

A Comprehensive Study on Design Considerations of 33/11KV Substation

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Abstract—A substation is a critical component of an electrical power system that facilitates the transformation, control, and distribution of electrical energy. It serves as a node in the power grid, enabling the transfer of electricity between different voltage levels, ensuring efficient and safe delivery to consumers. They are designed with considerations for load growth, fault tolerance, and environmental factors, making them essential for modern power systems.

A substation receives electric power from generating station via incoming transmission line and delivers electrical power via outgoing lines. The main function of substation is to receive electrical energy from generating station and transmit at high voltage from the generating station, reduced to a value appropriate for local distribution and provide facilities for switching. Basically, substations consist of power transformer, circuit breakers, isolators, relays, earthing, switches, current transformers, potential transformers, synchronous condenser/capacitor banks, etc. The voltage conversion will be obtained by use of power transformer which is considered as a heart of substations.

The design process of a sub-station begins with very elemental work of selection of site and estimation of requirements which includes capital and material. Choosing the right equipment is essential for the efficient and safe operation of the substation. It is also needed to keep in mind, the civil aspects of a sub-station design.

Our project is mainly concerned with the Design considerations of 33/11 kV substation the various components present in substation and a special focus on the design considerations of different equipments.

Index Terms—33/11 kV Substation, Power Transformer, Circuit Breaker, Protective Relays, Voltage Transformation, Electrical Power Distribution.

I. INTRODUCTION

The generating voltage is generally 11KV or higher, but in some cases, it may be as high as 6.6 kV or 33 kV. It is economical to generate voltages at lower voltages simultaneously, and it is economical to transmit power at higher voltages.

Bulk electric power is generated at power plants. This is transmitted to power receiving substations through transmission lines. These receiving power substations then distribute it to end-users through distribution lines. The combination of this transmission and distribution network is known as the electric power grid.

Electrical power transmission is done at high voltage, in a range of 33 kV to 765 kV, to minimize transmission losses.

Then this voltage is stepped down and distributed to end-users by using step-down transformers. These transformers reduce the voltage from high voltage to 415 V/220 V.

A well-designed substation ensures reliable power supply, operational safety, and cost-effectiveness while complying with regulatory standards and environmental requirements.

33/11KV Substation forms an important link between the transmission network and distribution network. It has a vital influence on the reliability service. Substation is constructed as near as possible to the load Centre. Site selection of substation includes various factors such as

- Availability of land and sufficient land
- Communication facility
- Atmospheric pollution
- Availability of essential amenities to the staff
- Future expansion/upgrade of substation

A. Single Line Diagram of 33/11KV Substation

A single line diagram also called the one-line diagram is a symbolic or graphical representation of a power system. It has a diagrammatic representation of all the equipment and connections. Standardized schematic symbols represent electrical elements such as circuit breakers, transformers, bus bars, and conductors, making them easy to read and understand. In a single line diagram, instead of representing each of the three phases with separate lines, a single conductor represents all three phases. A single line diagram makes it easy to understand an electrical system, particularly in the case of complicated systems in substations.

Single line diagrams are invaluable tools in the electrical power industry, providing a clear and concise representation of complex power systems. They simplify design, analysis, and maintenance processes, ensuring safety and efficiency.

II. SUBSTATION EQUIPMENT'S

Equipment selection is a crucial aspect of designing of 33/11KV substation. It involves choosing the right equipment that meets the technical, safety, and reliability requirements of the substation. Substation is the place where there us an assembly of various electrical apparatus to perform several transformations and switching action

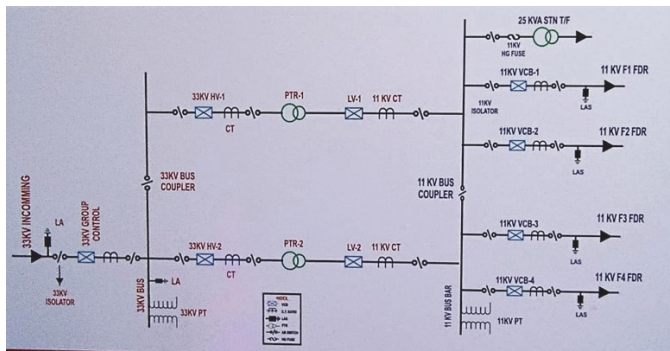


Fig. 1. Single Line Diagram of 33/11kV Substation

A. Busbars and Bus coupler

Busbars are critical components that serve as a common connection point for multiple circuits, facilitating the distribution and control of electrical power. Busbars are metallic conductors (typically copper or aluminum) used to collect, distribute, and transfer electrical power between incoming and outgoing lines in a substation.

