DESIGN CONSIDERATION OF ELECTRICAL DISTRIBUTION AND LIGHTNING PROTECTION SYSTEMS FOR HIGH-RISE BUILDING

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Abstract— In Myanmar, the populations in cities are increasing day by day because of urbanization and job opportunities. As a result, the number of floors and the height of high-rise buildings will increase in Yangon and Mandalay cities. A high level of safety, flexibility throughout the entire life cycle, a low level of environmental pollution, the integration of renewable energies and low costs are common demands nowadays that already have to be taken into consideration during the planning of a high-rise building. A special challenge is the coordination of the individual installations. This paper mainly expresses design of electrical distribution system and lightning protection system of high-rise building.

Index Terms— Electrical distribution system, Lightning protection system, Fire protection system, Water supply system, Air conditioning system, Busbar trunking, High-rise Building, Lightning protection.

I. INTRODUCTION

Presently our country is witnessing the higher growth in infrastructure development mainly in urban areas and there is disproportionate transit of population towards cities, which has generated the need of vertical extension of offices/residential/commercial buildings looking to constraints of land and commutation from far locations to city hub. Therefore to maintain fast growth of development along with ecological balance, there is need of High Rise Building (A building above four stories, and/or a building exceeding 15 meter or more in height above the average level of front road).

Expected growth of population is from around 60 million to around 90 million by the year 2040 in Myanmar. And the housing market is expected to grow continuously in the near future. Therefore, electrical installation in high rise building become important and it is necessary to use modern electrical installation methods.

II. MAIN ELECTRICAL INSTALLATIONS

Electrical installations are to be provided essentially in high-rise buildings incorporating all by laws and codes etc. may be divided in the systems: Power house, Power supply distribution system, Lighting system, Air conditioning system, Lift, Lightning Protection system, Fire protection system, Water supply system. In this paper, design consideration of electrical distribution system by using bus duct is discussed. And lightning protection system of 11th storey building is mentioned.

A. Distribution inside Large Buildings

In large buildings the type of distribution depends on the building type, dimension, the length of supply cables, and the loads. The distribution system can be divided into the vertical supply system (rising mains) and the horizontal supply (distribution at each floor level).

The arrangement of the rising mains depends on the size and shape of the building and suitable size of shafts for installing cables and bus ducts must be provided in coordination with the building architect. Modern electrical installations are placing increasing demands on all products of the electrical equipment manufacturer. Products must have reliable service life, adaptability to new requirements, low installation costs, low maintenance costs, inherent safety features, minimal purchase cost, energy efficiency, safe recycling. In an electrical distribution system, one area where savings can be made and provide the features listed above is in the use of busbar trunking systems.

B. Busbar Trunking System

Busbar trunking system (BBT) preforms the function of transporting current from one point to the other. BBT can tap off power to switchgear for further distribution using tap of boxes. BBT is totally enclosed, non-ventilated design busbar and is fully insulated using halogen free fire retardant epoxy insulation.

Busbar trunking installations can be categorised into two basic types: Distribution and Feeder. The busbar trunking unit (BTU) is designed to prevent the propagation of fire and limit the propagation of heat through building divisions (walls and floors), for a specified time under fire conditions. The tap-off unit usually contains the device providing overcurrent protection to the outgoing circuit terminated at the unit to distribute power to the required load.

Copper and Aluminium are both physically and economically viable for use as conductors in power busbar trunking systems (BTS). Aluminium conductor is used 630A -6000A. Copper conductor is used 630A-7500A.
Busbar trunking systems are designed to withstand the effects of short-circuit currents resulting from a fault at any load point in the system, e.g. at a tap-off outlet or at the end of a busbar trunking run.

