally ensure that field stress distribution is uniform.

Specifications of Busbar:-

- Rated Voltage(kV):- 220
- Standard Pipe Size:-
  Outer Diameter(mm):- 114.3
  Inner Diameter(mm):- 97.18

- Material:- Aluminium grade 91E conforming to IS:5082(1996)
- Area(mm^2):- 2844
- DC Resistance at $20^0C(\mu - ohm/m)$:- 11.0
- Weight(kgs/Mtr):- 7.678
- Current Carrying Capacity(Amps):- 3590
- Tubular bus conductor temperature when carrying rated current at site condition:- Should not exceed 45^0C above ambient

4.2.2 Circuit Breaker

GIS uses essentially the same dead tank SF_6 puffer circuit breakers as are used for AIS. Instead of SF_6 to air bushings mounted on the circuit breaker enclosure, the GIS circuit breaker is directly connected to the adjacent GIS module.

Specifications of Circuit Breaker:-

- Nominal System Voltage(kV):- 220
- Highest Operating Voltage(kV):- 245
- Number of Poles:- 3
- Rated Frequency(Hz):- 50
- Type of Circuit Breaker:- SF_6 Gas insulated
- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460
- Rated Short Circuit Breaking Current Capacity(kA for 1 Sec.):- 40

- Rated Short Circuit Making Current(kA):- 100
- Rated Short Time Current Carrying Capacity(kA for 1 Sec.):- 40
- Rated Current(Amp):- 1250
- First Pole to Clear Factor:- 1.3
- Rated Operating Sequence or Duty, C - Closing Operation O - Opening Operation:- O - 0.3 Sec. - CO - 3 Sec. - CO
- Auto Reclosing (Shall be suitable for 1 - phase & 3 - phase High Speed Auto Reclosing):- Single Phase Auto Reclosing
- Rated Line Charging Breaking Current(Amp):- 125
- Rated Out of Phase Breaking Current(kA):- 10
- Rated Cable Charging Breaking Current Capacity(Amp):- 250
- TRV peak value(kV):- 364
- Total Opening Time:- 1 Cycle (20 ms)
- Operating Mechanism:- Spring / hydraulic
- Rating for Auxiliary Circuits:- 10A at 220V DC
- Total Rated Break Time:- 2 Cycles (40ms)
- Rated Closing Time(ms) :- <55
- Type of Operation:- Individually Operated Single Pole
- Applicable Standards:- IEC-62271-100/ IEC-56/ IS-13118

4.2.3 Isolators and Earthing Switches

Disconnect switches have a moving contact that opens or closes a gap between stationary contacts when activated by an insulating operating rod that is itself moved by a sealed shaft coming through the enclosure wall. The stationary contacts have shields that provide the appropriate electric field distribution to avoid too high a surface electrical stress. The moving contact velocity is relatively low (compared to a circuit breaker moving contact) and the disconnect switch can interrupt only low levels of capacitive current (for example, disconnecting a section of GIS bus) or small inductive currents (for example, transformer magnetizing current). For transformer magnetizing current interruption duty, the disconnect switch is provided with a fast acting spring operating mechanism.

Ground switches have a moving contact that opens or closes a gap between the high-voltage conductor and the enclosure. Sliding contacts with appropriate electric-field shields are provided at the enclosure and the conductor. A maintenance ground switch is operated either manually or by motor drive to close or open in several seconds. When fully closed, it can carry the rated short-circuit current for the specified time period (1 or 3 sec) without damage. A fast acting ground switch has a high speed drive, usually a spring , and contact materials that withstand arcing so it can be closed twice onto an energized conductor without significant damage to itself or adjacent parts. Fast acting ground switches are frequently used at the connection point of the GIS to the rest of the electric power network, not only in case the connected line is energized, but also because the fast acting ground switch is able to handle discharge of trapped charge in a better manner. Ground switches are almost always provided with an insulating mount or an insulating bushing for the ground connection. In normal operation, the insulating element is bypassed with a bolted shunt to the GIS enclosure. During installation or maintenance, with the ground switch closed, the shunt can be removed and the ground switch used as a connection from test equipment to the GIS conductor. Voltage and current testing of the internal parts of the GIS can then be done without removing SF6 gas or opening the enclosure.

Specifications of Isolators and Earthing Switches:-

- Nominal System Voltage(kV):- 220
- Highest Operating Voltage(kV):- 245
- Rated Frequency(Hz):- 50
- Type:- SF_6 Insulated
- System Earthing:- Effectively Earthed
- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460
- Rated Normal Current(Amp):- 1250
- Rated Short Circuit Breaking Current(Rated Short Time Withstand Current) (kA for 1 Sec.):- 40
- Rated Maximum Duration of Short Circuit(Sec):- 1
- Rated Short Circuit Making Current(kA):- 100
- Rated Dynamic Withstand Current(kA):- 100
- No. of spare auxiliary contacts on each isolator:- 4 NO and 4 NC
- No. of spare auxiliary contacts on each earthing switch:- 4 NO and 4 NC
- Rated mechanical terminal load:- As per IEC

4.2.4 Current Transformer

Current transformers (CTs) are inductive ring type installed either inside the GIS enclosure or outside the GIS enclosure. The GIS conductor is the single turn primary for the CT. CTs inside the enclosure must be shielded from the electric field produced by the high voltage conductor or high transient voltages which may appear on the secondary through capacitive coupling. For CTs outside the enclosure, the enclosure itself must be provided with an insulating joint, and enclosure currents shunted around the CT. Both types of construction are in wide use.

Advanced CTs without a magnetic core (Rowgowski coil) have been developed to save space and reduce the cost of GIS. The Rowgowski coil type of CT is linear regardless of current due to the absence of magnetic core material that would saturate at high currents.

Specifications of Current Transformer:-

- Nominal System Voltage(kV):- 220
- Highest Operating Voltage(kV):- 245
- Rated Frequency(Hz):- 50
- System Earthing:- Effectively earthed
- Rated Short Time Withstand Current(kA for 3 Sec.):- 40
- Rated Dynamic Withstand Current(kAp):- 100
- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460
- Type of Transformation Ratio:- Multi Ratio
- Rated Continuous Thermal Current:- - 120

- Ratio Taps:- On Secondary Side
- Acceptable Limit of Temperature Rise above the Specified Ambient Temperature for continuous Operation of Rated Current:- As Per Standard
- Acceptable Partial Discharge Level at 1.1 times the Rated Voltage (pC):- 10
- Maximum Radio Interference Voltage at 1.1 times the Rated Voltage (V):- 1000 V
- rated current ratio(primary/secondary)(amp):- 600-300/1-1-1

4.2.5 Voltage Transformer

Voltage transformers (VTs) shall be of the metal enclosed, gas-insulated inductive type, mounted directly in the high voltage enclosure. Secondary terminals must be located in accessible grounded terminal boxes on the VT enclosure itself. The secondary connections must be wired to the terminal strip in the respective bay marshalling cubicle. VTs should be in segregated compartment and not forming a part of busbar.

Specifications of Voltage Transformer:-

- Nominal System Voltage(kV):- 220
- Highest Operating Voltage(kV):- 245
- Rated Frequency(Hz):- 50
- System Earthing:- Effectively Earthed
- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460

- Voltage Ratio:-
  Rated Primary Voltage(kVrms):- $220/\sqrt{3}$
  Rated Secondary Voltage(Volts) $110/\sqrt{3}$-$110/\sqrt{3}$-$110/\sqrt{3}$

- Rated Voltage Factor:- 1.2 Continuous and 1.5 for 30 Seconds

4.2.6 Transformer

Transformer is used to increase or decrease the voltage level without changing the frequency level. Transformer is the largest piece of equipment in a substation and it is, therefore, important from the point of view of substation layout. One of the important factors governing the layout of the substation is whether the transformer is a three phase unit or a unit of three single phase transformers. The space requirements with single phase banks are much larger than those with three phase transformers. However, when there is a limitation of transportation in hilly region or underground power house layout, single phase transformers are prefered.

Specifications of Transformer:-

- Type:- Three Phase, Oil Immersed

- Rated Frequency(Hz):- 50

- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460

- Capacity(MVA):- 125

- Type of Cooling:- ONAN/OFAF

- Voltage Ratio(kV):- 220/33

- Current(H.V. Side)(Amp):- 328.03

- Current(L.V. Side)(Amp):- 2186.9
- Winding Connection:- Star - Delta
- Tapping:- OLTC
- Neutral:- Solidly Grounded
- Vector Group:- Ynd11

4.2.7 Outdoor Bushing

Outdoor bushings, for the connection of conventional external conductors to the SF6 metal enclosed switchgear, shall be provided where specified and shall conform to the requirements. The dimensional and clearance requirements for the metal enclosure will be the responsibility of the manufacturer and their dimensions must be coordinated with the switchgear.

Specifications of Outdoor Bushing:-

- Rated Voltage(kV):- 220
- Rated Frequency(Hz):- 50
- Rated Current(A):- 1250
- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(KVrms):- 460
- Minimum total creepage distance (mm):- 6125

4.2.8 Lightning Arrester

The lightning arresters or surge diverters provide protection against surges. A lightning arrester or a surge diverter is a protective device which conducts the high voltage surges on the power system to the ground. Metal oxide gapless type surge arresters, which are being most widely used because of better protection level, high energy handling or discharge capability and low power loss under normal operating conditions. The most important and costly equipment in the substation is transformer and it is general practice to place surge arrester as near to the transformer as possible.

Specifications of Lightning Arrester:-

- Nominal System Voltage(kV):- 220
- Highest Operating Voltage(kV):- 245
- Rated Frequency(Hz):- 50
- System Earthing:- Effectively Earthed
- System Fault Level(KA for 1 Sec.):- 40
- Rated Insulation Level
  Rated Lightning Impulse Withstand Voltage to Earth and between Phases(kVp):- 1050
  1 min. Power Frequency Withstand Voltage to Earth(kVrms):- 460
- Rated Voltage of the Arrester(kVrms):- 196
- Maximum Continuous Operating Voltage(kVrms):- 141
- Type:- Heavy Duty, Station Class,Zno Gapless type
- Nominal Discharge Current(8/20 ms) (kA):- 10
- Power Frequency Spark-Over Voltage(kVp):- 294

- Maximum Impulse Spark-Over Voltage(kVp):- 849
- Residual(Discharge) Voltage(kVp):- 507
- Maximum Discharge Current(kA) (For Lightning Arrester of Station Class):- 100
- Maximum Radio Interference Voltage for Frequency between 0.5 MHz and 2 MHz(V for Surge Arrester):- < 500
- Partial Discharge Level(pC) (At 1.05 time Continuous Operating Voltage) :- Not more than 50
- Pressure Relief Class :- Short Circuit Level of 40 KA for 1 Sec.
- Provision for corona extinction:- Corona Ring is provided

Chapter 5

Design of Proposed Gas Insulated Substation

5.1 Single Line Diagram

A simplified pictorial representation of three phase network with all the components of a system on a single line representation is known as single line diagram. This diagram indicates the proposed busbar arrangement and relative positions of various equipment in substation.
The single line diagram of proposed substation is shown in figure 5.1.

5.2 Substation Layout and Sectional Elevation

- **Substation Layout**:- After the bus arrangement is decided and Single Line Diagram is prepared, Layout drawing is prepared to show the actual position of each equipment. General Layout shows the area acquired by switchyards of different voltage level. The electrical layout would reveal,
  - Physical position of each equipment
  - Distance between various equipment

  - Location of buildings like control room, Storage yard, Fire pump house, D.G. set room, etc

  The layout plan of proposed substation is shown in figure 5.3.

- Substation Sectional Elevation
  It shows,

  - Actual view of substation equipment connection

  The section elevation of proposed substation is shown in figure 5.4.

5.3 Protection Single Line Diagram

Protection is required for protecting equipment against fault. Protection single line diagram shows the protections provided in the substation. It also shows the different relays provided for transformer, equipments, busbar and bay etc.:-

Table 5.1: Protective Relays

Relay Code	**Relay**
50/50N	Inst. O/C and E/F Relay
51NS	Standby Earth Fault Relay
87T	Transformer Differential Relay
87BB	Busbar Differential Relay
63	Buchholz Relay
74	Alarm Relay
OSR	Oil Surge Relay

The protection single line diagram of proposed substation is shown in figure 5.2.