Design considerations of busbars are Current Carrying Capacity: Sized to handle the maximum load current without overheating (e.g., 630A, 1250A, or higher, depending on substation capacity). ShortCircuit Rating: Designed to withstand fault currents (e.g., 25kA for 3 seconds).

A bus coupler is a device or arrangement used to connect two or more busbars to enhance the flexibility, reliability, and continuity of power supply. It plays a critical role in managing power flow and ensuring operational efficiency.

B. Lightning arrester

A lightning arrester (or surge arrester) in a is a critical protective device designed to safeguard the substation's electrical equipment, such as transformers, circuit breakers, busbars, other components, and working personnel from overvoltages caused by lightning strikes or switching surges.

C. Circuit Breakers

Circuit breaker is a protective electrical device designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and interrupt fault feeding.

- Oil circuit breakers: It is used in the range of 33 to 132kV
- Vacuum circuit breakers: It is used in the range of 22 to 66kV
- Air circuit breakers: It is used in the range of 132 to 765kV
- SF6 circuit breakers: It is used in the range of 132 to 765kV

D. Isolator

An isolator, also known as a disconnect switch, is a mechanical switch used in substations to ensure a complete disconnection of a part of the circuit from the power system for safe maintenance or service. As the name implies isolator

isolates one portion of circuit from another and is not intended to be opened while current is flowing.

E. Instrument transformers

Instrument transformers in a 33/11 kV substation are critical for measurement, protection, and control of electrical systems. They step down high voltages and currents to safe, standardized levels for meters, relays, and other devices. The various types of instrument transformers in substation are:

- Current Transformer
- Potential Transformer

F. Relay

A relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a separate low-power signal, or where several circuits must be controlled by one signal.

G. Capacitor Banks

A capacitor bank is a grouping of several identical capacitors inter connected in parallel or in series with one another. Capacitor banks are used to improve power factor, enhance voltage stability, and optimize the efficiency of the electrical distribution system.

H. Power Transformer

Power Transformer is one of the most important equipment's in a power transmission and distribution system. A power transformer is a fixed device that converts power from one circuit to another without changing the frequency. A transformer is introduced as a static device because there are no moving or rotating components.

III. SPECIFICATIONS OF EQUIPMENT'S

The reliable operation of a 33/11kV substation mainly depends on the proper selection and specification of its equipment. Each component used in the substation is designed according to system voltage, load requirements, fault level, and operational safety standards. The major equipment used in the substation includes power transformers, current transformers (CTs), instrument voltage transformers (IVTs), lightning arresters, isolators, and vacuum circuit breakers (VCBs).

These devices perform important functions such as voltage transformation, protection, switching, measurement, and fault isolation. The technical specifications of the equipment determine the efficiency, stability, and reliability of the overall power system. Our work presents the detailed specifications of various substation equipment used in the proposed 33/11kV substation design.

TABLE I
 SPECIFICATIONS OF LIGHTNING ARRESTERS FOR 33kV AND 11kV SYSTEMS

S. No.	Particulars	33kV	11kV
1.	Type	MOV	MOV
2.	Highest System Voltage	36kV	12kV
3.	Rated Voltage	30kV	9kV
4.	Nominal Discharge Current	10kA	5kA
5.	Maximum Continuous Over Voltage	25kV	8kV
6.	System Frequency	50Hz ± 5%	50Hz ± 5%