Table 1: Factors for Feeder Bus Duct (Per 100')

<table>
<thead>
<tr>
<th>DUCT AMPERE RATIO</th>
<th>3 Phase Voltage (Aluminium)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>208</td>
</tr>
<tr>
<td>600</td>
<td>2.34</td>
</tr>
<tr>
<td>800</td>
<td>3.51</td>
</tr>
<tr>
<td>1000</td>
<td>1.9</td>
</tr>
<tr>
<td>1200</td>
<td>1.6</td>
</tr>
<tr>
<td>3000</td>
<td>0.9</td>
</tr>
<tr>
<td>2500</td>
<td>0.7</td>
</tr>
<tr>
<td>3000</td>
<td>0.6</td>
</tr>
<tr>
<td>4000</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Short Circuit Current ($I_{sc}$) = \( \frac{170000}{\text{Total Factor}} \) (1)

Where the load is tapped off the busbar trunking along its length this should also be taken into account by calculating the voltage drop for each section.

\[ V_d = \sqrt{5 \times \frac{I (\cos \theta + X s m t)}{R}} \] (2)

where,

- $V_d$ = Voltage drop
- $I$ = Load current
- $R$ = the actual conductor resistance
- $X$ = conductor reactance

Table 2: Voltage Drop

<table>
<thead>
<tr>
<th>CONDUCTOR</th>
<th>Rating in amps (A)</th>
<th>0.5</th>
<th>0.6</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.6</td>
<td>8.21</td>
<td>9.09</td>
<td>10.62</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>8.79</td>
<td>10.28</td>
<td>12.01</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>9.21</td>
<td>11.14</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>9.98</td>
<td>11.61</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>10.23</td>
<td>12.01</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>10.18</td>
<td>11.94</td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>11.14</td>
<td>13.3</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>11.61</td>
<td>15.1</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>12.01</td>
<td>15.1</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>12.61</td>
<td>15.1</td>
<td>17.1</td>
</tr>
</tbody>
</table>

C. Advantage of Using Busbar in Place of Cables
- Great advantage of price
- Easy & Quick installation
- Extensive choice of termination elements
- High short-circuit withstand
- Labour Cost for Installation is much lower
- Low voltage drop
- Compact & Small dimensions, space is saved
- 100% Reusable of standard elements
- Fire rating and Seismic Type Tested

II. LIGHTNING PROTECTION SYSTEM

Four Lightning Protection Levels (LPS) based on probable minimum and maximum lightning currents. These LPLs equate directly to classes of Lightning Protection System (LPS). The correlation between the four levels of LPL and LPS is identified in Table 1. In essence, the greater the LPL, the higher class of LPS is required. The class of LPS to be installed is governed by the result of the risk assessment calculation.

A. External LPS Design Considerations
The lightning protection designer must initially consider the thermal and explosive effects caused at the point of a lightning strike and the consequences to the structure under consideration. An isolated LPS is typically chosen when the structure is constructed of combustible materials or presents a risk of explosion. Conversely a non-isolated system may be fitted where no such danger exists. An external LPS consists of air termination system, down conductor system and earth termination system.

A.1. Air Termination System
The role of an air termination system is to capture the lightning discharge current and dissipate it harmlessly to earth via the down conductor and earth termination system. Therefore it is vitally important to use a correctly designed air termination system.

The standard makes it quite clear that all types of air termination systems that are used shall meet the positioning requirements laid down in the body of the standard. It highlights that the air termination components should be installed on corners, exposed points and edges of the structure.

The three basic methods recommended for determining the position of the air termination systems are the rolling sphere method, the protective angle method and the mesh method.

![Fig. 1 Application of the rolling sphere method](image-url)
A.2. Down Conductors
Down conductors should within the bounds of practical constraints take the most direct route from the air termination system. The greater the number of down conductors the better the lightning current is shared between them.

A.3. Earth Termination System
The earth termination system is vital for the dispersion of lightning current safely and effectively into the ground. The standard advocates a low earthing resistance requirement and points out that it can be achieved with an overall earth termination system of 10 ohms or less.

