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EVOLUTION OF DESIGN PARAMETERS OF EHV SUBSTATION EQUIPMENT & THEIR SIZING

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Abstract: This paper focuses on the design as well as proper sizing of electrical equipment in power transmission substations operating at various voltage levels from 33 kV to 220 kV. The study covers equipment such as power transformers, circuit breakers, isolators(disconnector), current transformers (CTs), lightning arresters, and potential transformers. A case study of a 220/33 kV pooling substation is presented using AutoCAD software, along with the a single-line diagram (SLD) that outlines the power flow and equipment ratings across the system. The proper selection of equipment ratings through proper sizing is important for achieving stability and reliability of power supply, while also ensuring the efficiency of substation operations as well as safety. The study highlights the important role of equipment sizing in the development of a dependable and efficient power transmission substation.

***IndexTerms* - Power Substation, Substation Equipment, Equipment Sizing, Designing, Single Line Diagram, Auto-CAD.**

I. INTRODUCTION

The continuous rise of electricity demand, especially in developing countries like India, is driven by rapid industrialization, urbanization, and agricultural development. To meet demand of load, the construction of new generating stations whether thermal, hydro, gas-based, nuclear and renewable is essential. However, these stations are often situated far from load centers, making it necessary to transmit large amounts of power for long distances. This can be achieved through Extra High Voltage (EHV) transmission systems, which have advantages like, improved efficiency, enhanced stability, and lower transmission losses. [1-11]

Substations play an important role in the electrical power system as points of connection between generation, transmission, and distribution networks. Substation have various electrical equipment required for voltage transformation, system protection, power flow control, and switching operations. The design of a substation varies depending on its voltage level, purpose, and geographical location. Voltage levels commonly used in transmission systems include 33kV, 66 kV, 132 kV, 220 kV, 400 kV, and 765 kV. [5-7,10]

One of the most important aspects of substation planning is the proper selection and sizing of equipment such as transformers, circuit breakers, isolators, lightning arresters, current transformers and potential transformers. Each of these components must be rated correctly to ensure that the substation can handle expected loads and fault conditions without failure. If equipment is undersized, it may suffer damage during operation, while oversized equipment can lead to capital & running costs. Therefore, optimum sizing is critical to both the performance and economic viability of the system. [11-14]

A single line diagram (SLD) is typically used during the initial design phase to represent the substation's electrical layout. It simplifies complex three-phase systems into a single line for easier analysis and planning, clearly showing how power flows from the source to various loads and through different substation components.

This paper explores the process of determining appropriate equipment size for EHV substations in delivering a stable, secure, reliable and efficient power supply.

II. REQUIRED EQUIPMENT

A power transmission substation comprises several very important equipment, each serving a distinct function to ensure safe and efficient energy transfer from generating stations to the distribution network. This equipment must be accurately selected and sized according to system voltage levels, expected loads, and fault conditions. Proper equipment sizing enhances operational reliability and system stability. The major equipment used in high-voltage substations are discussed below.

a. Power Transformer

The power transformer is a fundamental component used to step-up or step-down voltage levels between transmission and distribution systems. In transmission substations, these are often used to convert voltages such as 33 kV to 220 kV or 220 kV to 33 kV. The transformer must be selected based on load capacity, fault level, efficiency, and cooling method. It plays a major role in minimizing energy losses during long-distance transmission and ensuring voltage stability.

b. Circuit Breaker (CB)

Circuit breakers are automatic protection devices that interrupt flow of current under fault conditions. This saves the equipment and also isolate the faulty section, thereby minimizing damage and maintaining continuity in the rest of the system. Depending on their arc-quenching mechanism, circuit breakers may be classified as vacuum, SF_6 gas, oil, or air blast type. The choice of breaker is influenced by system voltage, interrupting capacity, and speed of operation. [3, 5-7]

c. Isolator (Disconnector)

An isolator is a manually or motorized operated mechanical switch used to secure a section of the substation it is completely de-energized before maintenance activities. Isolators are not designed to operate under load and it must be operated only after the circuit is opened by a breaker.[7] They provide visible isolation, enhancing safety for workers. Isolators are generally installed on both sides of circuit breakers and busbars for clear and secure disconnection.

d. Current Transformer (CT)