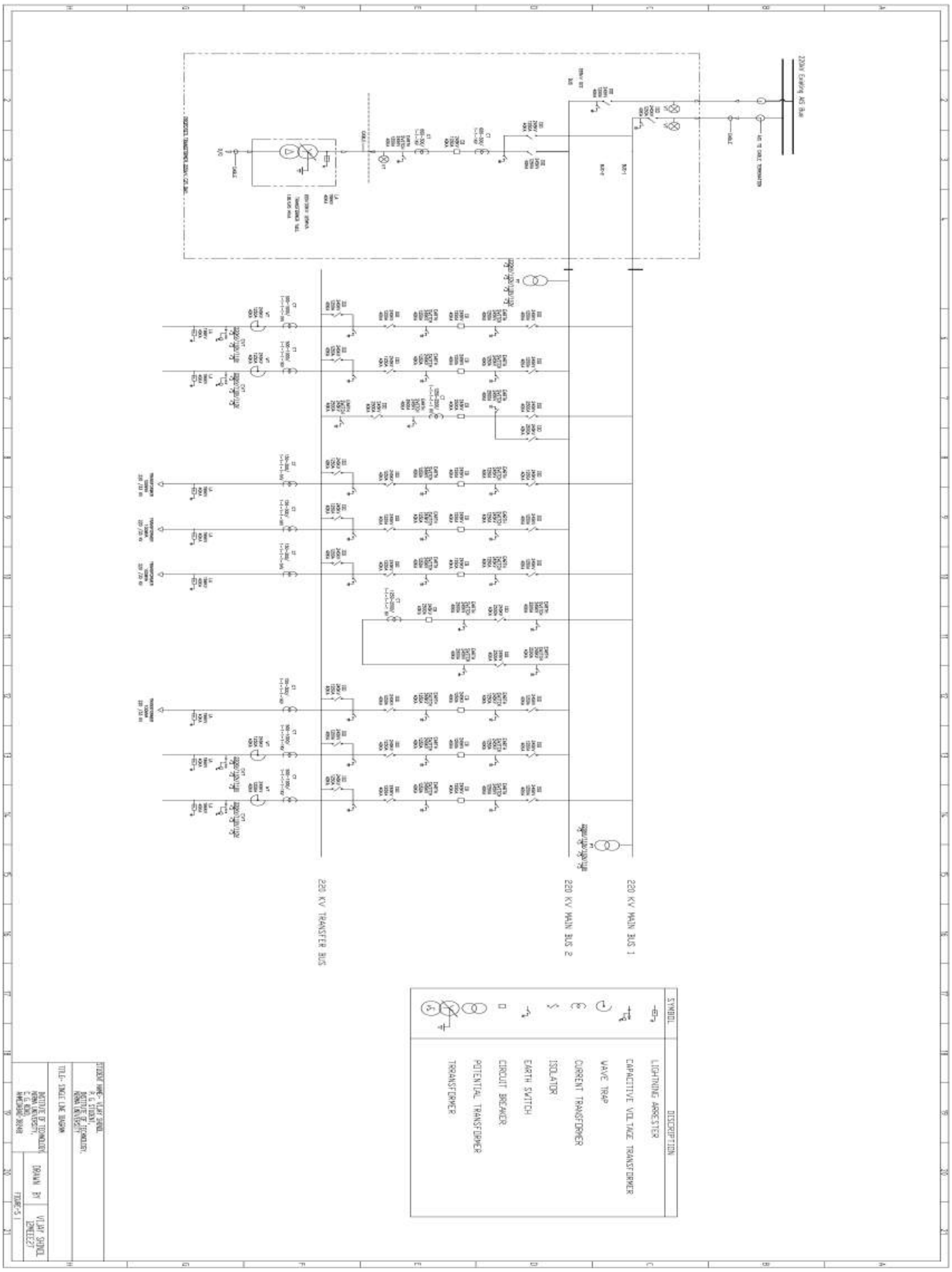


Figure 5.1: Single Line Diagram

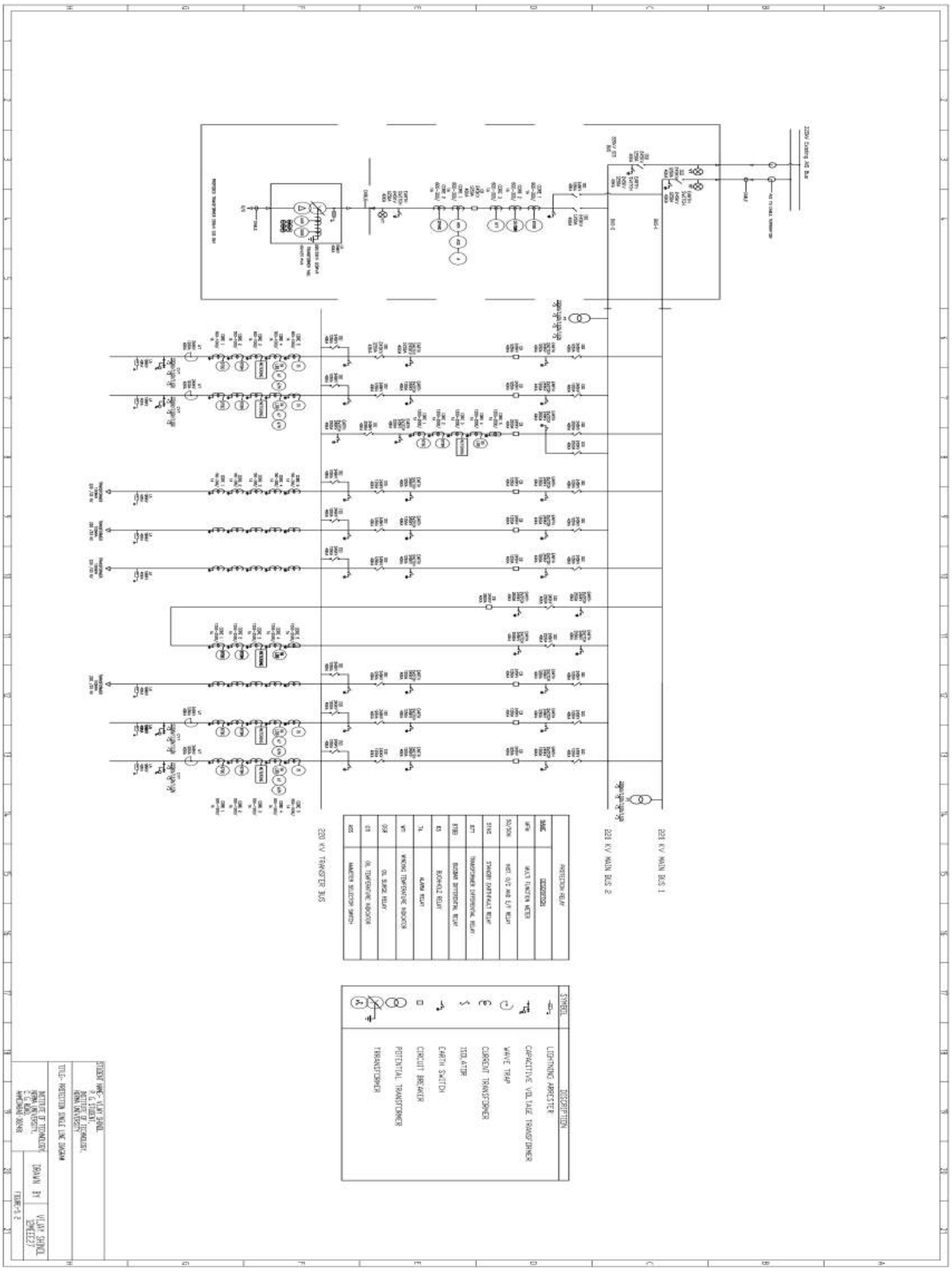


Figure 5.2: Protection Single line Diagram

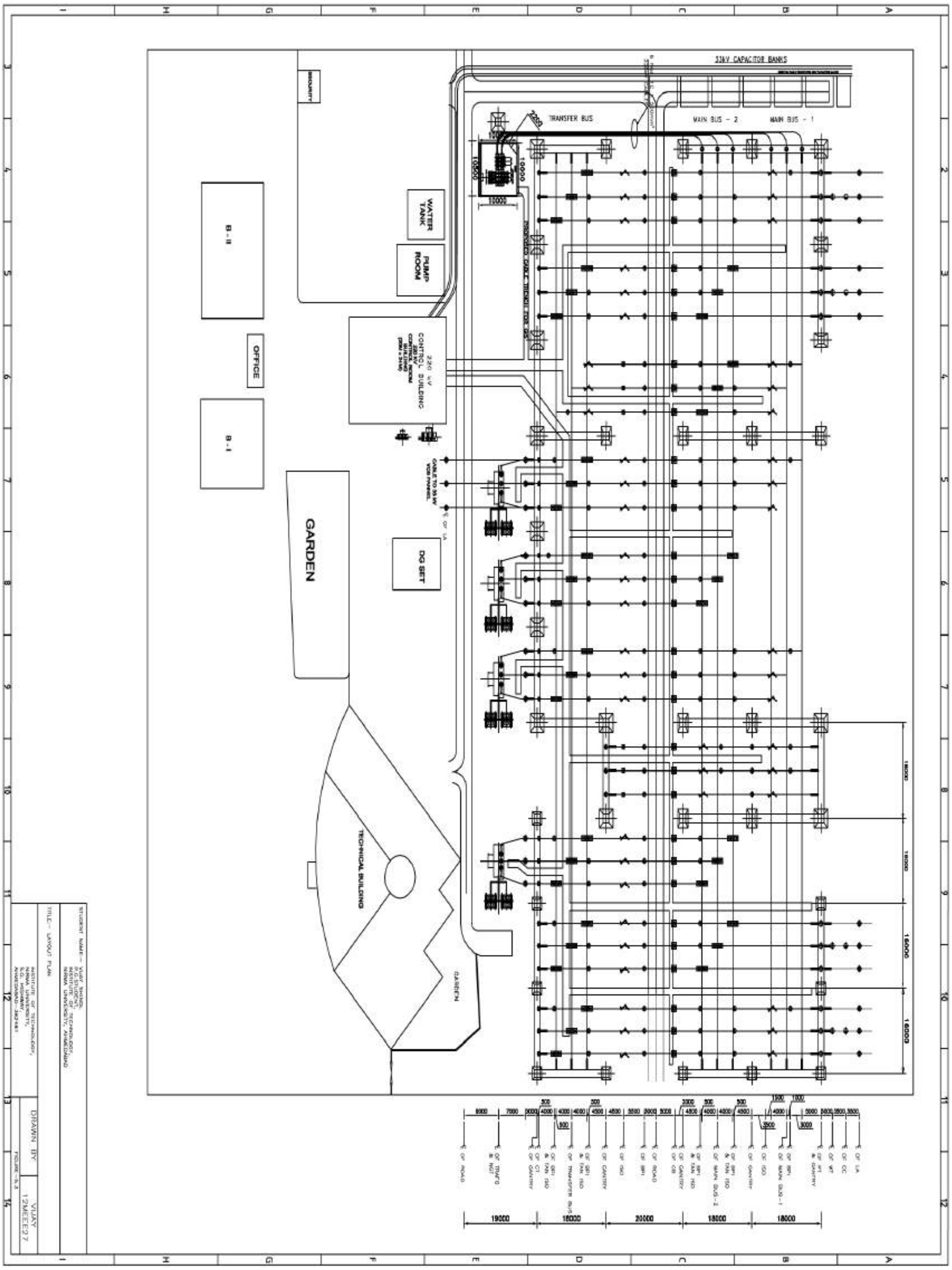


Figure 5.3: Layout Plan

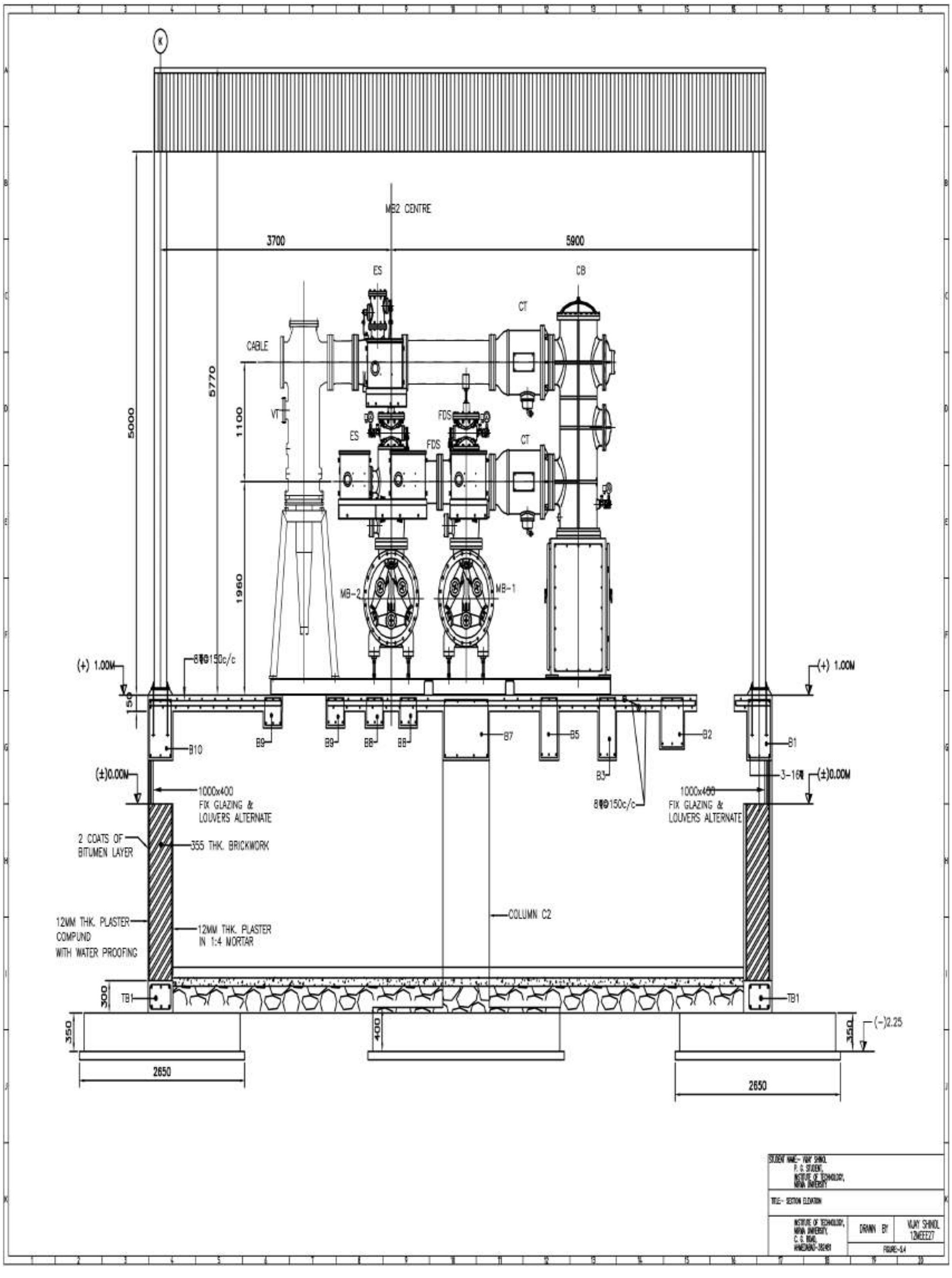


Figure 5.4: Layout Section Elevation

5.4 Substation Earthing

Earthing system is a vital part of all electrical systems. The proper earthing of a substation is important for the following two reasons:-

- It provides a means of dissipating electric current into the earth without exceeding the operating limits of the equipment.
- It provides a safety to protect personnel in the vicinity of grounded facilities from the dangers of electric shock under fault conditions.

A practical approach to safe grounding thus concerns and strives for controlling the interaction of two grounding systems, as follows:

- The intentional ground, consisting of ground electrodes buried at some depth below the earths surface.
- The accidental ground, temporarily established by a person exposed to a potential gradient in the vicinity of a grounded facility.

The primary requirements of a good earthing system in a substation are:-

- The impedances to ground should be as low as possible. In general, it should not exceed 1 ohm for substations with high fault levels(EHV substation) and 5 ohm for substations with low fault levels(Distribution substation).
- The Step and Touch potentials should be within safe limits.

To meet these requirements, an earthing system comprising an earthing mat buried at a suitable depth(usually 0.3-0.6 m) below ground, supplemented with ground rods at suitable points is provided in the substation. For Earthing mat, combined system of vertical and horizontal rods are used because horizontal conductors are most effective in reducing the danger of high step and touch voltages on the earth's surface, sufficiently long vertical ground rods will stabilize the performance of such a combined system. Under normal condition, the ground rods make little contribution in lowering the earth resistance. This grid system would be extended over the entire substation/switchyard and often beyond the fence line.

5.4.1 Special Consideration For GIS

- The individual metal enclosure sections of the GIS modules are made electrically continuous. In a continuous enclosure design, a voltage is induced in an enclosure by the current in the conductor that it surrounds, producing a longitudinal current flow in the enclosure. When a continuity of all phase enclosures is maintained through short connections at both ends, the enclosure current is only slightly less than that flowing in the inner bus in the opposite direction. This current returns through the enclosures of adjacent phases when the load is equalized between phases. The magnetizing current lags the enclosure current by approximately 90^0. The flux is mainly contained within the enclosure. single-phase enclosure GIS were multi point grounded.

- Another area required attention in GIS stations is earthing of metallic enclosures. The metallic enclosure of GIS have induced currents and specially during an internal earths fault the inductive voltage drop occurring with the GIS assembly must be taken into account for design to touch potential in GIS station. The touch voltages criteria of GIS station is

$$\sqrt{F_A^2 + E_G^2} < E_T(max)$$

Where,

F_A = The actual calculated touch voltage

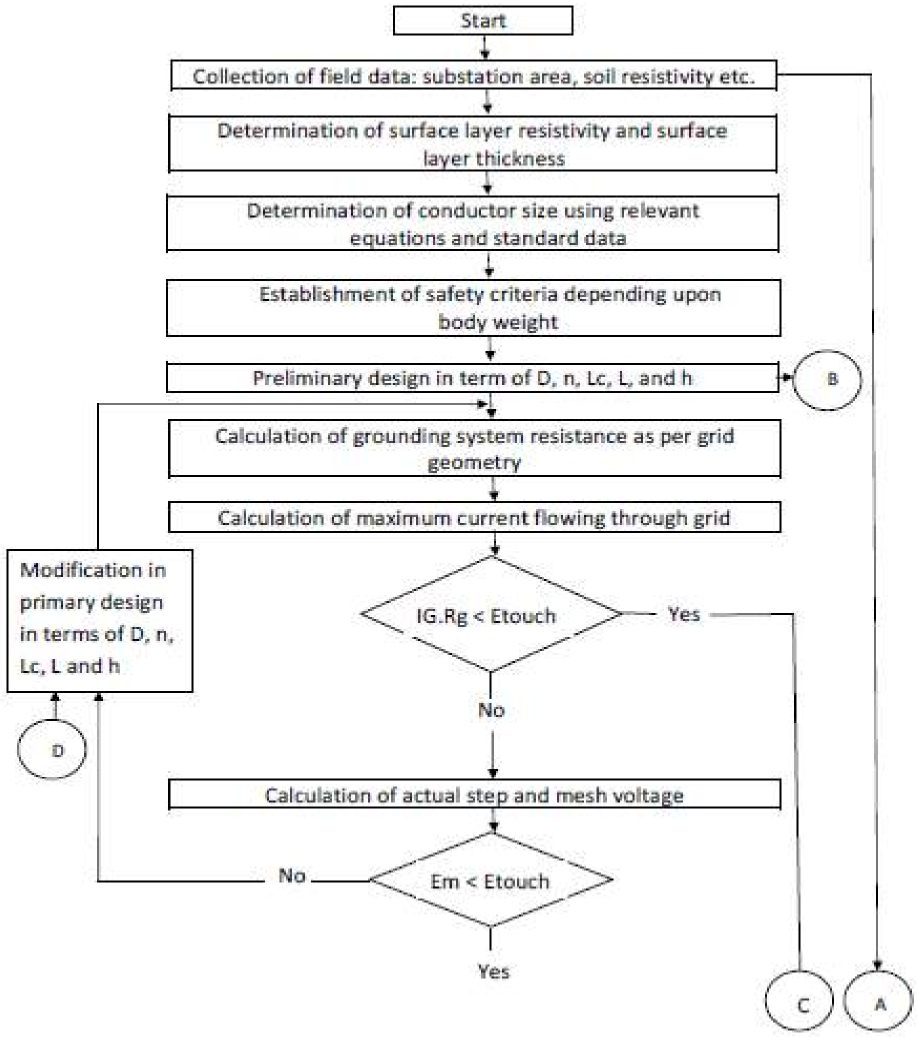
E_G = Maximum value of metal to metal voltage difference on and between GIS enclosures or between GIS enclosure and the supponing structures

$E_T(max)$ = Maximum permissible touch voltage

The earthing layout and riser connection diagram of proposed substation is shown in figure 5.6 and figure 5.7.

5.4.2 Design Procedure Block Diagram

The procedure block diagram illustrates the sequences of steps to design the ground grid. the procedure block diagram is shown in figure 5.5.