B. Internal LPS Design Considerations
The fundamental role of the internal LPS is to ensure the avoidance of dangerous sparking occurring within the structure to be protected. This could be due, following a lightning discharge, to lightning current flowing in the external LPS or indeed other conductive parts of the structure and attempting to flash or spark over to internal metallic installations.

B.1. Lightning Protection Zones (LPZs)
Lightning protection zones (LPZ) are used to define the electromagnetic environment. The zones are areas characterized according to threat of direct or indirect lightning flashes and full or partial electromagnetic field.

The LPZs can be split into two categories
- External Zones (LPZ 0A, LPZ 0B)
- Internal Zones (LPZ 1,2)

Fig. 2 Basic LPZ concept

External Zones: LPZ 0A is the area subject to direct lightning strokes and therefore may have to carry up to the full lightning current. This is typically the roof area of a structure. The full electromagnetic field occurs here. LPZ 0B is the area not subject to direct lightning strokes and is typically the sidewalls of a structure. However the full electromagnetic field still occurs here and conducted partial lightning currents and switching surges can occur here.

Internal Zones: LPZ 1 is the internal area that is subject to partial lightning currents. The conducted lightning currents and switching surges are reduced compared with the external zones LPZ 0A, LPZ 0B. This is typically the area where services enter the structure or where the main power switchboard is located. LPZ 2 is an internal area that is further located inside the structure where the remnants of lightning impulse currents and switching surges are reduced compared with LPZ 1. This is typically a screened room or, for mains power, at the sub-distribution board area.

C. Risk Management
The types of loss that could result from damage due to lightning must be identified for the structure.

\( R_1 \) risk of loss of human life
\( R_2 \) risk of loss of service to the public
\( R_3 \) risk of loss of cultural heritage
\( R_4 \) risk of loss of economic value

The primary risks will be referred to collectively as \( R_n \) where the subscript \( n \) indicates 1, 2, 3 or 4 as described above.

The risk management procedure is illustrated by the flow diagram shown in Fig. 3. The calculated risk \( R \) is then compared to its corresponding value of \( R_T \). If the result shows \( R \leq R_T \) then the structure is adequately protected for a particular type of loss. If the result shows \( R > R_T \) then the structure is not adequately protected for the type of loss, therefore protection measures need to be applied.

Fig. 3 Procedure for deciding the need for protection
Table 3: RISK COMPONENT

<table>
<thead>
<tr>
<th>Risk of Loss</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>R_x + R_y + R_z + R_w + R_0 + R_1 + R_2</td>
</tr>
<tr>
<td>R2</td>
<td>R_x + R_y + R_z + R_w + R_0 + R_1</td>
</tr>
<tr>
<td>R3</td>
<td>R_x + R_y + R_z + R_w + R_0 + R_1</td>
</tr>
<tr>
<td>R4</td>
<td>R_x + R_y</td>
</tr>
</tbody>
</table>

Table 4: RISK ASSESSMENT LOSSES

<table>
<thead>
<tr>
<th>Risk</th>
<th>Source of damage</th>
<th>Type of damage</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_x</td>
<td>SI</td>
<td>(1)</td>
<td>R_x = N_x + N_y x L_x</td>
</tr>
<tr>
<td>R_y</td>
<td>SI</td>
<td>(1)</td>
<td>R_y = N_x + N_y x L_y</td>
</tr>
<tr>
<td>R_z</td>
<td>SI</td>
<td>(1)</td>
<td>R_z = N_x + N_y x L_z</td>
</tr>
<tr>
<td>R_w</td>
<td>SI</td>
<td>(1)</td>
<td>R_w = N_x + N_y x L_w</td>
</tr>
<tr>
<td>R_0</td>
<td>SI</td>
<td>(1)</td>
<td>R_0 = N_x + N_y x L_0</td>
</tr>
<tr>
<td>R_1</td>
<td>SI</td>
<td>(1)</td>
<td>R_1 = N_x + N_y x L_1</td>
</tr>
<tr>
<td>R_2</td>
<td>SI</td>
<td>(1)</td>
<td>R_2 = N_x + N_y x L_2</td>
</tr>
</tbody>
</table>

D. Identification of Tolerable Risk R_T

If the calculated risk R_n is less than or equal to its corresponding value of R_T then the structure does not need any protection. If the risk R_n is greater than R_T then protection is required and further calculations are needed to determine exactly what protection measures are required to bring the value below that of R_T.