TABLE II
 SPECIFICATIONS OF POTENTIAL TRANSFORMER FOR 33kV AND 11kV SYSTEMS

S. No.	Particulars	33kV	11kV
1.	Type	IVT	IVT
2.	Highest System Voltage	36kV	12kV
3.	Primary/Secondary Voltage	$\frac{33}{\sqrt{3}} / \frac{110}{\sqrt{3}}$	$\frac{11}{\sqrt{3}} / \frac{110}{\sqrt{3}}$
4.	Rated Burden	50VA	100VA
5.	Class Of Accuracy	0.2/3P	0.2/3P
6.	Power Frequency Withstand Voltage	70kV	28kV
7.	System Frequency	50Hz	50Hz

TABLE III
 SPECIFICATIONS OF ISOLATOR FOR 33kV AND 11kV SYSTEMS

S. No.	Particulars	33kV	11kV
1.	Type	DB	DB
2.	Highest System Voltage	36kV	12kV
3.	Short Circuit Current	25kA for 1 second	13.1kA for 1 second
4.	Rated Peak Withstand Short Circuit Current	62.5kAp	33kAp
5.	Operated Mechanism	Motor/Man operated	Man operated
6.	Operating Time	12 second or less	12 second or less
7.	Pole	3 pole gang operated	3 pole gang operated
8.	System Frequency	50Hz	50Hz

TABLE IV
 SPECIFICATIONS OF CURRENT TRANSFORMER FOR 33kV AND 11kV SYSTEMS

S. No.	Particulars	33kV	11kV
1.	Highest System Voltage	36kV	12kV
2.	Primary/Secondary Current	1200-600-150/1-1-1-1 A	100-1200/1-1-1-1 A
3.	Short Circuit Current	25kA for 1 second	13.1kA for 1 second
4.	Burden	30VA	20VA
5.	Peak Short Circuit Current	62.5kAp	33kAp
6.	Operated Mechanism	Motor/Man operated	Motor/Man operated
7.	Max. Break Time	60ms or less than 3 cycles	60ms or less than 3 cycles
8.	Max. Closing Time	150ms	150ms
9.	Pole	3 pole gang operated	3 pole gang operated
10.	System Frequency	50Hz	50Hz

TABLE V
 SPECIFICATIONS OF POWER TRANSFORMER

S. No.	Particulars	Ratings
1.	Make	Toshiba
2.	Rated Power	12.5MVA
3.	Rated Voltage	HV : 33kV LV : 11kV
4.	No. Of Phases	3
5.	Tappings On	HV side
6.	Tapping Range	±5% in 2.5% steps
7.	Tap Changer	OLTC
8.	Vector Group	Dyn11
9.	Type Of Cooling	ONAN
10.	Percentage Impedance	7.49%

TABLE VI
 SPECIFICATIONS OF VACUUM CIRCUIT BREAKER FOR 33kV AND 11kV SYSTEMS

S. No.	Particulars	33kV	11kV
1.	Type	Vacuum	Vacuum
2.	Highest System Voltage	36kV	12kV
3.	Short Circuit Current	25kA for 1 second	25kA for 1 second
4.	Rated Short Circuit Making Current	62.5kAp	62.5kAp
5.	Operated Mechanism	Motor/Man operated	Motor/Man operated
6.	Max. Break Time	60ms or less than 3 cycles	60ms or less than 3 cycles
7.	Max. Closing Time	150ms	150ms
8.	Pole	3 pole gang operated	3 pole gang operated
9.	System Frequency	50Hz	50Hz

IV. DESIGN CALCULATIONS

A. Lightning Arrestor

For 33kV side

- Highest System Voltage (H.S.V)

$$H.S.V = 1.1 \times 33 = 36kV$$

- Rated Voltage

$$\begin{aligned} \text{Rated Voltage} &= \text{Highest System Voltage} \times \text{Ground Fault Factor} \\ &= 1.1 \times 36 \times 0.8 = 25kV \end{aligned}$$

Ground Fault Factor = 0.8 (for effectively/solid grounded system)

- Maximum Continuous Operating Voltage (MCOV)

$$\begin{aligned} MCOV &= \frac{f_{cov} \times \text{Maximum System Voltage}}{\sqrt{3}} \\ &= \frac{1.1 \times 36}{\sqrt{3}} = 22.86kV \end{aligned}$$