Current transformers are used to reduce high currents in the system to measurable levels suitable for metering and protection. They allow protective relays and measurement devices to operate safely without direct exposure to high-voltage & currents. CTs are carefully rated for accuracy, burden, and thermal performance, especially during system faults, to ensure dependable relay operation.

e. Lightning Arrester (LA)

Lightning arresters protect substation equipment from transient over voltages caused by lightning or switching operations. These devices divert surge currents safely to the ground, preventing damage to insulation and sensitive components. They are selected based on system voltage, insulation coordination, and energy absorption capacity.

f. Busbar

The busbar serves as a central conductor within the substation, connecting various incoming and outgoing transmission line. It must be capable of handling the maximum load current as well as withstand mechanical and thermal stresses during fault conditions. Materials like aluminium or copper are used depending on current rating, cost, and physical requirements. Proper design and support of the busbar are essential to maintain long-term operational integrity. [5,18]

g. Potential Transformer (PT)

A Potential Transformer (PT), also known as a Voltage Transformer (VT), is an essential instrument used in substations to step down high voltages to lower measurable values that are safe for use in metering, monitoring, and protective relaying equipment.

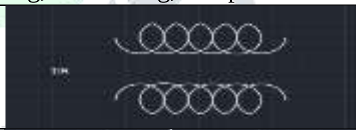
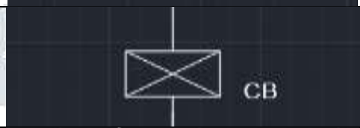
a. Power Transformer	
b. Circuit Breaker	
c. Isolator (Disconnector)	
d. Current Transformer (CT)	
e. Lightning Arrester	
f. Potential Transformer (PT)	

Fig 1. Equipment Symbol in SLD

III. EQUIPMENT SIZING

In substation equipment sizing here let us take a case study on the design and equipment sizing of a power transmission substation intended for renewable energy integration. The substation receives power from ten incoming 33 kV feeders; each connected to a solar or wind-based generation source. Every feeder contributes 30 MW, resulting in a total capacity of 300 MW of renewable power.

The primary function of this substation is to step up the voltage from 33 kV to 220 kV using suitable power transformers and associated equipment. The transformed power is then transmitted to the main transmission grid through a 220 kV outgoing line. The design emphasizes reliability, fault tolerance, and scalability to accommodate future increases in power generation.

This layout is particularly relevant in regions focusing on grid integration of renewable sources, helping reduce dependency on fossil fuels while maintaining grid stability through effective substation planning and equipment sizing.

- System Parameters: -

Table 1. System Parameters

Sr. No.	Details	Value		Unit
		220 kV System	33kV System	
1.	Nominal Rated Voltage	220	33	kVrms
2.	Highest System Voltage	245	36	kVrms
3.	Phase	3	3	Nos.
4.	Rated Frequency	50	50	Hz
5.	Ambient Temperature	50	50	°C
6.	Rated Fault current and its duration	50 - 1 sec.	25 - 3 sec.	kA
7.	System neutral earthing	Effectively earthed	Effectively earthed	
8.	Auxiliary AC Supply (3ph, 4wire, 50Hz)	415±10%	415±10%	V
9.	Auxiliary DC Supply (2 Wire)	220±10%	220±10%	V

- Below table shows different equipment sizing used for 220kV system.

Table 2. Equipment sizing for 220kV

Sr. No.	Details	Value	Qty.
		220 kV System	
1.	Power Transformer	220/33kV, 200MVA, 50Hz, ONAN / OFAN, YNd1, Z=10%	2 nos.
2.	Circuit Breaker (CB)	220kV, 3ph, SF_6 Type, 1200A, 50kA for 1 sec.	4 nos.
3.	Isolator (Disconnector)	220kV, 3ph, 1200A, 50kA for 1 sec.	17 nos.
4.	Current Transformer (CT)	1200/1A, 15VA at outgoing line	1 no.
		600/1A, 5VA at transformer	2 nos.
5.	Lightning Arrester (LA)	198kv, 10kA, Gapless metal oxide (ZnO)	3 nos.
6.	Potential Transformer (PT)	$\frac{220000}{\sqrt{3}} / \frac{110}{\sqrt{3}} / \frac{110}{\sqrt{3}}$, 1ph	3 nos.