Table 5: VALUES OF TOLERABLE RISK

<table>
<thead>
<tr>
<th>Types of loss</th>
<th>R_T (kWh/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of human life or permanent injuries</td>
<td>1 x 10^5</td>
</tr>
<tr>
<td>Loss of service to the public</td>
<td>1 x 10^4</td>
</tr>
<tr>
<td>Loss of cultural heritage</td>
<td>1 x 10^4</td>
</tr>
</tbody>
</table>

E. Collection Area

The physical dimensions of the structure are used to determine the effective collection area of the structure. For a simple box shaped structure, the collection area can be determined by:

$$ A_d = (L \times W) + (6 \times H (L - W)) + (9 \times \pi \times H^2) $$

where,

- $A_d$ = the collection area of an isolated structure in square meters
- $L$ = the length of structure in meters
- $W$ = the width of structure in meters
- $H$ = the height of structure in meters

F. Rolling sphere method with rod air terminations

When rods are to be used as the air termination for the protection of plane surfaces, the following calculation is useful:

$$ d = 2 \sqrt{2rh - h^2} $$

where,

- $d$ = distance between two rods (m)
- $r$ = radius of the rolling sphere (m)
- $h$ = height of the rods (m)

When rods are to be used as the air termination for the protection of roof top items, the following calculation of sphere penetration distance is useful:

$$ p = r - \sqrt{r^2 - \left(\frac{d}{2}\right)^2} $$

where,

- $p$ = penetration distance (m)
- $d$ = distance between two rods (m)
- $r$ = radius of the rolling sphere (m)

III. ELECTRICAL DISTRIBUTION SYSTEM FOR 11TH STOREYED BUILDING

A. Structural Configuration of the Building

- Type of structure: Eleven-storeyed RC building
- Type of occupancy: Residential building
- Size of building: Length = 210ft
- Size of building: Width = 156ft
- Height of building: Typical storey height = 10ft
- Height of building: Bottom storey height = 10ft
- Height of building: Overall height = 150ft

The following figure is the electrical layout plan of 11th storey building.

Fig. 4. Layout plan of 11th Storeyed Building
Load current of the building is 3899A. Electrical distribution design of the building is installed by using busbar trunking system. Aluminium Busbar trunking system is used in the building. Aluminium conductor rating in 4000A is chosen for this design.

### B. Selection of Transformer

#### B.1. Selection of Transformer

Total load for the building = 2159.85kW

Assume power factor is 0.8, diversity factor is 1.5.

Power consumption (kVA) = \( \frac{2159.85}{0.8} = 2699.81 \text{kVA} \)

The actual load demand = \( \frac{2699.81}{1.5} = 1799.87 \text{kVA} \)

For diversity factor of 1.5, it can be chosen enough the 2000kVA transformer with 11k/V, 0.4 kVA, 0.8 p.f.

#### C. Short Circuit Calculation for Feeder of Bus Duct

Total Factor = 0.6 (from Table 1)

Short Circuit Current (I_L) = \( \frac{12000}{0.45} = 26667 \text{A} \)

The short circuit current of the feeder of bus duct withstands 280kA.

### D. Voltage Drop Calculation of Rising Main Distribution using Busbar Trunking System

Assume power factor is 0.8.

\[ V_d = 10.6 \text{V} \text{ (from Table 2)} \]

Total load current = 3899A

For diversity factor = 1.5,

Actual load current = \( \frac{3899 - 2599}{1.5} = 2133 \text{A} \)

Rated Load current = 4000A

Actual distance = \( \frac{73}{100} = 0.73 \text{m} \)

\[ \text{Volt drop} = 0.6 \times \frac{2599 \times 73}{4000} = 5 \text{V} \]

By using busbar trunking for distribution system, actual volt drop of the residential building is 5V.