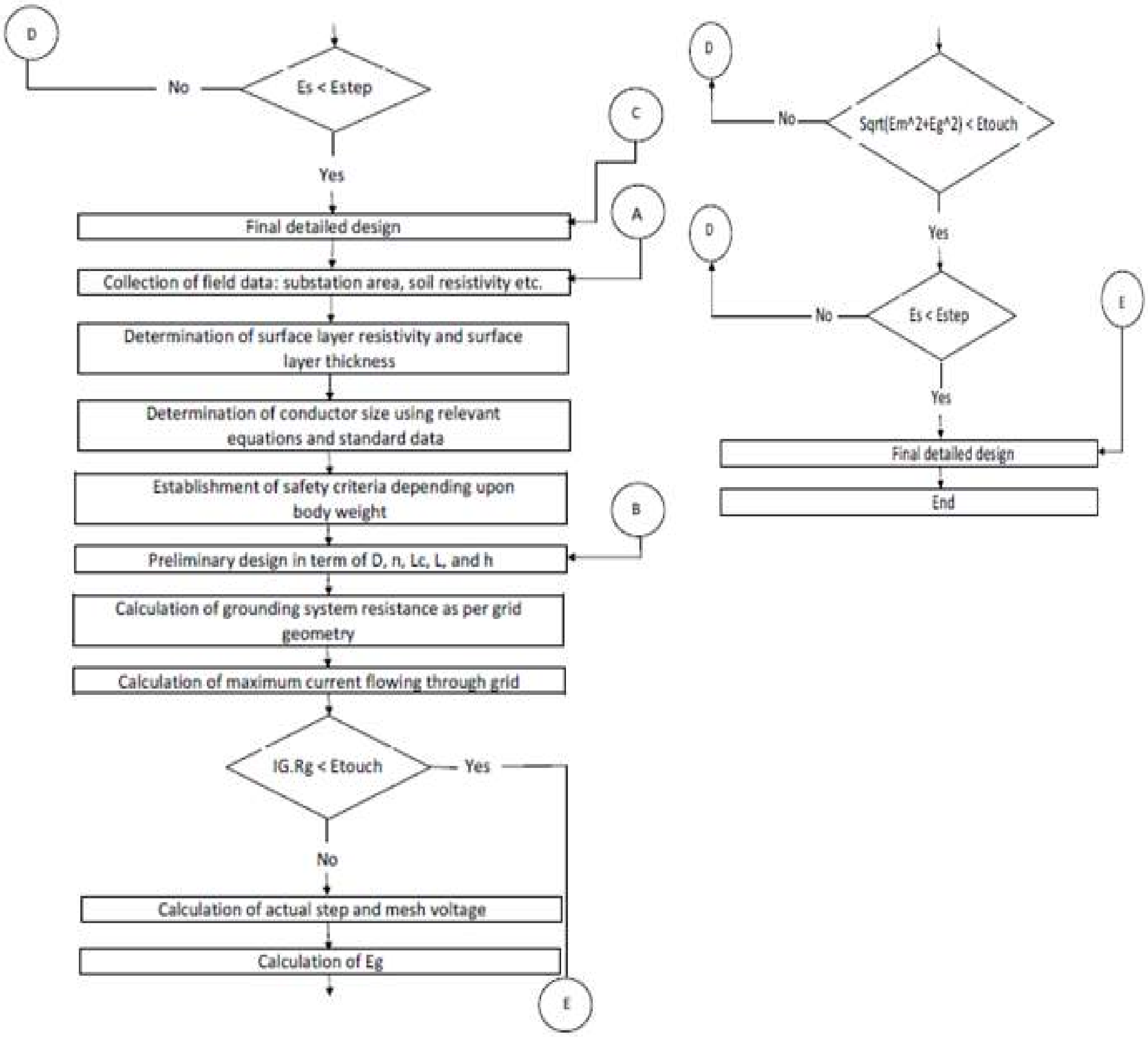


Figure 5.5: Design Procedure Block Diagram

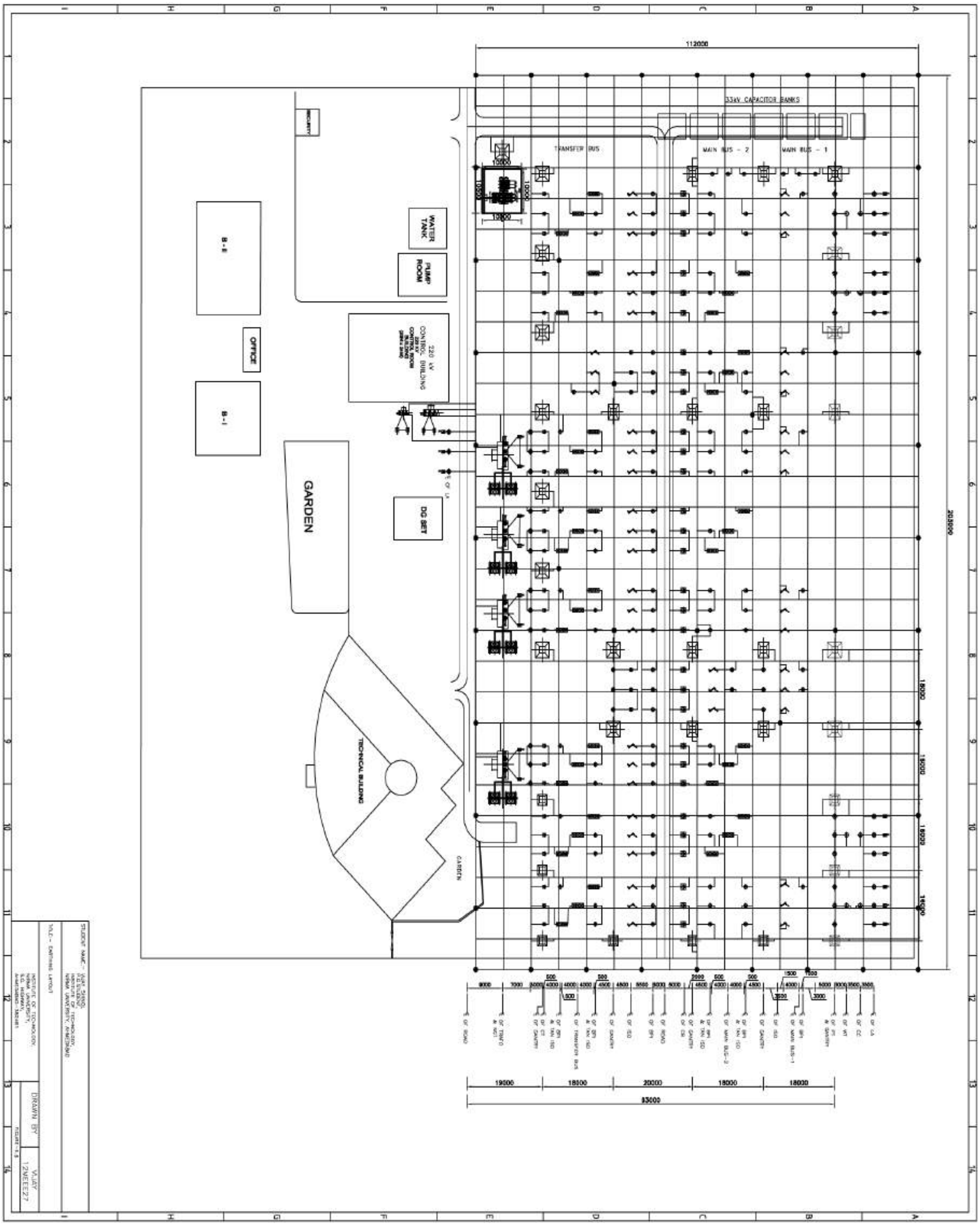


Figure 5.6: Earthing Layout

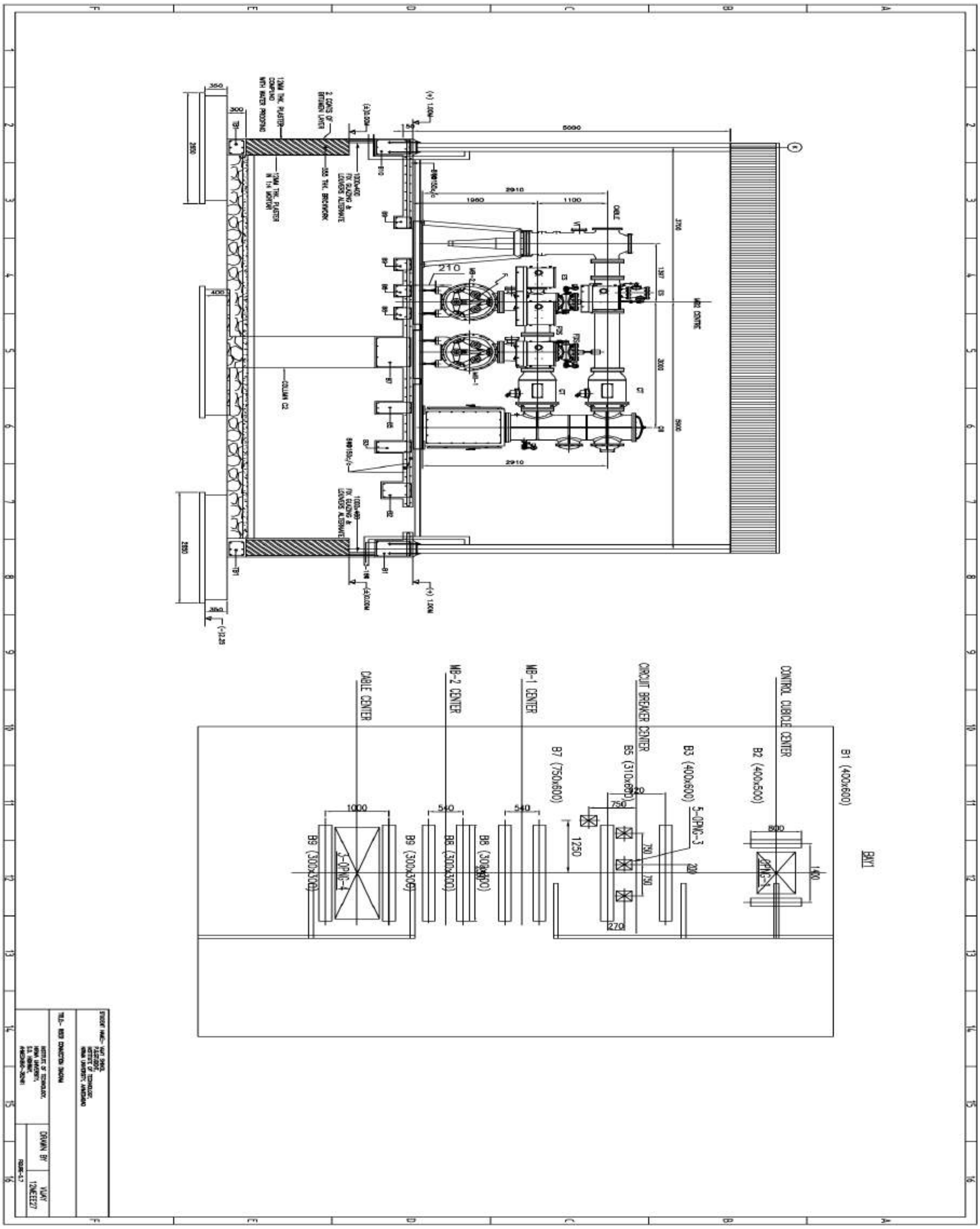


Figure 5.7: Riser Connection Diagram

Data required for design are:-

- Symmetrical fault current in substation(kA):- 40
- Duration of shock for determining allowable body current(Sec.):- 0.5
- Duration of fault current for sizing ground conductor(Sec.):- 1
- Surface layer resistivity(ohm-m)(**for AIS)**:- 3000
- Surface layer resistivity(ohm-m)(**for GIS)**:- 1000000
- Surface layer thickness(m):- 0.15
- Grid reference depth(m):- 1
- Soil resistivity(ohm-m):- 60
- Diameter of earthing conductor(m):- 0.04
- Depth of ground grid conductors(m):- 0.6
- Length of grid conductor in X direction(m):- 203
- Length of grid conductor in Y direction(m):- 112
- Spacing between parallel conductors(m):- 7
- Length of ground rod(m):- 3
- Number of rods placed:- 45
- Decrement factor for determining Ig:- 1
- Number of grid conductors in X direction:- 17
- Number of grid conductors in Y direction:- 30
- Equivalent Earthing mat area(m^2):- 22736

- Total Length of Buried Conductor(m):- 6946
- Total length of ground rods(m):- 135

For earthing mat conductor Zinc coated steel material has been used. Parameters considered for Zinc coated steel material:-

- RMS Current(kA):- 40
- Fusing temperature((^0C):- 419
- Ambient temperature(^0C):- 50
- Reference temperature for material constant(^0C):- 20
- Thermal coefficient of resistivity at 0 $^0C(1/^0C)$:- 0.00341
- Thermal coefficient of resistivity at 20 $^0C(1/^0C)$:- 0.0032
- Resistivity of the ground conductor at 20 $^0C(\mu$ohm.cm):- 20.1
- K_0 at 0 $^0C(1/^0C)$:- 293
- Duration of Current(sec.):- 1
- Thermal capacity, TCAP(J/$cm^3.^0C$):- 3.93

Detail cakculation of earthing design is given in AppendixA. Table gives the results of earthing design for both AIS and GIS.

- **Determination of Size of Conductor for Earthing Grid**

	AIS	**GIS**
Required area A_{mm^2}	688.79	688.79
Provided area A_{mm^2}	900	900

Here provided area is greater than required area. Hence it is safe.

	AIS	**GIS**
Surface layer derating factor C_s	0.77	0.77
Touch voltage $E_{touch50}$(V)	735	189455
Step voltage E_{step50}(V)	2449	757326

- **Touch and Step Voltage Criteria**

- **Determining grid resistance**

	AIS	**GIS**
Grid resistance $R_g(ohm)$	0.19	0.19

- **Maximum Grid Current**

	AIS	**GIS**
Fault current division factor S_f	0.60	0.60
Maximum grid current $I_G(A)$	24018.56	24018.56

- **Ground Potential Rise (GPR)**

	AIS	**GIS**
Ground potential rise(V)	4444	4444

- **Mesh Voltage**

	AIS	**GIS**
Total length of grid conductor (m) L_c	6811	6811
peripheral length of the grid (m) L_p	630	630
Spacing factor for mesh voltage K_m	0.62	0.62
Irregularity factor K_i	3.915	3.915
Mesh voltage E_m(V)	501.60	501.60

- **Step voltage**

	AIS	**GIS**
Spacing factor for step voltage	0.353	0.353
Step voltageE_s(V)	380.857	380.857

- **Calculation of E_g**

	AIS	**GIS**
	Not Required	Required
Frequency f(HZ)		50
I_s		40000
r_1 (m)		0.1675
r_2 (m)		0.1742
resistivity $\rho(ohm - m)$		0.000000029
For vertical length		
L(m)		2.91
structure piller length L1(m)		0.21
number of piller		9
R_e(ohm)		$1.1733 * 10^{-5}$
X_{Le}(ohm)		0.000234375
R_s(ohm)		0.0000091
X_{Ls}(ohm)		$4.76475 * 10^{-6}$
For horizontal length		
L(m)		3
R_e(ohm)		$1.20962 * 10^{-5}$
X_{Le}(ohm)		0.00024
$\mid Z \mid$		0.00048
E_g(V)		19.28
Touch voltage Criteria	501.60	501.97

- **Comparision**

  For AIS:-

	Tolerable	**Calculated**
Touch voltage(V)	735.32	501.600
Step voltage(V)	2449.12	380.857

For GIS:-

	Tolerable	**Calculated**
Touch voltage(V)	189454.50	501.97
Step voltage(V)	757325.86	380.857

5.5 CT Sizing

CT Sizing is an important calculation which gives Knee Point Voltage and selection of primary to secondary current ratio of Current Transformer. The knee-point voltage of a current transformer is the magnitude of the secondary voltage after which the output current does not follow linear relationship with input current. That means, proportional relationship between input and output is no longer within declared accuracy. After knee point, saturation of the CT core occurs. The performance of a protection function will depend on the quality of the measured current signal. Saturation of the current transformer will cause distortion of the current signal and can result in a failure to operate or cause unwanted operations of some functions. To ensure correct operation, the current transformers must be able to correctly produce the current for a minimum time before the CT will begin to saturate. By selecting a CT with operating point below the knee point, proper operation of the protection can be ensured.

5.5.1 Selection of Parameters of CT-1 on GIS Transformer Bay

Cable route length from CT to Relay Panel = 54 m

Core - 1

Purpose	**Busbar Differential Protection**
Ratio	
Primary Current I_{pn}	600-300 A
Secondary Current I_{sn}	1 A
Rated Current of The Protection IED I_r	1 A
Accuracy Class	PS
Maximum Fault Current I_{fmax}	40000 A
Conductor Cross-Section	4 mm^2
Conductor Material	Copper
Number of Run Per Phase	2
Specific Resistance of Copper	0.0216 ohm.m
Two Way Lead Loop Resistance R_L	$(2 * 54 * 0.0216/4)/2$
	0.2916 ohm
Relay Burden	0.020 VA
	$0.020/1^2$ ohm
	0.020 ohm
Current Transformer Secondary Winding Resistance	5 ohm

Min. Knee Point Voltage Requirement

$$V_{Kmin} = 0.5Ifmax * (I_{sn}/I_{pn}) * (R_{ct} + R_L + R_b/I_r^2)V \tag{5.1}$$

$$\mathrm{V}_{Kmin} = 177.05V$$

We have selected a CT which gives Min. Knee Point Voltage of 177.05 V.

Core - 2

Purpose	**Over Current Protection**
Ratio	
Primary Current I_{pn}	600-300 A
Secondary Current I_{sn}	1 A
Rated Current of The Protection IED I_r	1 A
Accuracy Class	5P20
Maximum Fault Current I_{fmax}	12000 A
Conductor Cross-Section	4 mm^2
Conductor Material	Copper
Number of Run Per Phase	2
Specific Resistance of Copper	0.0216 ohm.m
Two Way Lead Loop Resistance R_L	$(2 * 54 * 0.0216/4)/2$
	0.2916 ohm
Relay Burden	0.020 VA
	$0.020/1^2$ ohm
	0.020 ohm
Current Transformer Secondary Winding Resistance	5 ohm

Min. Knee Point Voltage Requirement

$$V_{Kmin} = (I_{kmax} * I_{sn}/I_{pn}) * (R_{ct} + R_L + R_b/I_r^2)V \tag{5.2}$$

$$\mathrm{V}_{Kmin} = 106.232V$$

We have selected a CT which gives Min. Knee Point Voltage of 106.232 V.

Core - 3

Purpose	**Transformer Differential Protection**
Ratio	
Primary Current I_{pn}	600-300 A
Secondary Current I_{sn}	1 A
Rated Current of The Protection IED I_r	1 A
Accuracy Class	PS
Rated Primary Current of The Transformer	328.0399 A
Maximum Primary Fundamental Frequency Current	6560.789 A
Conductor Cross-Section	4 mm^2
Conductor Material	Copper
Number of Run Per Phase	2
Specific Resistance of Copper	0.0216 ohm.m
Two Way Lead Loop Resistance R_L	$(2 * 54 * 0.0216/4)/2$
	0.2916 ohm
Relay Burden	0.020 VA
	$0.020/1^2$ ohm
	0.020 ohm
Current Transformer Secondary Winding Resistance	5 ohm

Min. Knee Point Voltage Requirement

$$V_{Kmin} = 30 * (I_{nt} * I_{sn}/I_{pn}) * (R_{ct} + R_L + S_r/I_r^2)V \tag{5.3}$$

$$\text{V}_{Kmin} = 87.12V$$

$$V_{Kmin} = 2 * (I_{tf} * I_{sn}/I_{pn}) * (R_{ct} + R_L + S_r/I_r^2)V \tag{5.4}$$

$$\text{V}_{Kmin} = 116.161V$$

We have selected a CT which gives Min. Knee Point Voltage of 116.161V.

