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Case Study on Load Flow and Short Circuit Analysis of a 33/11 kV Substation Using ETAP Software

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Abstract:-

This project represents the performance and simulation analysis of a 33/11 kV substation using ETAP *(Electrical Transient Analyzer program)* software. The primary purpose of the project is to calculate the transient behavior and load flow analysis of the electrical substation to ensure the electrical safety, system efficiency, system reliability and flexibility.

The study start with the proper modeling of SLD *(Single Line Diagram)* of a 33/11 kV substation. It includes various types of components *Grid, Step down Transformer, Cable, Circuit Breaker, Bus Bars, Contactor and also various types Loads.* The load flow analysis is performs by using the Newton-Raphson method. It shows the power flow in the bus bar that is *(Real Power kW+ Reactive power kVAR),* losses on buses and voltage graph at lagging and leading condition. This analysis helps to identify the loading on various buses, over-voltage and under voltage at peak load.

Short-Circuit fault consists line to line, line to ground, and three phase short circuit. The short-circuit analysis helps to calculate the minimum and maximum short circuit current and fault current.

The results of ETAP software shows the power factor correction and how much power delivered to the load and also it shows the voltage profile graph at leading or lagging. The main factor is losses in system or substation *(I^2R).*

Furthermore, the electrical software of simulation tools such as ETAP and EPLAN slightly improves system performance and planning of electrical substation. by performing load flow analysis and short-circuit analysis before actual construction of substation, this analysis helps identify potential operation issues and also this predications reduces losses, increases system efficiency and increase overall reliability. Therefore, pre-planning minimize the risk of equipment failure and other faults.

Keywords:- 33/11 substation, ETAP, step down transformer, circuit breaker, leading and lagging power factor.

1. Introduction:-

The 33/11 kV substation consists *(Primary voltage 33 kV and Secondary voltage 11 kV)*[1]. The primary component in the substation is step down transformer, VCB *(vacuum circuit breaker)* and also consists cables and contactor[1].

In the electrical system substation is very important factor. It converts high voltage into medium voltage by using step down transformer[2]. The 33/11 kV substation is used for commercial, industrial and residential use[3]. In the everyday the demand of electricity will be increased. For this peak demand the substation design is very important to determine the losses and power flow through the bus bar[4].

In the modern huge electrical system the calculation of losses are not possible so, for this purpose design of single line diagram is very important[5]. For this purpose there are some electrical software are such as ETAP, EPLAN and etc[6]. This software reduces the complexity of electrical system. These tools are help to improve the efficiency, reliability and flexibility[1]. This electrical tool has some specific feature such as:-

- Load Flow Studies *(Power Flow)*:-

This analysis is very important for steady state analysis[2]. It calculate the real (p) power and reactive power (Q) and also voltage magnitude *(voltage profile).* The ETAP software determines the each bus power[9]. this tool reduces the overloading condition via determine the bus power[10]. The result is voltage is in stable or normal condition with $^{+}$- 5% tolerance[7].

- Short Circuit and Losses:-

This short circuit analysis consists various types fault such as L-L *(Line to Line)*, L-L-L-G *(Three Phase Short Circuited with Ground)*, L-L-G *(Two Phase short Circuited with Ground).* This electrical tool helps analyze the short circuit fault and losses at buses and lines[8].

While the designing of a 33/11 kV substation in ETAP software. The important factor is transformer turn ratio and transformer primary and secondary impedance ratio[3]. For the primary voltage *(33/11kv)* there are two transformers used in the substation for emergency condition that is when the one line is faulted then the second line will be provided[3]. At the secondary side there are four transformers *(11/2.5 kV)* will be used[4]. There are four types of loads are used in the ETAP software i.e. Lumped load, Static load and induction motor for earthing purpose[9].

2. Objectives:-

The primary objectives of the project is system modeling *(SLD)*, Performance and behavior of System, Safety verification Load Flow Analysis, Short-Circuit Analysis, Identify the various types of faults like line to line, three phase short circuit to ground and two phase short circuit with grounding[5]:-

- To develop proper E- Model of 33/11 kV substation:-

Construct the proper single line diagram of 33/11 kV substation in E-TAP software. Use accurate data for utility power supply, transformer, bus bars and cables[3].

- To calculate the steady state performance of substation by using Load Flow Analysis *(newton raphson method):-*

Analyze of voltage graph, Active and power flow and system by using the newton raphson method[5]. The function of the system is to ensure the all buses is in normal condition and normal operating voltage and current[6].

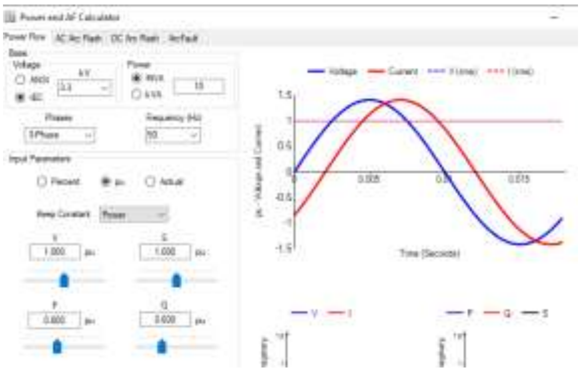

Fig 2.1. Calculation of voltage p.u (per unit)

From fig a. shows the voltage per unit (1.000pu). It shows system is in normal operating condition[7]. The normal range of operating voltage per unit is (Typically 0.95 to 1.05 pu) thus there is no equipment is overloaded under high power demand[8].

- To perform fault analysis:-

Calculate the maximum and minimum short circuit current by using line-to-line fault, three-phase short circuit with ground and etc. This fault analysis ensures the circuit breaker *(vacuum circuit breaker)* work properly at fault condition[9].