### IV. CALCULATION OF LIGHTNING PROTECTION SYSTEM FOR 11TH STOREYED BUILDING

In building, the risk of loss of human life R1 and loss of service to the public R2 are considered.

\[ Z_1 = \text{Entrance area to the building} \]

\[ Z_2 = \text{Garden} \]

\[ Z_3 = \text{internal building} \]

#### Table 8: CHARACTERISTICS OF THE STRUCTURE AND ITS ENVIRONMENT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (m)</td>
<td>L, W, H</td>
<td>64, 48, 46</td>
</tr>
<tr>
<td>Location Factor</td>
<td>C_d</td>
<td>0.5</td>
</tr>
<tr>
<td>Shield at structure boundary</td>
<td>K_d1</td>
<td>1</td>
</tr>
<tr>
<td>Shield internal to structure</td>
<td>K_d2</td>
<td>1</td>
</tr>
<tr>
<td>People present inside/inside the structure</td>
<td>n</td>
<td>380</td>
</tr>
<tr>
<td>Soil resistivity (ohm m)</td>
<td>ρ</td>
<td>150</td>
</tr>
<tr>
<td>Lightning flash density (1/km²/year)</td>
<td>N</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Risk R_1 and R_2 are calculated by using formula in Table 3 and 4. Other required data achieve from IEC 62305-2 and Myanmar National Building Code. Risk of loss of human life \( R_1 = 3.296 \times 10^{-5} \text{ } \times 1 \times 10^3 \)

Tolerable risk \( R_t = 1 \times 10^3 \text{ } \times 10^3 \)

Therefore protection measures need to be instigated.

For the first attempt at reducing \( R_1 \) we will apply a structural LPS IV.

The recalculated value of \( R_1 = 0.516 \times 10^{-5} \text{ } \times 1 \times 10^3 \)

Therefore, protection has been achieved with regard to loss of human life \( R_1 \).

Risk of loss of service to the public \( R_2 = 11.74 \times 10^{-4} \text{ } \times 1 \times 10^4 \)

Tolerable risk \( R_t = 1 \times 10^4 \text{ } \times 10^4 \)

Therefore protection measures need to be instigated.

For the first attempt at reducing \( R_2 \) we will apply a structural LPS IV. The recalculated value of \( R_2 = 0.631 \times 10^{-4} \text{ } \times 1 \times 10^4 \)
This solution ensures that the actual risks $R_1$ and $R_2$ are both lower than their tolerable value $R_T$.

So, the building is designed with LPS IV for lightning protection system. The building is protected using the rolling sphere method. The method is suitable for defining zones of protection for all types of structure. Maximum value of rolling sphere radius corresponding to the class of LPS IV is 60m.

Distance between air terminations is 21.8m. So, the building needs 12 numbers air termination rod (height 0.5m). In earth termination system, (Loam) soil resistivity is 150Ωm. So, 8 earth rods (2.4m length) are required to achieve 10 ohms or less.

CONCLUSIONS

Electrical installation is very important for daily life of residences and safety to be convenient. In this paper, design consideration of load current and voltage drop of busbar for high-rise building are presented. Voltage drop by using busbar from transformer to top of the building is 5V. So, busbar trunking system can reduce voltage drop than design used cable tray system. Moreover, using busbar trunking for electrical distribution system of high rise building is reliability, low installation costs, low maintenance costs, minimal purchase cost, safe recycling, etc. Electrical system of building is important to protect lightning. The buildings should be installed good lightning protection to protect damages caused lightning. This lightning protection design is calculated by considerateness characteristics of the building, its environment and risk management of the building when lightning strikes it. So, the design is a good lightning protection system for the high-rise building.

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