5.5.2 Selection of Parameters of CT-2 on GIS Transformer Bay

Cable route length from CT to Relay Panel = 58 m

Core - 1

Purpose	**Metering**
Ratio	
Primary Current I_{pn}	600-300 A
Secondary Current I_{sn}	1 A
Rated Current of The Protection IED I_r	1 A
Accuracy Class	0.2
Selected Rated Burden	15 VA
Conductor Cross-Section	4 mm^2
Conductor Material	Copper
Number of Run Per Phase	2
Specific Resistance of Copper	0.0216 ohm.m
Two Way Lead Loop Resistance R_L	$(2 * 58 * 0.0216/4)/2$
	0.3132 ohm
Instrument Connected And Their Burden (Multifunction Meter)	1 VA
Current Transformer Secondary Winding Resistance	5 ohm

Total connected burden = Lead burden + Instrument burden + CT secondary winding burden

= 6.3132 VA

We have selected CT with a burden of 15 VA. Hence, CT selected is adequate.

5.5.3 Selection of Parameters of Bushing CT on Transformer

Cable route length from CT to Relay Panel = 55 m

Purpose	**Restricted Earth Fault Protection**
Ratio	
Primary Current Ipn	600-300 A
Secondary Current I_{sn}	1 A
Rated Current of The Protection IED I_r	1 A
Accuracy Class	5P20
Rated Primary Current of The Transformer	328.0399 A
Maximum Primary Fundamental Frequency Current	6560.798 A
Conductor Cross-Section	4 mm^2
Conductor Material	Copper
Number of Run Per Phase	2
Specific Resistance of Copper	0.0216 ohm.m
Two Way Lead Loop Resistance R_L	$(2 * 55 * 0.0216/4)/2$
	0.297 ohm
Relay Burden	0.020 VA
	$0.020/1^2$ ohm
	0.020 ohm
Current Transformer Secondary Winding Resistance	5 ohm

Min. Knee Point Voltage Requirement

$$V_{Kmin} = 30 * (I_{nt} * I_{sn}/I_{pn}) * (R_{ct} + R_L + S_r/I_r^2)V \tag{5.5}$$

$$\mathrm{V}_{Kmin} = 87.209V$$

$$VKmin = 2 * (I_{etf} * I_{sn}/I_{pn}) * (R_{ct} + R_L + S_r/I_r^2)V \tag{5.6}$$

$$\mathrm{V}_{Kmin} = 116.279V$$

We have selected a CT which gives Min. Knee Point Voltage of 116.279 V.

Figure 5.8: Direct Stroke Lightning Protection Diagram

5.6 Direct Stroke Lightning Protection

Earth shield wire is used in substation to protect equipment from direct stroke of lightning and Lightning Mast is used for the protection of building and remaining equipment in the substation which are not protected from Earth Shield Wire. Building of GIS is protected from direct stroke of lightning using Lightning Mast. Diagram of DSLP shows the projected area that is protected from Direct Stoke of Lightning. For preparation of DSLP diagram of this substation, Fixed angle method is used in which protected distance from Lightning Mast can be calculated. In this method,45 degree protection is considered. The protective zone of lightning mast is shown in figure 5.8.

Lightning Protection Calculation of Lightning Mast

The calculations for the Lightning protection by Lightning Mast is based on IEEE 998-2012 for lightning protection.

- Height of Lightning Mast h = 21 m
  Where height of lightning mast is the sum of structure height 19m and height of rod 2m.

- Height of the object to be protected hx = 5.77 m

- Active height of the lightning conductor ha = h - h_x = 15.23 m

The protection angle of shielding is considered as 45 degree as per IEEE 998-2012. calculation of radius of protection as per IEEE 998-2012 using the following equation:

$$tan45 = r_x/h - h_x \tag{5.7}$$

Radius of protective zone at height $h_x * r_x = 15.23m$

The object must be fully located within the radius of 15.23 m which represents the protective zone of lightning mast.

5.7 Busbar Sizing

Busbar sizing 25 is done to verify the increment in temperature of SF_6 must not go beyond critical temparature at rated current passing through busbar. For 220 kV GIS busbar, 4" aluminium tubular pipe has been used in proposed substation.

Required input data are:-

Description	Symbol	Unit	Values
Outer Diameter of Conductor	d_o	mm	114.3
Inner Diameter of Conductor	d_i	mm	97.18
Area	A	mm^2	2844
Length	L	m	3
Thermal Conductivity of alluminium	k	$w * m^{-1} * k^{-1}$	205
Mass density	ρ	kg/m^3	$2.8 * 10^{-8}$
Emissivity Co-efficient in Respect to Black Body	ε	-	0.75
Stefan-Boltzmann Constant	σ	$w * m^{-2} * k^{-4}$	$5.67 * E^{-8}$
Thermal Conductivity of SF_6	k	$w * m^{-1} * k^{-1}$	0.0136
Specific heat	C_p	J/kg.K	668.92
Gravity	g	m/s^2	9.8
Fluid temparature	T_∞	^0C	20
Surrounding temperature	T_{sur}	^0C	20
Fluid temparature	T_∞	K	293
Surrounding temperature	T_{sur}	K	293
Dynamic viscosity	μ	kg/s.m	1.377 * 10⁻4
Viscosity	ν	m^2/s	2.268 * 10^{-5}

Conduction heat transfer:-

$$Q = \frac{I^2 * \frac{\rho * L}{A}}{A} \tag{5.8}$$

$$Q = \frac{936^2 * \frac{2.8*10^{-8}*3}{0.002844}}{0.002844}$$

$$Q = 9.098 * 10^3\ W/m^2$$

$$Q = \frac{(T_1 - T_2) * K}{ln \frac{d_o}{d_i}} \tag{5.9}$$

$$9.098 * 10^3 = \frac{(T_1 - 20)*205}{ln \frac{0.114}{0.0972}}$$

$$T_1 = 27.075\ ^0C$$

Where T_1 is the surface temperature.

So that,

$$T_1 = T_S = 27.075\ ^0C$$

$$Grashofnumber Gr_L = \frac{g * \beta * (T_s - T_\infty) * L^3}{\nu^2} \tag{5.10}$$

$$Gr_L = \frac{9.8*3.372*10^{-3}*(27.075-20)*3^3}{(2.268*10^{-5})^2}$$

$$Gr_L = 1.227 * 10^{10}$$

$$Prandltnumber P_r = \frac{\mu * C_p}{K} \tag{5.11}$$

$$P_r = \frac{1.377*10^{-4}*668.92}{0.0136}$$

$$P_r = 6.772$$

$$Rayleighnumber Ra_L = Gr_L * P_r \tag{5.12}$$

$$Ra_L = 1.227 * 10^{10} * 6.772$$

$$Ra_L = 8.30 * 10^{10}$$

$$Nu_L = [0.825 + \frac{0.387 * Ra_L^{1/6}}{[1 + (\frac{0.492}{P_r})^{9/16}]^{8/27}}]^2 \tag{5.13}$$

$$Nu_L = [0.825 + \frac{25.55}{1.0629}]^2$$

$$Nu_L = 618.16$$

$$Nu_L = \frac{h * L}{K} \tag{5.14}$$

$$\frac{h*L}{K} = 618.16$$

$$\text{h} = \frac{618.16*0.0136}{3}$$

Convection heat transfer coefficient h = 2.80 $W/m^2.K$

$$Q = Q_{conv} + Q_{rad} \tag{5.15}$$

$$Q = h * \pi * D * L * (T_s - T_\infty) + \varepsilon * \pi * D * L * \sigma * (T_s^4 - T_{sur}^4) \tag{5.16}$$

Q =

$$2.80 * \pi * 0.114 * 3 * (27.075 - 20) + 0.75 * \pi * 0.114 * 3 * 5.67 * 10^{-8} * (300.075^4 - 293^4)$$

Q = 21.35 + 33.75

Here, the convection loss is 21.35 W and it is responsible for increase in temparature of SF_6 gas. But the temparature of SF_6 is not increased above surhace temperature. surface temperature is below the value of critical temperature. So that, SF_6 is safe and hence the busbar design is safe.

5.7.1 Simulation Result of Busbar

The simulation result of busbar for given dimension are shown in figure 5.9.

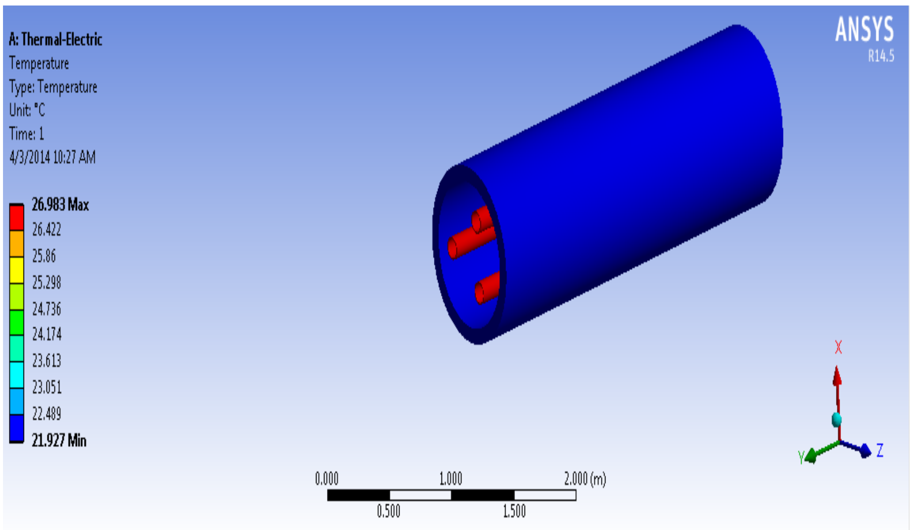


Figure 5.9: Simulation Result of Busbar

5.8 Control Room Layout And Panel Arrangement

It shows the panel arrangement in control room. It also shows the arrangement that is located at first floor and second floor. In this control room layout the location for control panel and relay panel of GIS is proposed. So that, Additional floor is not required for GIS panels.

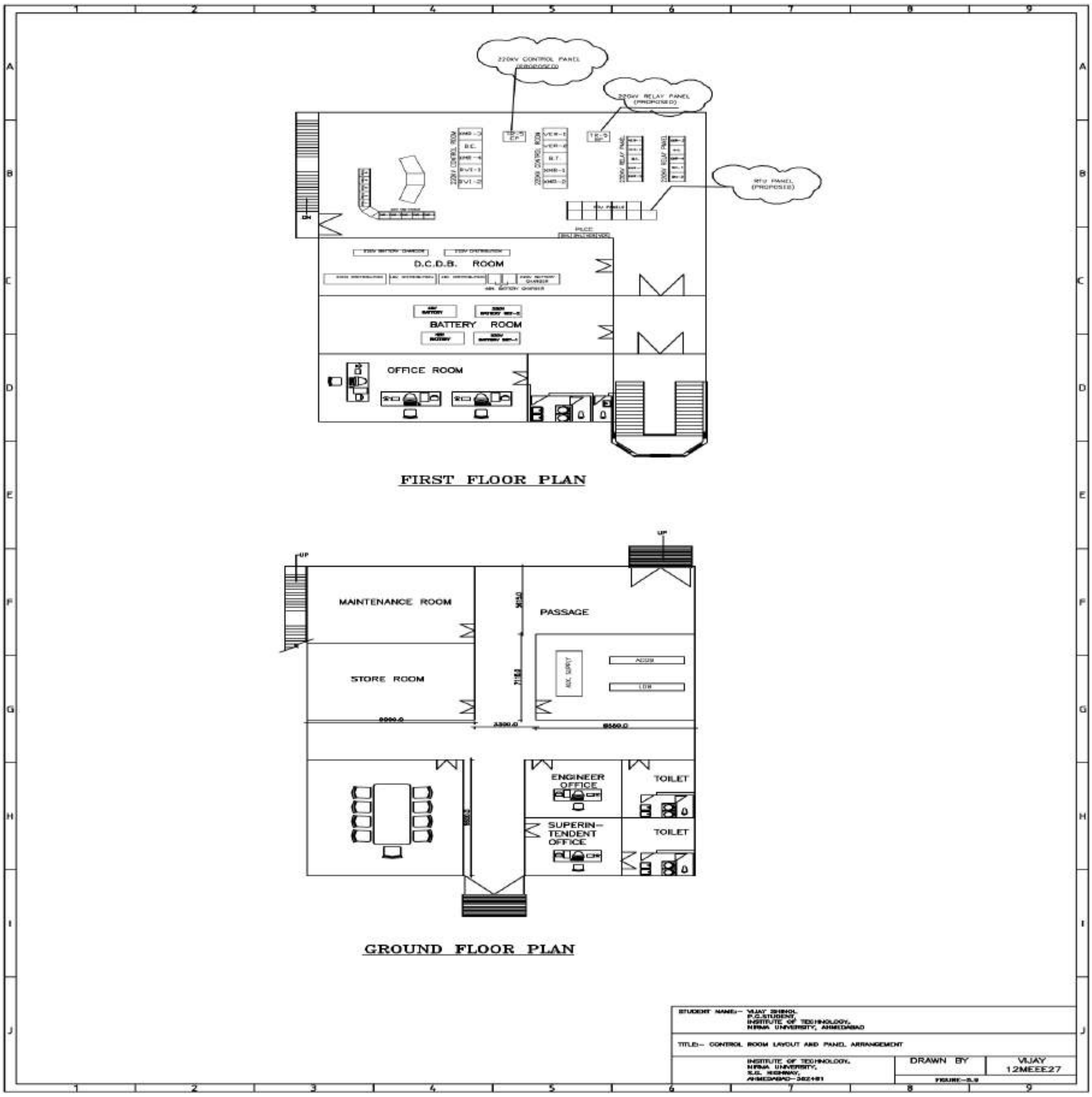


Figure 5.10: Control Room Layout and Panel Arrangement

5.9 Illumination Design

Good illumination in substation is necessary to facilatate normal operation and maintenance activities and at the same time to ensure safety of the working personnel. The lighting system of a particular area whether outdoor or indoor should be designed in such a way that uniform illumination is achieved. As far as possible any dark spots should be avoided. For this, proper lux level has to be maintained which requires careful placing of the luminaries and selection of proper mounting heights. For outdoor switchyard, average illumination level shall be 50 lux on main equipment and 20 lux on balance area of switchyard.For other parts of substation, recommended values of lux level are:-

Table 5.2: Recommended Lux Level

Particulars	**Lux level**
Control Room / Control Desk	300
Control Room / rear face of panel	150
Battery Room	100
Office and Reception	300
Maintenance Room	300
Corridors	70
Approach Road / Pathways	20
Conferance Room	300
Store Room	100
Fire Pump House	150
Test Room	450
Entrance Loby	150
D.G. Set Room	150

In outdoor area, luminaries should be directed as far as possible towards transformers, circuit breaker/disconnect switches, their mechanism boxes etc., where some operations may be necessary at night.

The choice of lamps, i.e., incandescent, fluorescent, mercury vapour, sodium vapour, halogen etc., depends mainly on nature of work, the number of hour of utilization, the cost of energy and the power available for utilization. For this substation, for switchyard lighting sodium vapour lamps are used and for control room lighting FTL and CFL are used. The foremost criterion in the design of illumination system of indoor area such as control room, workshop, repair bay, offices etc., is that illumination at the working height throughout the area should be as uniform as possible so as to avoid eye fatigue.In practice, complete uniformity of illumination is difficult to achieve and a ratio of minimum intensity to maximum equal to about 70 percent ususually considered acceptable.

The purpose of street lighting in substations is to promote safety and convenience on the approach roads, service roads and side walls inside switchyard. the aim should be to provide conditions of visibility adequate for accurate, certain and comfortable seeing.

Emergency lighting is called for in case of AC supply failure in substations. In indoor installations such as a control room, switchgear rooms etc., DC lamps connected to the DC supply system should be provided at suitable locations. These are brought in to service in case of ac supply failure. These are normally wired through automatic changeover contactor at DC distribution board.

CGLux 3.15 software is used for illumination design of switchyard and control room. The simulation result of GIS room is shown in appendixB, based on that illumination design of control room was carried out.

5.10 Station Auxiliary Supply

Station auxiliary supply is also an important part of substation. Station supply can be designed in two ways. In first method, supply is taken from a line passing nearer to the substation through tapping and then step down to distribution voltage. In second method, from lowest voltage of substation and then it is stepped down to distribution voltage. AC supply both single and three-phase, are needed in a substation for internal use for several function such as:-

- Illumination
- Battery Charging
- Transformer cooling system
- Transformer tap changing drives
- Power supplies for communication equipments
- Breaker/disconnect switch motors
- Fire protection system
- Marshalling kiosk lighting / Heating
- Air conditioning equipment

Generally, station supply is taken at 66 kV, 33 kV or 11 kV voltages. If voltage level is 66 kV or 33 kV, it is first stepped down to 11 kV. Station supply for this substation is taken from 33 kV outgoing line through tapping. Station transformer for this substation is of capacity 300 kVA. Then that voltage level is again stepped down to 415 V through auxiliary transformers. The auxiliary transformer is connected to the indoor AC distribution panel through cables. In the event of shutdown of the entire station, to ensure availability of AC auxiliary supply for charging of protective equipments, DG set is provided.