Where,

$$f_{cov} = 1.1 \text{ for H.S.V} > 100kV$$

$$f_{cov} = 1.05 \text{ for H.S.V} < 100\text{kV}$$

- Continuous Operating Voltage (COV)

$$\begin{aligned} \text{COV} &= \frac{f_{cov} \times \text{Nominal System Voltage}}{\sqrt{3}} \\ &= \frac{1.05 \times 33}{\sqrt{3}} = 20\text{kV} \end{aligned}$$

- Nominal Discharge Current

$$= 10\text{kA}$$

(As per IEC recommendations)

For 11KV Side

- Highest System Voltage (H.S.V)

$$\text{H.S.V} = 1.1 \times 11 = 12.1\text{kV}$$

- Rated Voltage

$$\begin{aligned} \text{Rated Voltage} &= \text{Highest System Voltage} \times \text{Ground Fault Factor} \\ &= 1.1 \times 12.1 \times 0.8 = 10.64\text{kV} \end{aligned}$$

Ground Fault Factor = 0.8 (for effectively/solid grounded system)

- Maximum Continuous Operating Voltage (MCOV)

$$\begin{aligned} \text{MCOV} &= \frac{f_{cov} \times \text{Maximum System Voltage}}{\sqrt{3}} \\ &= \frac{1.1 \times 12.1}{\sqrt{3}} = 7.33\text{kV} \end{aligned}$$

Where,

$$f_{cov} = 1.1 \text{ for H.S.V} > 100\text{kV}$$

$$f_{cov} = 1.05 \text{ for H.S.V} < 100\text{kV}$$

- Continuous Operating Voltage (COV)

$$\begin{aligned} \text{COV} &= \frac{f_{cov} \times \text{Nominal System Voltage}}{\sqrt{3}} \\ &= \frac{1.05 \times 11}{\sqrt{3}} = 6.66\text{kV} \end{aligned}$$

- Nominal Discharge Current

$$= 5\text{kA}$$

(As per IEC recommendations)

B. Potential Transformer

For 33KV Side

- Rated Primary Voltage

$$V_1 = 33000\text{V}$$

- Rated Secondary Voltage

$$V_2 = 110\text{V}$$

- Turns Ratio

$$\begin{aligned} \frac{V_2}{V_1} &= \frac{N_2}{N_1} \\ &= \frac{110}{33000} \end{aligned}$$

- Highest System Voltage

$$= 36\text{kV}$$

- Power Frequency Withstand Voltage

$$= 2.1 \times 36$$

$$\approx 70\text{kV}$$

For 11KV Side

- Rated Primary Voltage

$$V_1 = 11000\text{V}$$

- Rated Secondary Voltage

$$V_2 = 110\text{V}$$

- Turns Ratio

$$\begin{aligned} \frac{V_2}{V_1} &= \frac{N_2}{N_1} \\ &= \frac{110}{11000} \end{aligned}$$

- Highest System Voltage

$$= 12\text{kV}$$

- Power Frequency Withstand Voltage

$$= 2.1 \times 12$$

$$\approx 28\text{kV}$$

C. Current Transformer

For 33KV Side

- Rated Primary Current

$$\begin{aligned} I_1 &= \frac{31.5 \times 10^6}{\sqrt{3} \times 33 \times 10^3} \\ &= 551.107\text{A} \approx 600\text{A} \end{aligned}$$

- Rated Secondary Current

$$I_2 = 1\text{A}$$

(As per IEC standards)

- Selected Current Transformer

$$\text{CT Ratio} = 1200-600/1-1-1-1\text{A}$$

- Turns Ratio

$$\begin{aligned} \frac{I_2}{I_1} &= \frac{N_1}{N_2} \\ &= \frac{1}{600} \end{aligned}$$