- Below table shows different equipment sizing used for 33kV system

Table 2. Equipment sizing for 33kV

Sr. No.	Details	Value	Qty.
		33 kV System	
1.	Circuit Breaker (CB)	33kV, 3ph, SF_6 Type, 1200A, 50kA for 1 sec.	12 nos.
2.	Isolator (Disconnector)	33kV, 3ph, 1200A, 25kA for 3 sec.	12 nos.
3.	Current Transformer (CT)	600/1A, 5VA at Incoming feeder	10 nos.
		3000/1A, 15VA at transformer	2 nos.
4.	Lightning Arrester (LA)	36kv, 10kA, Gapless metal oxide (ZnO)	12 nos.

5.	**Potential Transformer (PT)**	$\frac{33000}{\sqrt{3}} / \frac{110}{\sqrt{3}} / \frac{110}{\sqrt{3}}$, **1ph**	**12 nos.**

IV. SINGLE LINE DIAGRAM & PLAN VIEW OF SUBSTATION

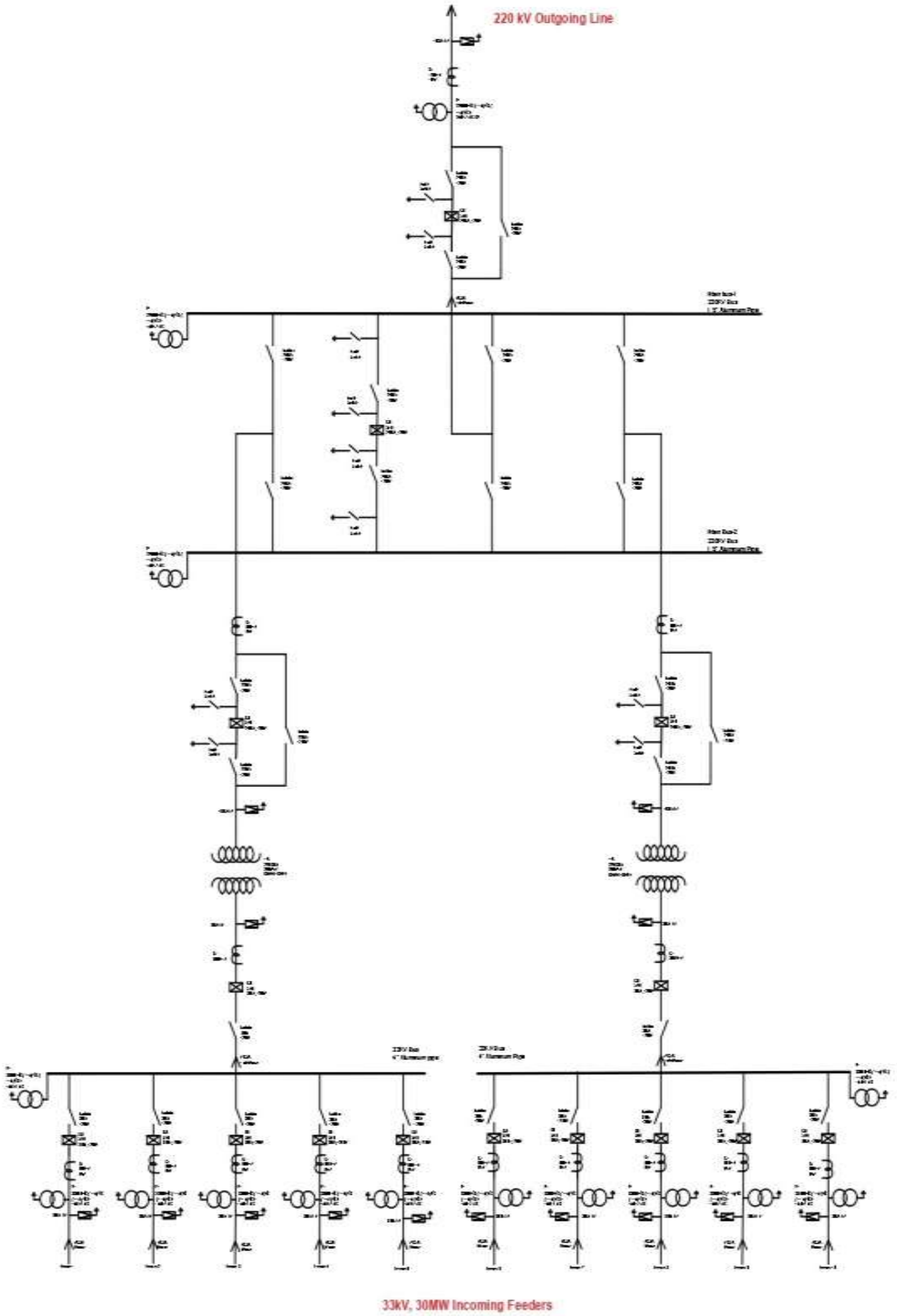


Fig. 2 Single Line Diagram

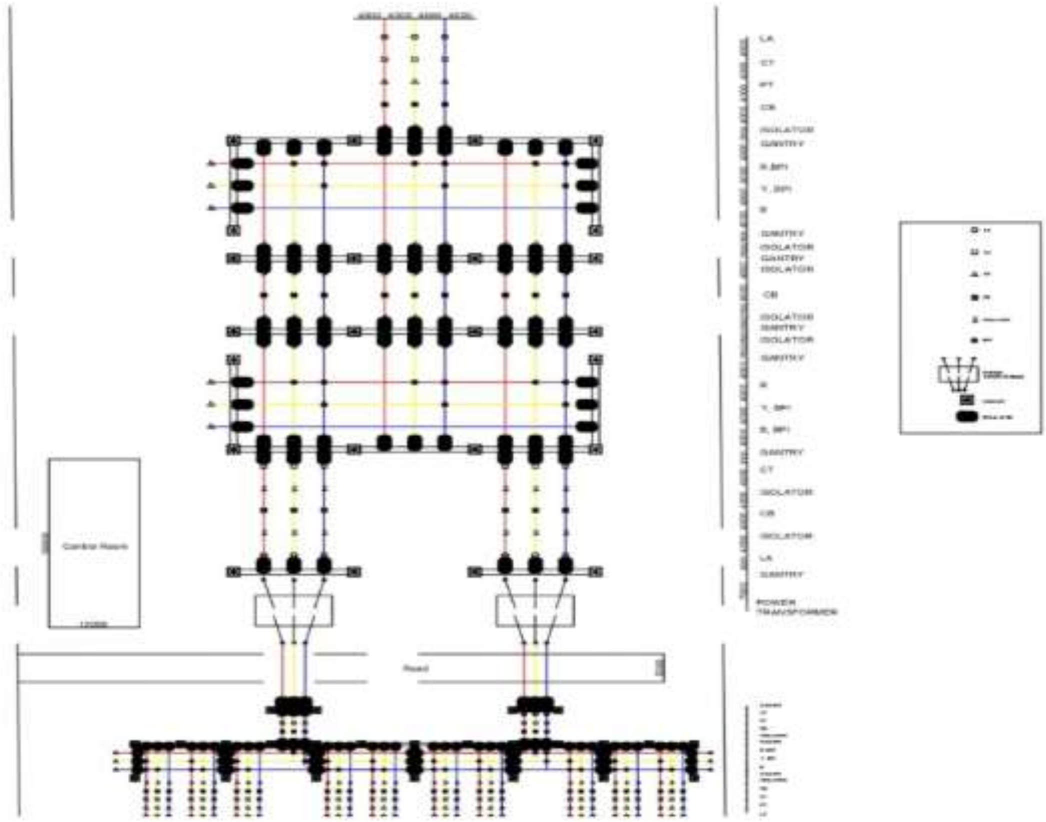


Fig. 3 Plan View

V. Conclusion

The efficient operation of a power transmission substation depends significantly on the correct sizing of its major equipment. This study is presented in a detailed understanding of the sizing principles of various substation equipment such as transformers, circuit breakers, isolators, CTs, PTs, lightning arresters, and busbars. Accurate sizing not only enhances the safety and reliability of the substation but also improves its ability to handle load growth, fault conditions, and varying power quality scenarios.

A practical case study was easy to understand how to size a substation equipment. The substation receives power from ten 33 kV feeders, each supplying 30 MW from solar and wind sources. This 300 MW of renewable energy is stepped up to 220 kV and transferred to the main grid.

In the future, substation design can benefit from smart technologies, real-time monitoring, and optimization tools. As renewable energy integration increases, there is scope to study equipment performance under variable loads, use software analysis and/or simulations for accuracy, and adopt compact solutions like GIS or hybrid and with energy storage systems and protection system.

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