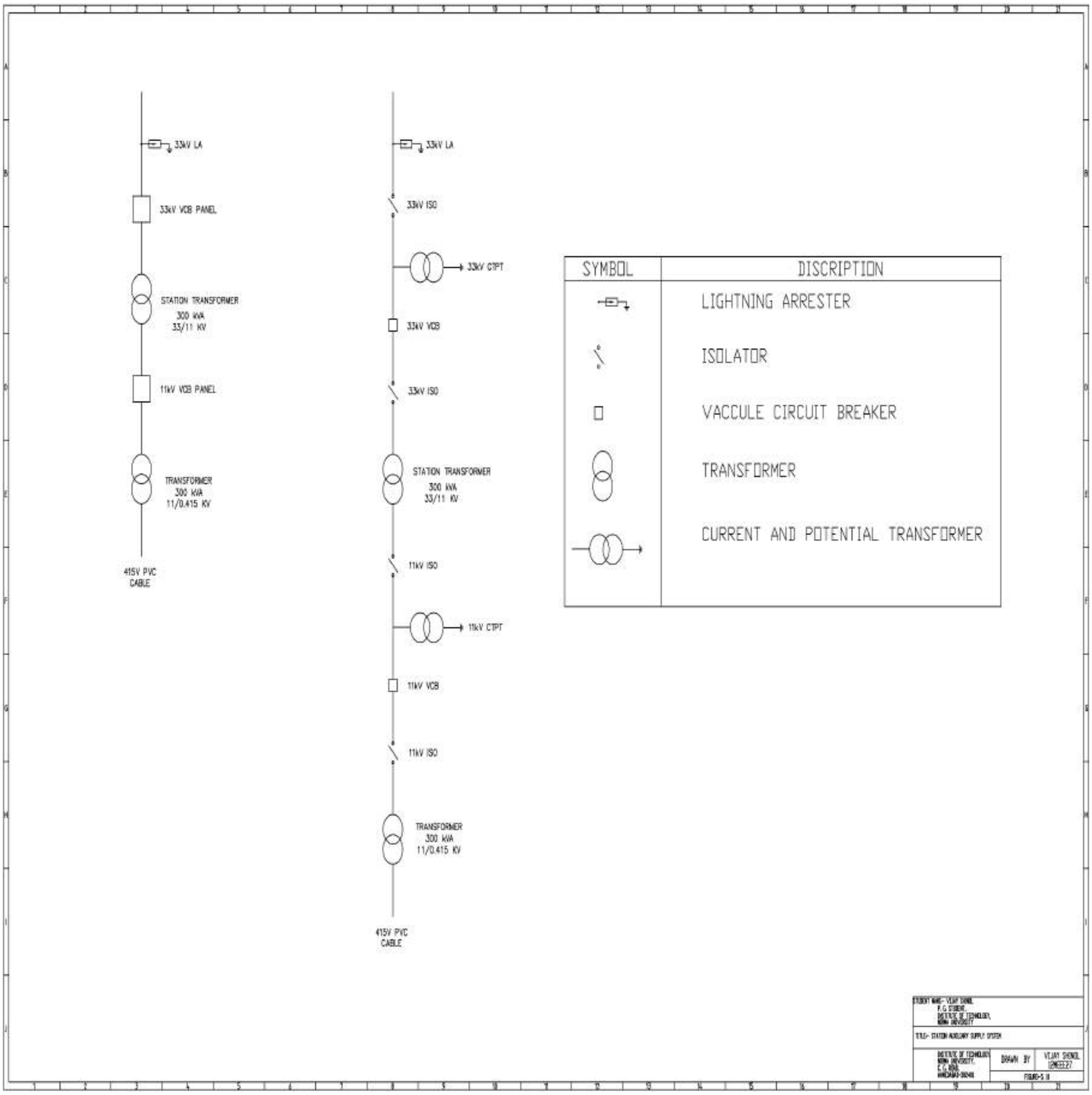


Figure 5.11: Station Auxiliary Supply System

5.11 Battery Sizing Calculation

DC auxiliary supply is required for relays, instrumentation, closing and tripping of circuit breaker, emergency lighting, control board indications etc. During normal operation, battery charger provides the required DC supply. An arrangement shall be made to supply an uninterrupted DC supply to load wherever the battery charger is facilitated with float/boost charging. The charging equipment generally consists of float charger and boost charger. In major substations, twin float chargers and twin boost chargers or with float cum boost charges with a suitable switching cubicles are generally used for reliability. However, to take care of failure of the AC supply, a storage battery of adequate capacity is provided to meet the DC requirement. Normally, the storage battery merely keeps floating on the direct current system and DC load is supplied by the float charger. In case of failure of rectifier (charger) in substation or failure of AC auxiliary supply the battery is drained. when AC power supply is resumed the boost charger charges the battery very quichly and restores itś normal voltage & capacity.

The voltage commonly used for the DC auxiliary supply is 110 or 220 volts batteries for substation equipment and 48 volts for PLCC equipments. Generally, Lead-Acid batteries are used. Its sizing has been done according to IEEE 485-1997.

Capacity of the battery should be adequate to supply,

- Momentary current required for operation of switchgear.
- The contineous load of indicating lamps, relay and contactors etc.

- Emergency lighting load.

Rating and quantity of battery sets used for different voltage levels are:-

Voltage Level (kV)	**Battery Voltage (V)**	**Quantity**	**Battery Capacity (AH)**	**Battery Charger Capacity (A)**
220 and 33	220	1	275	60
PLCC	48	1	25	10

DC Load Details

Summary of equipment wise DC load assesment is tabulated below:

Sr No.	Load Discription	Pannel Quantity		Contineous Load (W)		Momentary Load (W)	
		Exist.	Future	Unit	Total	Unit	Total
A	**220 kV Relay & Control Panels**						
	Line Relay Panel	4	0	99	396	285	1140
	Line Control Panel	4	0	103	412	5	20
	Transformer Relay Panel	4	1	111	555	287	1435
	Transformer Control Panel	4	1	103	515	5	25
	Transformer RTCC Panel	4	1	100	500	0	0
	Busbar relay Panel	2	0	89	178	275	550
	Busbar control Panel	2	0	103	206	5	10
	Local Control Cubic Panel	0	1	65	65	165	165
	Others	5	0	126	630	0	0
B	**33 kV VCB Panels**	4	1	201	1005	225	1125
	Sub-total				**4462**		**4460**
C	**Switchgears (No of Circuit Breakers)**	10	1				
	Drive Mechanisam					345	3795
	Trip Coil					690	7590
							11385
D	Isolator Operation	29	5			373	**12682**
E	**Emergency Loads**						
	Emergency DC Lights	8		60	**480**		

1) Total continuous load for 8 Hrs

$$= \frac{4462}{220} = 20.2818182 \approx \mathbf{20} \text{ Amps}$$

2) Emergency DC Lighting Load for 3 Hrs

$$= \frac{480}{220} = 2.18181818 \approx \mathbf{2} \text{ Amps}$$

3) Momentry Loads for 1 minute

a) Assuming Simultaneous Triping of 11nos of 220 kV CBs and isolator operation in case of Busbar fault

$$= \frac{24067}{220} = \mathbf{109.395455} = \mathbf{109} \text{ Amps}$$

b) Momentary load of panel

$$\text{Load} = \frac{4460}{220} = 20.2727273 \approx \mathbf{20} \text{ Amps}$$

Total momentary load for 1 min

Total load = **129** Amps

4) At the time of restoration, the following simultaneous operations assumed

At the time of restoration, simultaneous closing of one incomer and one outgoing feeder (controlling the transformer) and tripping of one breaker if fault persists. It also considers that one spring charge motor is in the process of starting and one motor is running.

At the time of restoration		Quantity	Unit	Total
1	Circuit Breaker Making Coil	1	345	345
2	One CB Tripping Coil	1	345	345
3	One Motor Starting	1	373	373
4	One Motor Running	1	373	373
				1436

$$\text{Load} = \frac{1436}{220} = 6.52727273 \approx \mathbf{7} \text{ Amps}$$

Figure 5.12: 220 V DC Load Detail

DC Load Details

Summary of equipment wise DC load assesment is tabulated below:

Sr No.	Load Discription	Pannel Quantity		Contineous Load (W)	
		Exist.	Future	Unit	Total
A	**220 kV PLCC Panel**				
	PLCC Panel	4	0	23	92
	Sub-total				**92**

1) Total continuous load for 8 Hrs

$$= \frac{92}{48} = 1.91666667 \approx \mathbf{2} \text{ Amps}$$

Figure 5.13: 48 V DC Load Detail

DC System Parameters

Enter following data:

Nominal DC System Voltage	:	220	V
Float charging voltage per cell	:	2	V
Standard temp. for rating cell capacity	:	25	°C
Design Margin factor Kd	:	1.15	
Temperature Correction Factor Kt	:	1	
Ageing Factor Ka	:	1.25	
Maximum Equilizing voltage per cell	:	2.33	V

Number of Battery Cells = Nominal DC System Voltage / Float charging voltage per cell

= 220 / 2

= 110

Hence, consider = 110 Nos of cells

Allowable DC system voltage based on 2.33 V per Cell equilizing voltage of Battery Bank

= 256.3 V

Voltage Window = 187 - 253 V

Number of cells governed by maximum system voltage is = Maximum System Voltage / Equilizing voltage per cell

= 253 / 2.33

= 108.5837 V

Hence consider = 109 V

End Of Discharge Voltage = Minimum System Voltage / No. of Cells

= 187 / 109

= 1.715596

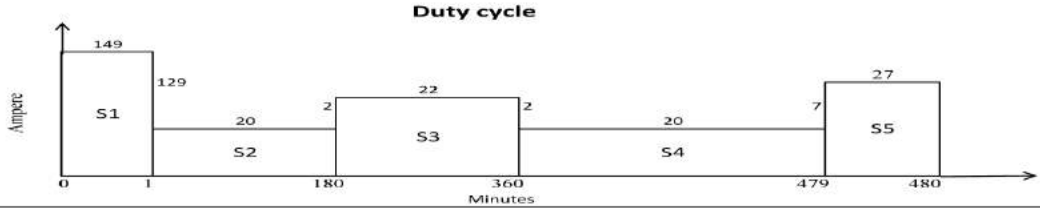
CELL SIZING CALCULATION

For Cell sizing calculations Ampere hour method using KT Capacity fector is used per IEEE Standard 485 based on 8hr duration & 1.71 final Volts per Cell.

KT factor based on Manufacturer`s Typical Performance curve and Cell data:

Discharge Periods per min	**1**	**119**	**120**	**179**	**180**	**299**
KT factor	0.77	2.85	2.87	3.68	3.7	5.6
Discharge Periods per min	**300**	**359**	**360**	**478**	**479**	**480**
KT factor	5.62	6.27	6.29	8.12	8.15	8.17

Duty cycle



Section 1
Cell Size = 149*0.77
= 114.73 AH

Section 2 = (149 x 3.7) - (129 x 3.68)
Cell Size = 76.58 AH

Section 3 = (149 x 6.29) - (129 x 6.27) + (2 x 3.7)
Cell Size = 135.78 AH

Section 4 = (149 x 8.15) - (129 x 8.12) + (2 x 5.6) - (2 x 2.85)
Cell Size = 172.37 AH

Section 5 = (149 x 8.17) - (129 x 8.15) + (2 x 5.62) - (2 x 2.87) + (7 x 0.77)
Cell Size = 176.87 AH

Applying Temp. Correction factor, Aging = 254.250625 AH
Consider = **275** AH

Battery Charger Calculation

The Ampere Capacity of the charger for substation applications can be determined by following equation :

A = L + BIF x C / H

A = Charge Capacity in Amps
= (To be calculated)
L = Continuous Load in Amps
= 20 Amps
BIF = Battery inefficiency Factor
1.1 for Lead-Acid
1.4 for Ni-Cd
C = Discharge in AH
= 275 AH
H = Battery Rechage Time in Hrs
= 8 Hrs
A = 20 + 302.5 / 8
A = 57.8125
= **60** **Amps**

The Lead-Acid battery of 220V , 275 AH for 8 hours duration, having 2 V output voltage of each module is selected.
The charger selected is Float cum Boost charger with 60A rating.

Figure 5.14: 220 V Battery Sizing

DC System Parameters

Enter following data:

Nominal DC System Voltage	:	48	V
Float charging voltage per cell	:	2	V
Standard temp. for rating cell capacity	:	25	°C
Design Margin factor Kd	:	1.15	
Temperature Correction Factor Kt	:	1	
Ageing Factor Ka	:	1.25	
Maximum Equilizing voltage per cell	:	2.33	V

Number of Battery Cells = Nominal DC System Voltage / Float charging voltage per cell

= 48 / 2

= 24

Hence, consider ≈ 24 Nos of cells

Allowable DC system voltage based on 2.33 V per Cell equilizing voltage of Battery Bank

= 55.92 V

Voltage Window = 41 - 55 V

Number of cells governed by maximum system voltage is = Maximum System Voltage / Equilizing voltage per cell

= 55 / 2.33

= 23.60515 V

Hence consider ≈ 24 V

End Of Discharge Voltage = Minimum System Voltage / No. of Cells

= 40.8 / 24

= 1.7

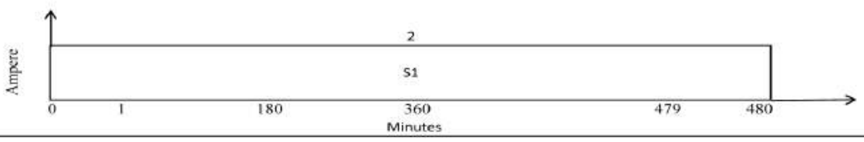
CELL SIZING CALCULATION

For Cell sizing calculations Ampere hour method using KT Capacity fector is used per IEEE Standard 485 based on 8hr duration & 1.71 final Volts per Cell.

KT factor based on Manufacturer`s Typical Performance curve and Cell data:

Discharge Periods per min	**1**	**119**	**120**	**179**	**180**	**299**
KT factor	0.77	2.85	2.87	3.68	3.7	5.6
Discharge Periods per min	**300**	**359**	**360**	**478**	**479**	**480**
KT factor	5.62	6.27	6.29	8.12	8.15	8.17

Duty cycle



Section

Cell Size = 2*8.17

= 16.34 AH

Applying Temp. Correction factor, Aging = 23.48875 AH

= **25** AH

Battery Charger Calculation

The Ampere Capacity of the charger for substation applications can be determined by following equation :

A = L + BIF x C / H

A = Charge Capacity in Amps

= (To be calculated)

L = Continuous Load in Amps

= 2 Amps

BIF = Battery inefficiency Factor

1.1 for Lead-Acid

1.4 for Ni-Cd

C = Discharge in AH

= 25 AH

H = Battery Rechage Time in Hrs

= 8 Hrs

A = 2 + 27.5 / 8

A = 5.4375

≈ **10** **Amps**

The Lead-Acid battery of 220V , 25 AH for 8 hours duration, having 2 V output voltage of each module is selected.

The charger selected is Float cum Boost charger with 10A rating.

Figure 5.15: 48 V Battery Sizing

5.12 Distribution Board

Load Distribution Board:- Load Distribution Board is provided in the control room to distribute the load of switchyard, control room and substation colony. Switchyard load covers outdoor lighting of switchyard, street lighting and indoor lighting of D.G. set room, GIS room and Fire Pump house. For switchyard, one load distribution boards is provided. Two load distribution board is provided for control room and two load distribution board is provided for substation colony which covers street lighting load, B-1 load and B-2 load.

AC Distribution Board:- AC load of substation is distributed through AC Distribution Board. Load Distribution Board gets supply through AC Distribution Board. AC Distribution Board also distributes supply to Bay Marshalling Kiosk, Local control cubical, Panels of control room, Pumps, Battery Charger panels, Transformer cooler control box, Tap changing system of transformers and crane. In case of failure of station supply, D.G. set of 175 KVA capacity will supply the required load of substation. For this substation, 0ne AC distribution boards is provided.

DC Distribution Board:- When AC supply is available, DC load will get supply through battery charger panel. When AC load is not available, DC load will get supply through battery set provided. DC load is distributed through DC Distribution Board. DC Distribution Board distributes supply to BMK, LCC, Relay Control panels, DC emergency lighting and PLCC panels. For each voltage level of 220 V, 110 V and 48 V, separate DC Distribution Board has to be provided. For this substation, one DCDB for 220 V and one for 48 V systems are provided.