- Highest System Voltage

$$V_m = 36\text{kV}$$

- Short Circuit Current

$$I_{sc} = 25\text{kA}$$

- Rated Short Circuit Making Current

$$I_m = 2.5 \times 25 \\ = 62.5\text{kA}$$

For 11KV Side

- Rated Primary Current

$$I_1 = \frac{31.5 \times 10^6}{\sqrt{3} \times 11 \times 10^3} \\ = 1653.32\text{A} \approx 1200\text{A}$$

- Rated Secondary Current

$$I_2 = 1\text{A}$$

(As per IEC standards)

- Selected Current Transformer

$$\text{CT Ratio} = 100-1200/1-1-1-1\text{A}$$

- Turns Ratio

$$\frac{I_2}{I_1} = \frac{N_1}{N_2} \\ = \frac{1}{1200}$$

- Highest System Voltage

$$V_m = 12\text{kV}$$

- Short Circuit Current

$$I_{sc} = 13.1\text{kA}$$

- Peak Short Circuit Current

$$I_p = 2.5 \times 13.1 \\ = 32.75\text{kA} \approx 33\text{kA}$$

D. Isolator

For 33KV Side

- Type of Isolator

Double Break Isolator

- Highest System Voltage

$$V_m = 36\text{kV}$$

- Short Circuit Current

$$I_{sc} = 25\text{kA}$$

- Peak Short Circuit Current

$$I_p = 2.5 \times 25 \\ = 62.5\text{kA}$$

For 11KV Side

- Type of Isolator

Double Break Isolator

- Highest System Voltage

$$V_m = 12\text{kV}$$

- Short Circuit Current

$$I_{sc} = 13.1\text{kA}$$

- Peak Short Circuit Current

$$I_p = 2.5 \times 13.1 \\ = 32.75\text{kA}$$

E. Circuit Breaker

For 33KV Side

- Type of Circuit Breaker

Vacuum Circuit Breaker

- Highest System Voltage

$$V_m = 1.1 \times 33 \\ = 36\text{kV}$$

- Short Circuit Current

$$I_{sc} = 25\text{kA}$$

(As per IEC standards)

- Making Current

$$I_p = 2.5 \times 25 \\ = 62.5\text{kA}$$

For 11KV Side

- Type of Circuit Breaker

Vacuum Circuit Breaker

- Highest System Voltage

$$V_m = 1.1 \times 11 \\ = 12.1\text{kV}$$

- Short Circuit Current

$$I_{sc} = 25\text{kA}$$

(As per IEC standards)

- Making Current

$$I_p = 2.5 \times 25 \\ = 62.5\text{kA}$$

F. Power Transformer

- Rated Primary Voltage

$$V_1 = 33\text{kV}$$

- Rated Secondary Voltage

$$V_2 = 11\text{kV}$$

- Full Load Current on Primary Side

$$\begin{aligned} I_1 &= \frac{\text{MVA}_T \times 10^6}{\sqrt{3} \times V_1 \times 10^3} \\ &= \frac{12.5 \times 10^6}{\sqrt{3} \times 33 \times 10^3} \\ &= 218.6\text{A} \end{aligned}$$

- Full Load Current on Secondary Side

$$\begin{aligned} I_2 &= \frac{\text{MVA}_T \times 10^6}{\sqrt{3} \times V_2 \times 10^3} \\ &= \frac{12.5 \times 10^6}{\sqrt{3} \times 11 \times 10^3} \\ &= 656.0\text{A} \end{aligned}$$

- Short Circuit Current on Primary Side

$$I_{sc} = 25\text{kA}$$

(As per IEC standards)

- Short Circuit Current on Secondary Side

$$I_{sc} = 10.5\text{kA}$$

(As per IEC standards)

V. CONCLUSION

This work provides an overview of different equipment in 33/11KV substation and design considerations of substation equipment. Each element of the substation — from power transformers, circuit breakers, and lightning arresters to control systems, auxiliary supplies, and protection schemes — must be carefully selected and engineered to meet operational, safety, and future expansion needs. Key design considerations include load demand, short circuit levels, equipment ratings, system reliability, and compliance with national and international standards such as IEC and IS codes.

This work provides an understanding of

- Single line diagram of 33/11KV substation
- Various Substation equipment in detail
- Specifications of the different equipment
- Design calculations of various substation equipment

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