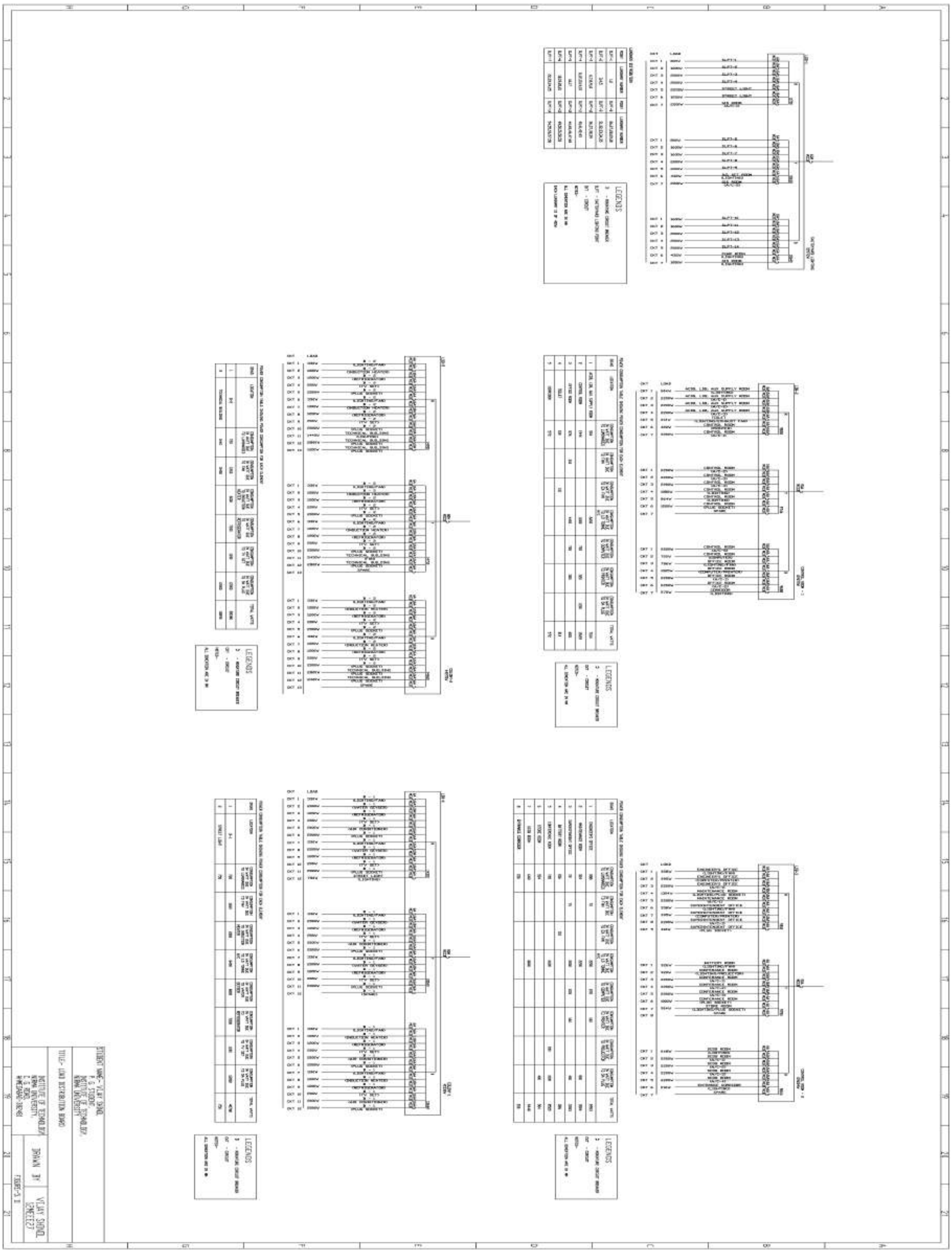


Figure 5.16: Load Distribution Board

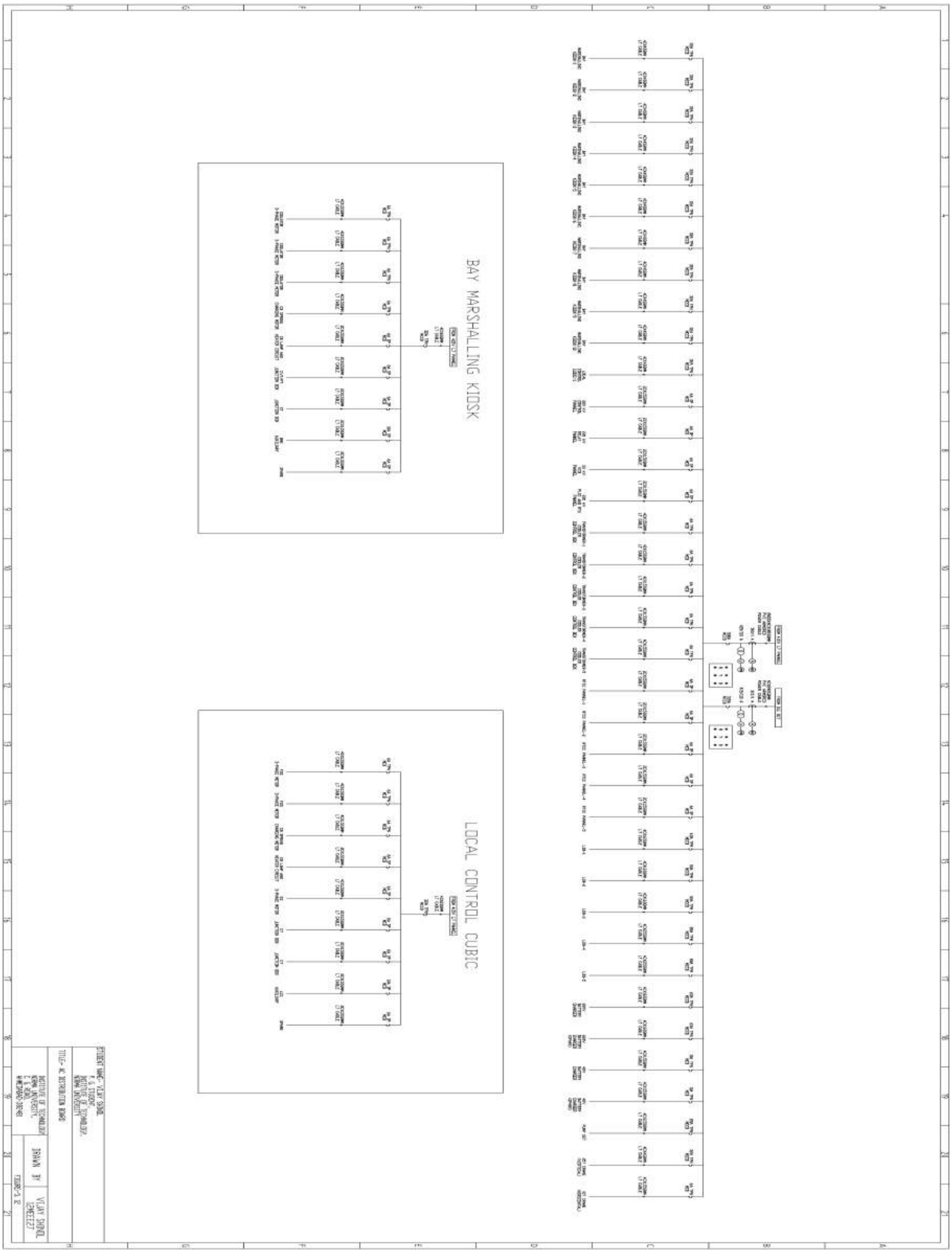


Figure 5.17: AC Distribution Board

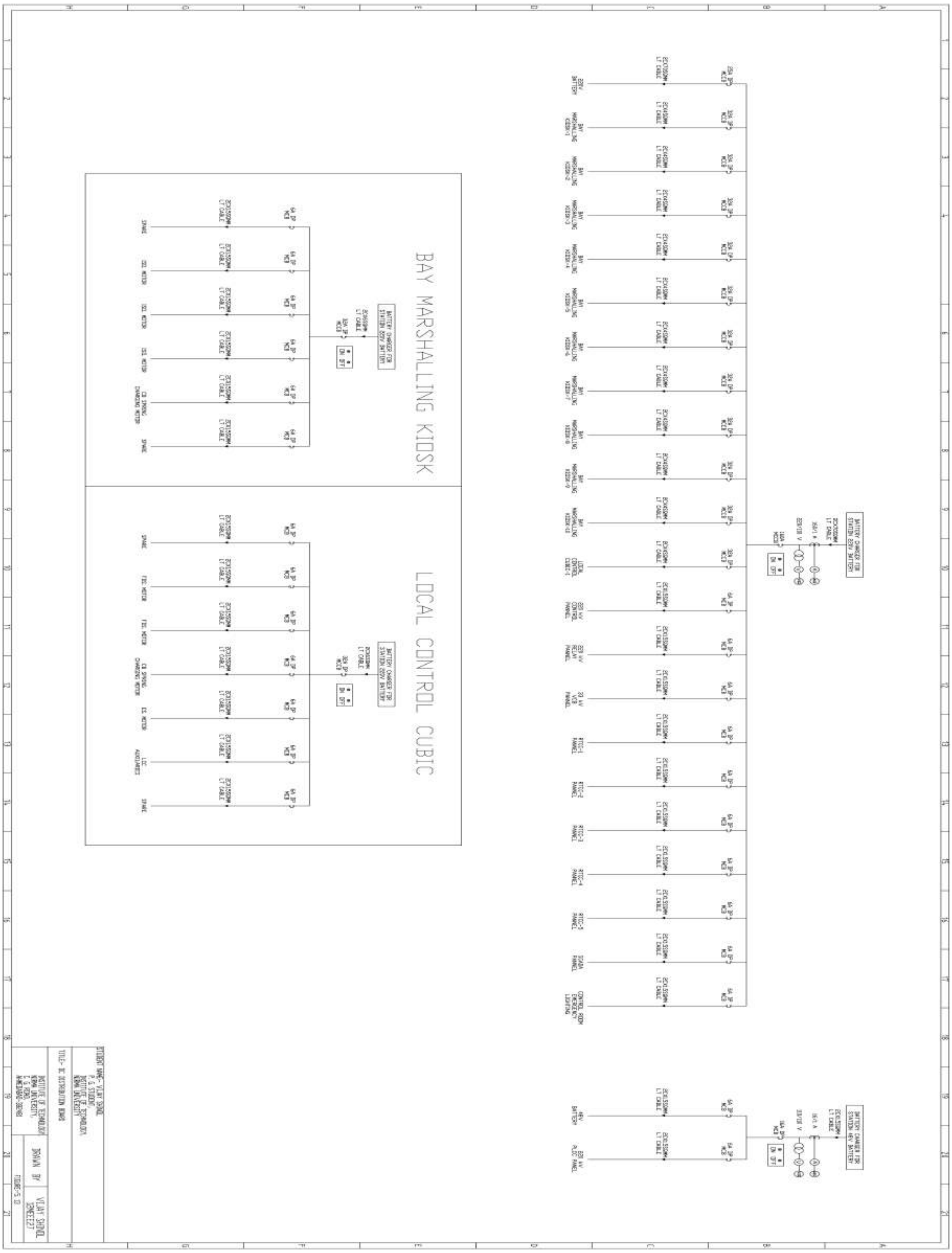


Figure 5.18: DC Distribution Board

5.13 Cable Trench Layout

Cable Trench is normaly laid for cable run. It includes both power and control cables. It also includes the cables from lighting equipment in substation. In cable trench, trays are used to support cables. Power and control cables shall be laid in separate trays. Cables from equipment/kiosk to trench are taken through PVC pipes. Cable trays are made with provision that a maintenance personal can work easily.

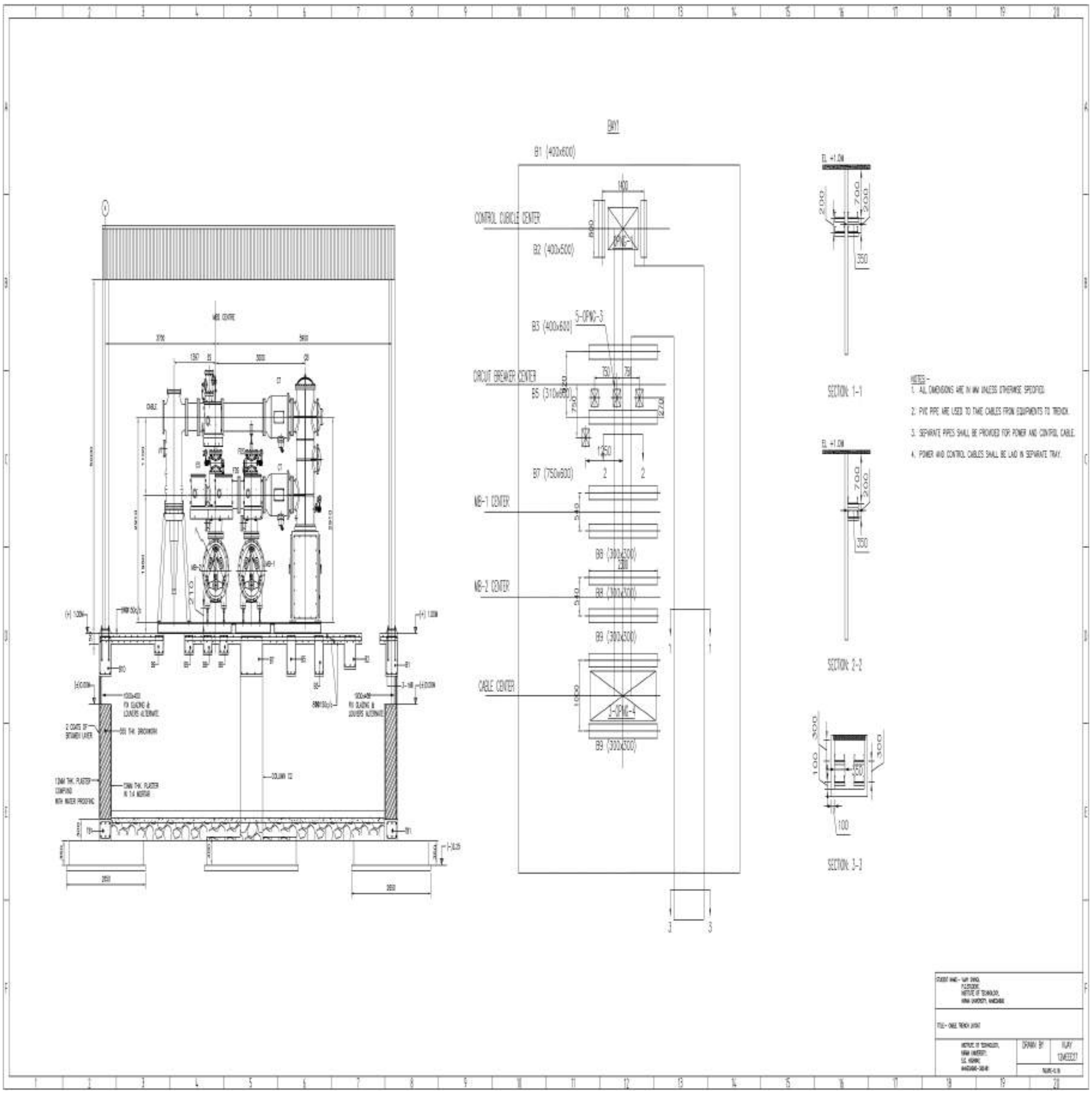


Figure 5.19: Cable Trench Layout

5.14 Cable Schedule

Cable schedule means the schedule which contains cable length, no of core in cable, function of each core, route from field to panel or from one location to other. Total requirement of different power and control cable are shown in figure 5.20.

SUMMARY OF POWER CABLES FOR GIS		
SR NO	NO OF CORES	QTY (MTR)
1	4C X 4 SQMM	125
2	4C X 1.5 SQMM	190
3	2C X 4 SQMM	85
4	2C X 1.5 SQMM	400

SUMMARY OF CONTROL CABLES FOR GIS		
SR NO	NO OF CORES	QTY (MTR)
1	24C X 2.5 SQMM	220
2	19C X 2.5 SQMM	150
3	14C X 2.5 SQMM	125
4	12C X 2.5 SQMM	225
5	10C X 2.5 SQMM	320
6	4C X 2.5 SQMM	635

Figure 5.20: Summary of Power and Control Cable

5.15 SCADA System

The SCADA system shall perform data acquisition from remote terminal units (RTUs) located at substations. The RTU data includes status and sequence of event inputs. RTU communications shall utilise the IEC 61850 protocols. The substation SCADA system shall exchange various types of real time and historical data with the PC based MS office applications. The scada system for proposed substation is shown in figure 5.21.

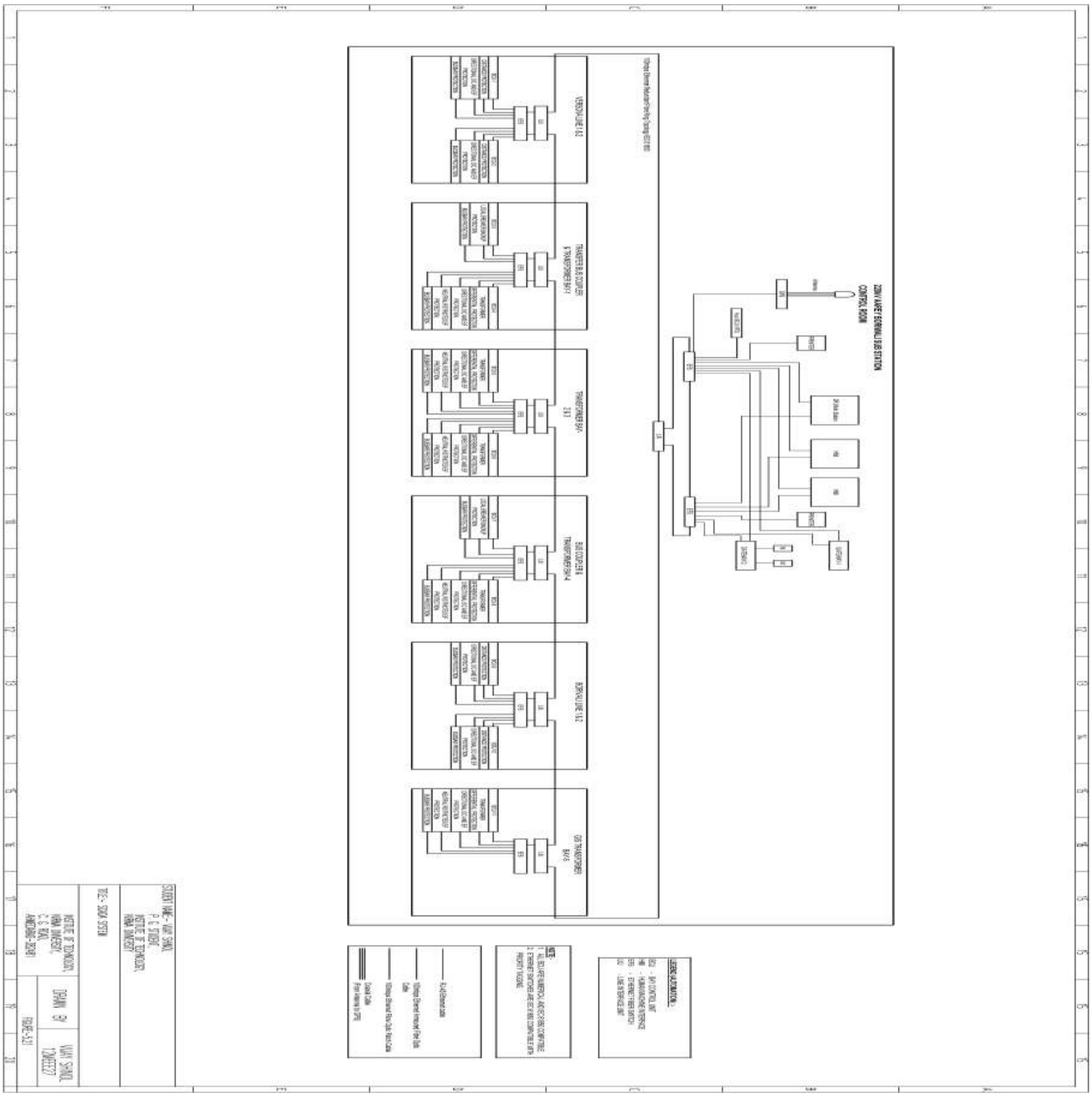


Figure 5.21: SCADA System

5.16 Interface Between AIS and GIS

AIS bus is connected to GIS bus through 1C x 500 mm^2 power cable. the bending radius of power cable is 20 times the diameter of conductor and it is 2200 mm. If the power cable is bended beyond its bending radius then power cable is stressed more and it may damage.

5.17 Reconductring Requirement

The existing AIS substation is having 220 kV main bus of Twin AAAC Zebra. The main bus gantry structures and column foundations are designed to take the mechanical load of twin conductor only. This Main bus bar can be loaded up to 1935 Amps. With additional demand, the bus bar current will go to 1620 Amps. So, there is no need to replace the existing bus of AIS.

5.17.1 Another Case Study

The existing receiving substation at Magthane, Borivali is having 220 kV main bus of Twin ACSR Moose. This main bus bar can be loaded for about 1500 Amps. With additional demand, the bus bar current will go to 3100 Amps. This has become necessary to allow the additional power evacuation from the existing bus to the proposed GIS in the substation. The existing bus gantries of the substations cannot withstand the load of Quad Moose and replacing them would need a very long shut down. The metropolitan city of Mumbai cannot afford long shut down. For this particular application it is proposed to use Twin ACSS Curlew conductor instead of existing Twin ACSR Moose Conductor. Since the mechanical properties of ACSS Curlew and ACSR Moose conductor are nearly same, it will be possible to string them on the existing gantry structures without any modification and their foundations also need no change.

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

Due to increase in load demand, it is required to increase capacity of substation. In urban AIS substation where space is main constraint. GIS extension provides a solution. One bay of GIS required much less space as compared to one bay of AIS and it is possible to augment the capacity of AIS substation.
The AIS cum GIS substation means extension of existing bus in such a manner that we can create more line bays and transformer bays.
While doing so, the capacity of existing bus (AIS) should not be exceeded. Failing this the bus may have to be changed.

6.2 Future Scope

- Design and Analysis of Gas Insulated Bus duct system
- Replacement of SF_6 with distilled water as a dielectric medium
- Breakdown And Thermal Study of SF_6 gas
- Relay coordination

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Appendix A

Earthing Design Calculation

Data required for design are:-

- Symmetrical fault current in substation(kA):- 40
- Duration of shock for determining allowable body current(Sec.):- 0.5
- Duration of fault current for sizing ground conductor(Sec.):- 1
- Surface layer resistivity(ohm-m)(**for AIS)**:- 3000
- Surface layer resistivity(ohm-m)(**for GIS)**:- 1000000
- Surface layer thickness(m):- 0.15
- Grid reference depth(m):- 1
- Soil resistivity(ohm-m):- 60
- diameter of earthing conductor:- 0.04
- Depth of ground grid conductors(m):- 0.6
- Length of grid conductor in X direction(m):- 203
- Length of grid conductor in Y direction(m):- 112
- Spacing between parallel conductors(m):- 7
- Length of ground rod(m):- 3
- Number of rods placed:- 45
- Decrement factor for determining Ig:- 1
- Number of grid conductors in X direction:- 17

- Number of grid conductors in Y direction:- 30
- Equivalent Earthing mat area(m^2):- 22736
- Total Length of Buried Conductor(m):- 6946
- Total length of ground rods(m):- 135

For earthing mat conductor Zinc coated steel material has been used. Parameters considered for Zinc coated steel material:-

- RMS Current(KA):- 40
- Fusing temperature((^0C):- 419
- Ambient temperature(^0C):- 50
- Reference temperature for material constant(^0C):- 20
- Thermal coefficient of resistivity at 0 $^0C(1/^0C)$:- 0.00341
- Thermal coefficient of resistivity at 20 $^0C(1/^0C)$:- 0.0032
- Resistivity of the ground conductor at 20 ^0C(μohm.cm):- 20.1
- K_0 at 0 $^0C(1/^0C)$:- 293
- Duration of Current(sec.):- 1
- Thermal capacity, TCAP(J/$cm^3.^0C$):- 3.93

For Air Insulated Substation

Step 1:- Determination of Size of Conductor for Earthing Grid

$$A_{mm^2} = I * \frac{1}{\sqrt{(\frac{T_{CPA}*10^{-4}}{t_c*\rho_r*\alpha_r})ln(\frac{K_o+T_m}{K_o+T_a})}} \tag{A.1}$$

A_{mm^2} =598.94

From CBIP Publication No 223, The following values of Corrosion factor has been considerd for different types of soil resistivity.

- In case of conductors to be laid in soils having resistivity greater than 100 Ohm-metre - **No allowance**
- In case of conductors to be laid in soils having resistivity from 25 to 100 Ohm-metre - **15 percent allowance**
- In case of conductors to be laid in soils having resistivity lower than 25 Ohm-metre or where treatment of soil around electrodes is carried out - **30 percent allowance**

A_{mm^2}=598.94 X 1.15

A_{mm^2}=688.79

Provided area of conductor from CBIP 223,

Provided Area = 75 * 12

Provided Area= 900

Step 2:- Touch and Step Voltage Criteria

$$C_s = \frac{1 - (0.09 * (1 - \rho/\rho_s))}{2 * h_s * 0.09} \tag{A.2}$$

C_s=0.77

$$E_{touch50} = (1000 + 1.5c_s\rho_s) * (0.116/\sqrt{ts}) \tag{A.3}$$

$E_{touch50}$ =735V

$$E_{step50} = (1000 + 6c_s\rho_s) * (0.116/\sqrt{ts}) \tag{A.4}$$

E_{step50} =2449

Step 3:- Determining Grid Resistance

The value of Grid Resistance is,

$$R_g = \rho * [\frac{1}{t} + \frac{1}{\sqrt{20A}}(1 + \frac{1}{1 + h\sqrt{20A}})] \tag{A.5}$$

R_g =0.19 ohm

Step 4:- Maximum Grid Current

Maximum Grid CurrentI_G is determined by,

$$I_G = D_f * S_f * I_g \tag{A.6}$$

Consider Dt = 1 for fault duration of 1 Sec. Using Table: C1(IEEE 80(2000), pg no:-150), the equivalent impedance of the transmission and distribution ground system for 4 lines and 4 distribution feeder is Z_{eq} = 0.23+0.12i.

$$S_f = |\frac{Z_{eq}}{Z_{eq} + R_g}| \tag{A.7}$$

S_f= 0.60

$I_G = D_f * S_f * I_g$

I_G= 24018.56 A

Step 5:- GPR

$$GPR = I_G * R_g \tag{A.8}$$

GPR = 4444V

Step 6:- Mesh Voltage

$$K_h = (1 + \frac{h}{h_0})^{0.5} \tag{A.9}$$

$$K_h = 1.265$$

$$n = n_a * n_b * n_c * n_d \tag{A.10}$$

$$n_a = \frac{2 * L_c}{L_p} \tag{A.11}$$

Where,
L_c = Total Length of conductor
L_p = Peripheral Length of the earthing equivalent area

$$L_c = ((Lx * Nx) + (Ly * Ny)) \tag{A.12}$$

$$L_c = 6811$$

$$L_p = (2 * Lx) + (2 * Ly) \tag{A.13}$$

$$L_p = 630$$
$$n_a = 21.62$$

$$n_b = \sqrt{\frac{L_p}{4 * \sqrt{A}}} \tag{A.14}$$

$$n_b = 1.022$$
$$n_c \ \& \ n_d = 1$$
$$\text{n} = 22.10$$
$$k_{ii} = 1$$

$$K_m = \frac{1}{2 * \pi} * [ln(\frac{D^2}{16 * h * d} + \frac{(D + 2 * h)^2}{8 * D * d} - \frac{h}{4 * d}) + \frac{k_{ii}}{k_h} ln \frac{8}{\pi * (2 * n - 1)}] \tag{A.15}$$

$$k_m = 0.62$$

$$K_i = 0.644 + 0.148 * n \tag{A.16}$$

$$K_i = 3.915$$

so that,

$$E_m = \frac{\rho * I_G * K_m * K_i}{L_c + [1.55 + 1.22 * (\frac{L_r}{\sqrt{L_x^2 + L_y^2}})] * L_R} \tag{A.17}$$

$$E_m = 501.60V$$

Step 7:- Calculation of Step Voltage

$$K_s = \frac{1}{\pi}(\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}(1 - 0.5^{n-2})) \tag{A.18}$$

$$K_s = 0.353$$

$$E_s = \frac{(\rho * I_G * K_s * K_i)}{(0.75 * L_c + 0.85 * L_R)} \tag{A.19}$$

$$E_s = 380.857$$

Step 8:- Comparison between calculated tolerable Step and Touch voltages

Tolerable Touch Voltage (V) = **735.32** is greater than Calculated Touch Voltage (V) = **501.60**

Tolerable Step Voltage (V) = **2449.12** is greater than Calculated Step Voltage (V) = **380.86**

Hence Earthing design is safe.

For Gas Insulated Substation

Step 1:- Determination of Size of Conductor for Earthing Grid

$$A_{mm^2} = I * \frac{1}{\sqrt{(\frac{T_{CPA}*10^{-4}}{t_c*\rho_r*\alpha_r})ln(\frac{K_o+T_m}{K_o+T_a})}} \tag{A.20}$$

$$A_{mm^2} = 598.94$$

From CBIP Publication No 223, The following values of Corrosion factor has been considerd for different types of soil resistivity.

- In case of conductors to be laid in soils having resistivity greater than 100 Ohm-metre - **No allowance**
- In case of conductors to be laid in soils having resistivity from 25 to 100 Ohm-metre - **15 percent allowance**
- In case of conductors to be laid in soils having resistivity lower than 25 Ohm-metre or where treatment of soil around electrodes is carried out - **30 percent allowance**

$$A_{mm^2}=598.94 \text{ X } 1.15$$

$$A_{mm^2}=688.79$$

Provided area of conductor from CBIP 223,

Provided Area = 75 * 12

Provided Area = 900

Step 2:- Touch and Step Voltage Criteria

$$C_s = \frac{1-(0.09*(1-\rho/\rho_s))}{2*h_s*0.09} \tag{A.21}$$

$$C_s\text{=}0.77$$

$$E_{touch50} = (1000 + 1.5c_s\rho_s) * (0.116/\sqrt{ts}) \tag{A.22}$$

$$E_{touch50} \text{ =189455V}$$

$$E_{step50} = (1000 + 6c_s\rho_s) * (0.116/\sqrt{ts}) \tag{A.23}$$

$$E_{step50} = 757326$$

Step 3:- Determining Grid Resistance

The value of Grid Resistance is,

$$R_g = \rho * [\frac{1}{t} + \frac{1}{\sqrt{20A}}(1 + \frac{1}{1+h\sqrt{20A}})] \tag{A.24}$$

$$R_g = 0.19ohm$$

Step 4:- Maximum Grid Current

Maximum Grid CurrentI_G is determined by,

$$I_G = D_f * S_f * I_g \tag{A.25}$$

Consider Dt = 1 for fault duration of 1 Sec. Using Table: C1(IEEE 80(2000), pg no:-150), the equivalent impedance of the transmission and distribution ground system for 4 lines and 5 distribution feeder is Z_{eq} = 0.23+0.12i.

$$S_f = |\frac{Z_{eq}}{Z_{eq} + R_g}| \tag{A.26}$$

$$S_f = 0.60$$

$$I_G = D_f * S_f * I_g$$

$$I_G\text{= 24018.56A}$$

Step 5:- GPR

$$GPR = I_G * R_g \tag{A.27}$$

$$\text{GPR = 4444V}$$

Step 6:- Mesh Voltage

$$K_h = (1 + \frac{h}{h_0})^{0.5} \tag{A.28}$$

$$K_h = 1.265$$

$$n = n_a * n_b * n_c * n_d \tag{A.29}$$

$$n_a = \frac{2 * L_c}{L_p} \tag{A.30}$$

Where,
L_c = Total Length of conductor
L_p = Peripheral Length of the earthing equivalent area

$$Lc = ((Lx * Nx) + (Ly * Ny)) \tag{A.31}$$

$$L_c = 6811$$

$$L_p = (2 * Lx) + (2 * Ly) \tag{A.32}$$

$$L_p = 630$$
$$n_a = 21.62$$

$$n_b = \sqrt{\frac{L_p}{4 * \sqrt{A}}} \tag{A.33}$$

$$n_b = 1.022$$
$$n_c \& n_d = 1$$
$$\text{n} = 22.10$$
$$k_i i = 1$$

$$K_m = \frac{1}{2 * \pi} * [ln(\frac{D^2}{16 * h * d} + \frac{(D + 2 * h)^2}{8 * D * d} - \frac{h}{4 * d}) + \frac{k_{ii}}{k_h} ln \frac{8}{\pi * (2 * n - 1)}] \tag{A.34}$$

$$k_m = 0.62$$

$$K_i = 0.644 + 0.148 * n \tag{A.35}$$

$$K_i = 3.915$$

$$E_m = \frac{\rho * I_G * K_m * K_i}{L_c + [1.55 + 1.22 * (\frac{L_r}{\sqrt{L_x^2 + L_y^2}})] * L_R} \tag{A.36}$$

$$E_m = 501.60V$$

Step 7:- Calculation of Step Voltage

$$K_s = \frac{1}{\pi}(\frac{1}{2h} + \frac{1}{D + h} + \frac{1}{D}(1 - 0.5^{n-2})) \tag{A.37}$$

$$K_s = 0.353$$

$$E_s = \frac{(\rho * I_G * K_s * K_i)}{(0.75 * L_c + 0.85 * L_R)} \tag{A.38}$$

$$E_s = 380.857$$

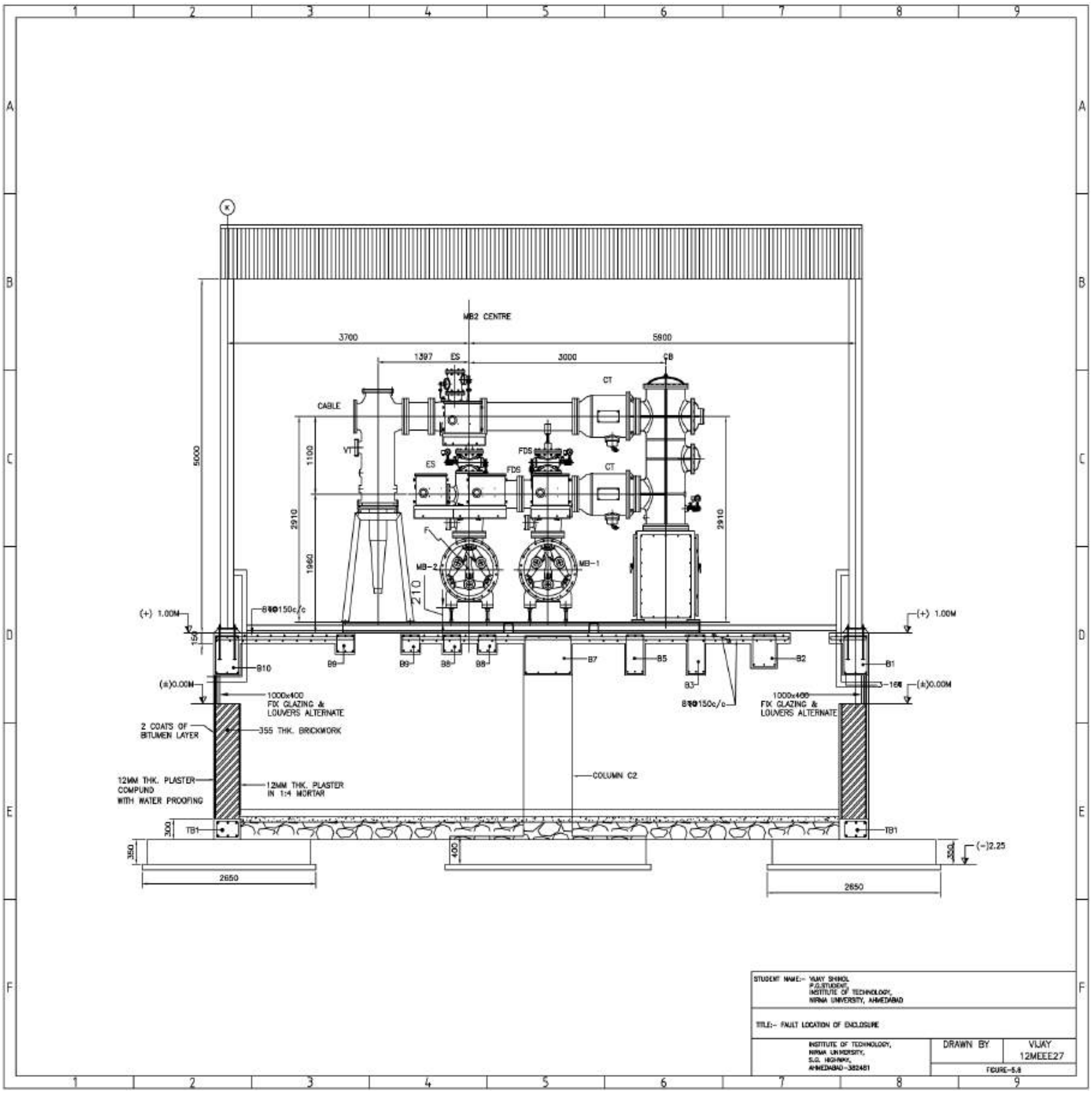


Figure A.1: Fault Location of Enclosure

Step 8:- Calculation of E_g

For Vertical Length

- Frequency f(HZ):- 50
- I_s:- 40000
- r_1 (m):- 0.1675
- r_2 (m):- 0.1742
- resistivity (ohm-m):- 0.000000029
- L(m):- 2.91
- Structure Piller Length L1(m):- 0.21
- Number of Piller:- 9

$$A(m^2) = \pi * (r_2^2 - r_1^2) \tag{A.39}$$

A = 0.007192331

$$R_e = \frac{\rho * l}{A} \tag{A.40}$$

$$R_e = 1.17333 * e^{-05}$$

$$L_e(H/m) = 2 * \mu * s(\frac{1}{(r_2^2 - r_1^2)}) * (\frac{r_2^2 - 3 * r_1^2}{4} + \frac{r_1^4}{r_2^2 - r_1^2} * Ln(\frac{r_2}{r_1}) * 10) \tag{A.41}$$

$$L_e(H/m) = 2.56371 * e^{-}07$$

$$X_{Le}(ohm) = 2 * \pi * f * L_e * L \tag{A.42}$$

$$X_{Le}(ohm) = 0.000234375$$

$$R_s(ohm) = \frac{(390\mu ohmperm * L1)}{numberofpiller} \tag{A.43}$$

$$R_s(ohm) = 0.0000091$$

$$L_s(nHperm) = 650$$

$$X_{Ls} = \frac{(2 * 3.14 * f * L_s * L1)}{numberofpillers} \tag{A.44}$$

$X_{Ls}(ohm)$ =4.76475 * $e^{-}06$

For Horizontal Length

- Frequency f(HZ):- 50
- r_1 (m):- 0.1675
- r_2 (m):- 0.1742
- resistivity (ohm-m):- 0.000000029

- L(m):- 3

$$A(m^2) = \pi * (r_2^2 - r_1^2) \tag{A.45}$$

$$\text{A} = 0.007192331$$

$$R_e = \frac{\rho * l}{A} \tag{A.46}$$

$$R_e = 1.20962 * e^{-05}$$

$$L_e(H/m) = 2 * \mu * s(\frac{1}{(r_2^2 - r_1^2)}) * (\frac{r_2^2 - 3 * r_1^2}{4} + \frac{r_1^4}{r_2^2 - r_1^2} * Ln(\frac{r_2}{r_1}) * 10) \tag{A.47}$$

$$L_e(H/m) = 2.56371 * e^-07$$

$$X_{Le}(ohm) = 2 * \pi * f * L_e * L \tag{A.48}$$

$$X_{Le} \text{ (ohm)} = 0.000241624$$

$$\mid Z \mid (ohm) = 0.000481891$$

$$E_g(V) = \mid Z \mid * I \tag{A.49}$$

$$E_g(V) = 19.27563143$$

$$\sqrt{E_m^2 + E_g^2} = 501.9705175\text{V}$$

Step 9:- Comparison between calculated tolerable Step and Touch voltages

Tolerable Touch Voltage (V) = **189454.50** is greater than Calculated Touch Voltage (V) = **501.97**

Tolerable Step Voltage (V) = **757325.86** is greater than Calculated Step Voltage (V) = **380.86**

Hence Earthing design is safe.

Appendix B

Illumination Design of GIS Room

Input Data	Notation	Value
Lengh of GIS Room (m)	L	10
Width of GIS Room (m)	W	10
Required Level of Illumination (lux)	E	300
Coefficient of Utilization Factor	COU	0.55
Maintenance Factor	MF	0.7
Provided Luminaries (Indistrial Type)	-	2 * 36W FTL
Lumens Output at 230 V	-	3250

Lumens output of single fitting with two lamp at 230 volt

$$= 2 * 3250$$

$$= 6500 \text{ Lumens}$$

Total area where illumination is provided (A)

$$= 10 * 10$$

$$= 100 \text{ Sq Mtr}$$

Total lumens required for above area

$$= 100 * 300$$

$$= 30000$$

Lumens output of each set

$$= 6500 * 0.55 * 0.7$$

$$= 2502.5$$

Total nos. of fitting required = $\frac{Totallumensrequired}{Lumensoutputofeachset}$

$$= 30000/2502.5$$

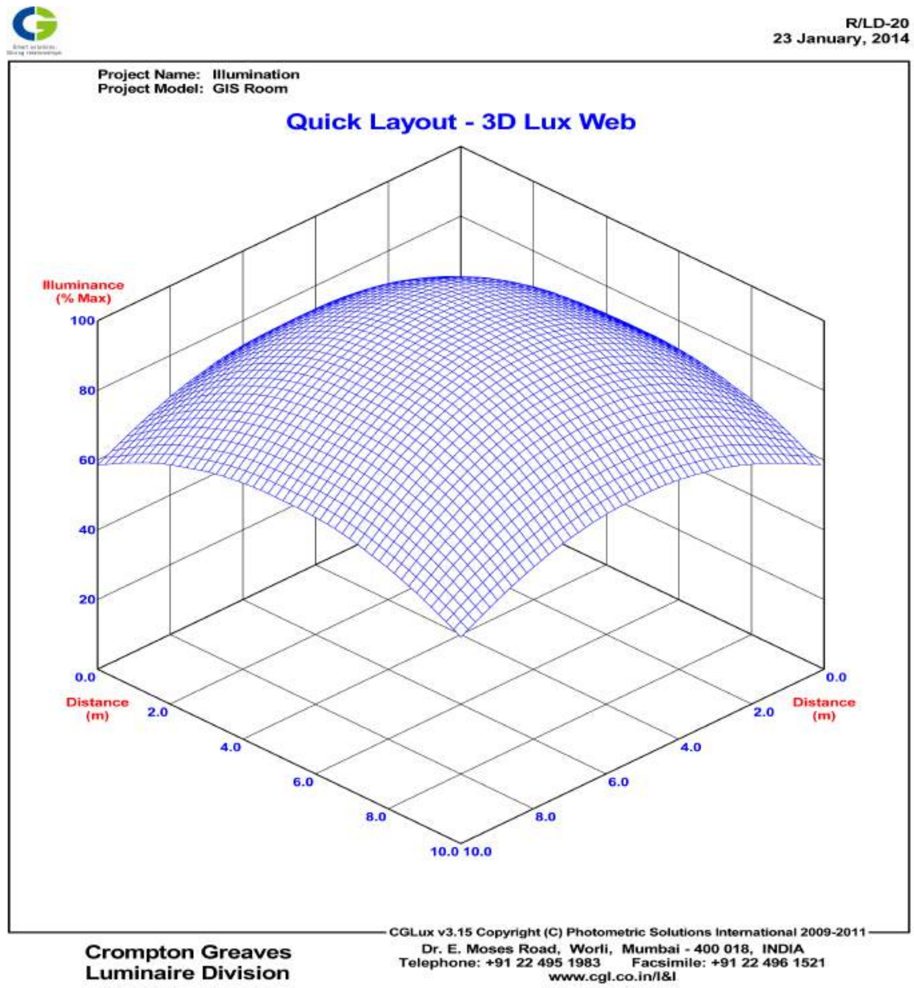
$$= 11.988$$

Say = 12 set

Hence considering no. of set = 12 Set

Hence no. of lamp = 24

The simulation result of illumination design of GIS room is shown below.


R/LD-20
23 January, 2014
Project Name: Illumination
Project Model: GIS Room
Quick Layout - 3D Lux Web
Illuminance
(% Max)
100
80
60
40
20
0.0
Distance
(m)
2.0
4.0
6.0
8.0
10.0
10.0
8.0
6.0
4.0
2.0
0.0
Distance
(m)
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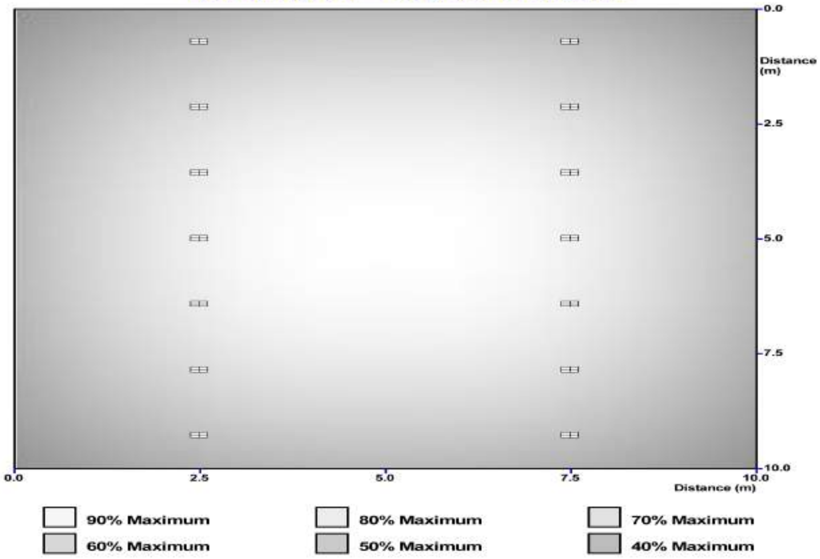
R/LD-20
23 January, 2014

Project Name: Illumination
Project Model: GIS Room

Quick Layout - GreyScale Diagram



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R/LD-20
23 January, 2014

Project Name: Illumination
Project Model: GIS Room

Quick Layout - Illuminance Tabulation

Illuminance: Average = 319 lx Max / Min: 1.563 Maximum = 372 lx Ave / Min: 1.340 Minimum = 238 lx

Distance (m)

Distance (m)	0.50	0.97	1.45	1.92	2.39	2.87	3.34	3.82	4.29	4.76	5.24	5.71	6.18	6.66	7.13	7.61	8.08	8.55	9.03	9.50
0.50	238	249	259	268	274	281	286	288	290	290	290	289	288	286	281	275	269	261	251	240
0.97	248	261	272	282	289	296	302	304	306	306	306	305	304	302	297	290	284	274	263	251
1.45	259	272	284	294	302	310	315	319	320	321	321	320	319	316	311	304	296	286	274	261
1.92	267	282	295	305	314	322	328	332	333	334	334	333	332	328	323	315	307	297	284	269
2.39	274	290	304	315	324	333	339	343	345	345	345	344	343	339	334	325	317	306	292	277
2.87	281	297	311	323	333	342	348	352	354	354	354	354	352	348	342	334	325	313	299	283
3.34	285	302	317	329	339	348	355	359	361	362	362	361	359	355	349	340	331	319	304	288
3.82	289	306	321	334	344	354	360	364	366	367	367	366	364	360	354	345	336	323	308	291
4.29	291	309	324	337	347	357	363	368	370	370	370	370	368	364	357	348	338	325	310	293
4.76	292	309	325	338	348	358	365	369	371	372	372	371	369	365	358	349	339	327	311	294
5.24	292	309	325	338	349	358	365	369	371	372	372	371	369	365	358	349	340	326	311	294
5.71	291	309	324	337	347	356	363	367	370	370	370	370	367	363	357	348	338	325	310	293
6.18	289	306	321	334	344	353	360	364	366	367	367	366	364	360	354	345	335	323	308	291
6.66	285	302	317	329	339	348	355	359	361	361	361	361	359	355	349	340	330	318	304	287
7.13	281	297	311	323	332	341	347	351	353	354	354	353	351	348	341	333	324	312	298	282
7.61	275	290	304	315	324	332	338	342	344	344	344	344	342	339	333	324	315	304	291	276
8.08	267	282	294	305	314	321	327	330	332	333	333	332	331	327	322	314	306	295	282	268
8.55	259	272	284	294	302	309	314	317	319	320	320	319	318	315	309	302	294	284	272	259
9.03	249	261	272	281	289	295	300	303	305	305	305	305	303	300	295	289	281	272	261	249
9.50	238	249	259	267	274	279	284	287	289	289	289	289	287	284	280	274	267	259	249	238

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R/LD-20
23 January, 2014

Project Name: Illumination
Project Model: GIS Room

Quick Layout - Installation Data

Luminaire Type no. 1: IPC1424EB

Type: *INDUSTRIAL*
Cat. No.: *IPC1424EB*
Length: *0.262 m*
Width: *1.248 m*
Height: *0.090 m*

Lamp Type: *36W FTL*
No. of Lamps: *2*
Lumens per Lamp: *3250.0 lm*
Light Output Ratio: *72.8 %*
Rated Power: *89.6 W*

Luminaire Layout

#	Type	X (m)	Y (m)	H (m)	O (°)	T (°)
1	1	2.50	0.71	5.31	0.00	0.00
2	1	7.50	0.71	5.31	0.00	0.00
3	1	2.50	2.14	5.31	0.00	0.00
4	1	7.50	2.14	5.31	0.00	0.00
5	1	2.50	3.57	5.31	0.00	0.00
6	1	7.50	3.57	5.31	0.00	0.00
7	1	2.50	5.00	5.31	0.00	0.00
8	1	7.50	5.00	5.31	0.00	0.00
9	1	2.50	6.43	5.31	0.00	0.00
10	1	7.50	6.43	5.31	0.00	0.00
11	1	2.50	7.86	5.31	0.00	0.00
12	1	7.50	7.86	5.31	0.00	0.00
13	1	2.50	9.29	5.31	0.00	0.00
14	1	7.50	9.29	5.31	0.00	0.00

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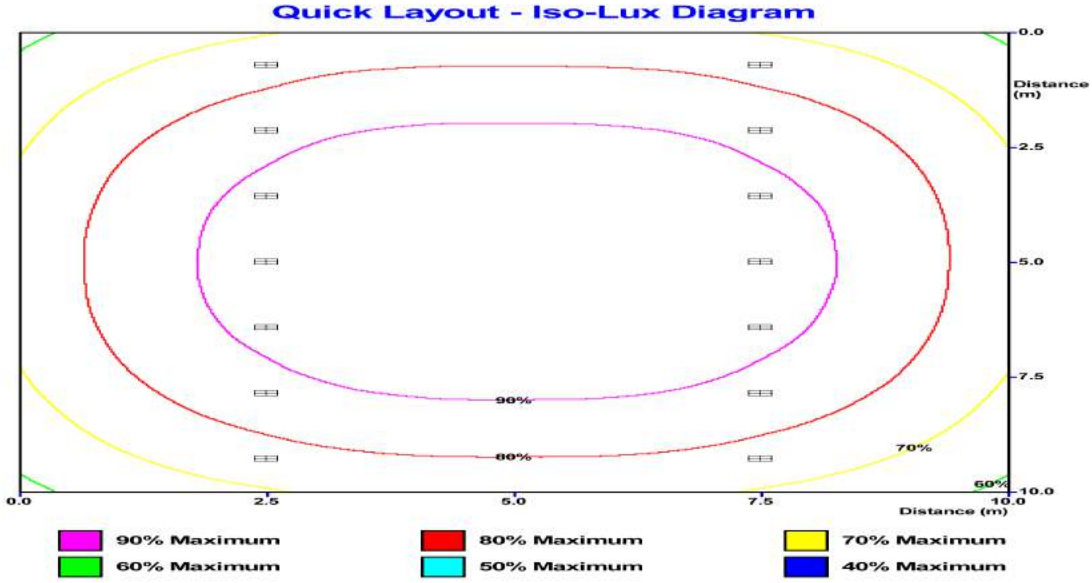
R/LD-20
23 January, 2014

Project Name: Illumination
Project Model: GIS Room

Quick Layout - Iso-Lux Diagram



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R/LD-20
23 January, 2014

Project Name: Illumination
Project Model: GIS Room

Quick Layout - Project Data Sheet

Project Data

Room Length: *10.0 m*	Ceiling Reflectance: *0.80*
Room Width: *10.0 m*	Wall Reflectance: *0.50*
Ceiling Height: *5.80 m*	Floor Reflectance: *0.20*
Workplane Height: *0.40 m*	Maintenance Factor: *0.70*

Luminaire Type Summary

Number	Luminaire Type	Catalogue Number
14	INDUSTRIAL	IPC1424EB

Illuminance Data Summary

Average Illuminance (Eave): *319 lx*
Maximum Illuminance (Emax): *372 lx at x = 5.24 m, y = 4.76 m*
Minimum Illuminance (Emin): *238 lx at x = 0.50 m, y = 0.50 m*
Uniformity 1 - Emin / Emax: *0.640 (1 : 1.56)*
Uniformity 2 - Emin / Eave: *0.747 (1 : 1.34)*

Total lamp flux: *91000 lm*
Total lamp flux per unit area: *910 lm / squ. m*
Utilance: *50 %*
Total electrical power: *1250 W*
Total electrical power per unit area: *12.5 W / squ. m*

All calculation results are based on the nominal values of lamps, ballasts, luminaires and other design assumptions (M.F. / R.F.). Any deviations in these parameters may affect the illumination design.

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R/LD-20
23 January, 2014

Project Name: Illumination
Project Model: GIS Room

Quick Layout - Project Layout

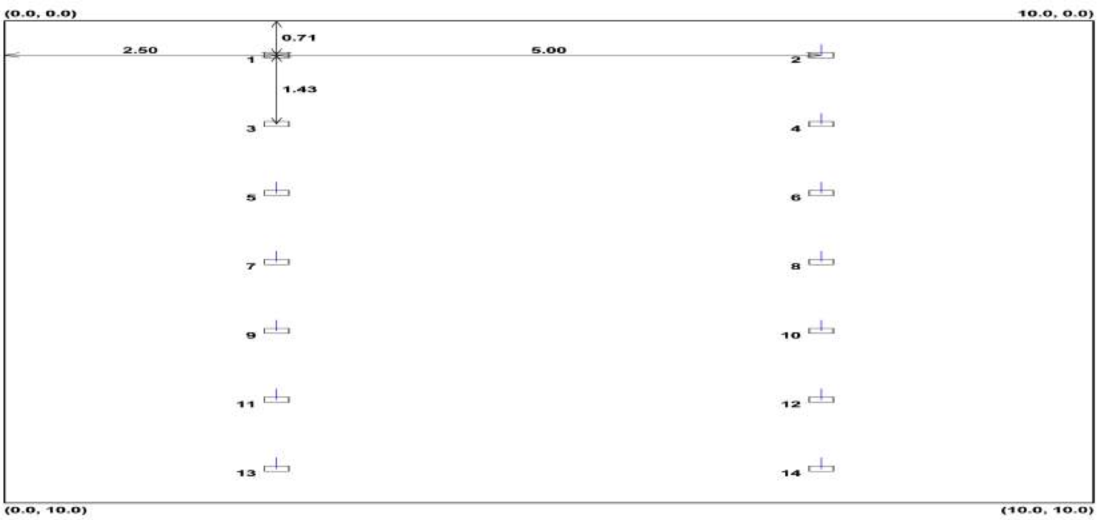

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Figure B.1: Illumination Design of GIS Room