- Voltage Profile:-

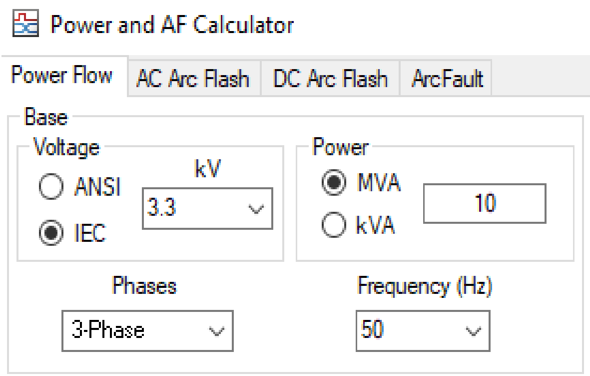

Fig 2.2 Power and AF calculator of (IEC)

To determine the proper supply to the transformer and maintain the 11 kV, voltage profile within the safe voltage and standard $\pm$ 5 % tolerance with rated frequency *(as per rule of international Electro-technical commission)*[10].

3. Literature Review:-

Many researchers have studied the design, simulation and load flow analysis also short circuit analysis of electrical substation. It helps to determine the *(Real power kW + Reactive power kVAR)* also, this simulation determines the various types losses are occurred in transformer side and in transmission line. This analysis determine by using E-TAP software *(electrical transient analyzer program)*[3].
This improves the performance and reliability of the substation *(33/11 kV)*[11].

E-TAP software analyze the load flow analysis of 33/11 kV substation by developing a single line diagram *(SLD)*[3]. In this paper the *newton raphson method* used for load flow analysis for determine the voltage across buses, losses and power flow *(active power + reactive power)*[4]. The result is helps to understand the voltage drop across each bus, voltage regulation, over-loading and power loss. This result allows engineer to improves performance and reliability of the system[12].

In this paper the case is conducted on 33/11 kV substation at Rohinkhed, Maharashtra.

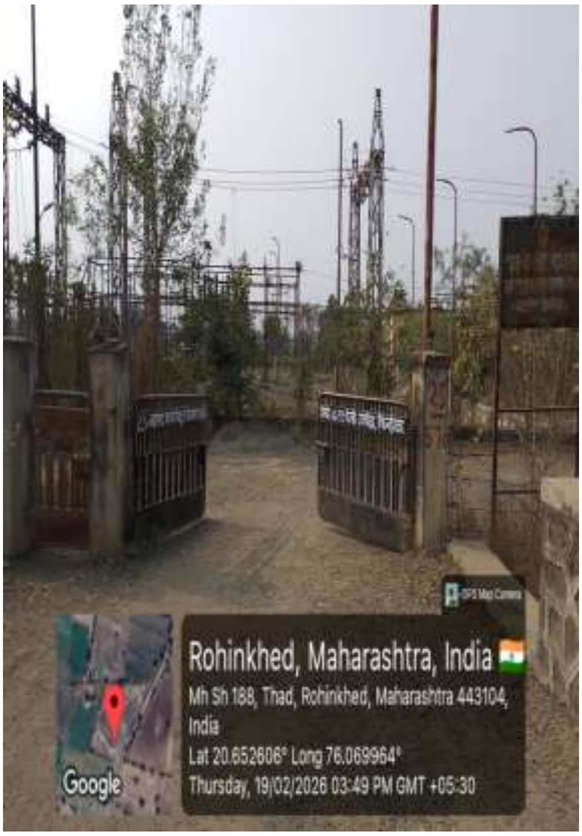

Fig c. Substation at Rohinkhed, maharashtra

This substation is modeling on EATP software. This case study performs that load flow analysis to demonstrate planning and operation of substation[9]. Because, it determines the voltage regulation, power flow and losses in the power system[7]. The ETAP software use for complex calculation and also, determine the load flow studies. It allows to visualize the power system and also it improves system real time operation[5].

In the single line diagram *(SLD)* also use the integrated renewable energy sources in the substation. For example, a study on a 33/11 kV substation with solar installation used to analyze the power loss and overloaded condition and short circuit calculations under different voltage levels[6]. The result shows that the renewable power can reduces the voltage loss and power loss at different voltage levels. But, it increases the short circuit condition. So, it require proper protection system against over voltage and short circuit condition for example, proper use and proper ratings of circuit breaker to reduce the fault condition[13]. The load flow analysis is very important factor for calculation of power loss and for overloaded condition[14]. By the use ETAP software it shows system is in normal operating condition or abnormal condition by using identify the each bus power *(active power + reactive Power)*, and also from transformers overloading condition and technical fault in the system[2]. This ETAP software also allows to test corrective measures such as adding of load bank (capacitor bank), relay unit, distribution of load and system optimization before installing them in real substation[5]. The primary use of E-TAP software is RTO *(Real Time Operation)*[15].

In addition to load flow studies, the short circuit analysis is widely used to determine short circuit current, maximum fault current and overload condition[16]. This analysis helps to design the proper rating of circuit breaker, relays, contactors, transformers and other protective devices[17]. It ensures the power system is in normal operating condition[1].

From this literature review it is clear that the ETAP software is a powerful tool for designing and analyzing substation[7]. It provides accurate data from single line diagram[17]. However, many studies focus mainly on load flow analysis and also it explore more topic such as automation, IOT smart grid and also real time monitoring system in 33/11 substation[18].

4. Methodology:-

This methodology represents the design and load flow analysis of 33/11 kV substation using ETAP software[16]. The modeling of 33/11 kV substation performs load flow analysis and short circuit analysis and also calculate the losses under various operating condition[4].

4.1. Data Collection:-

The collection of data for single line diagram *(SLD)*:-

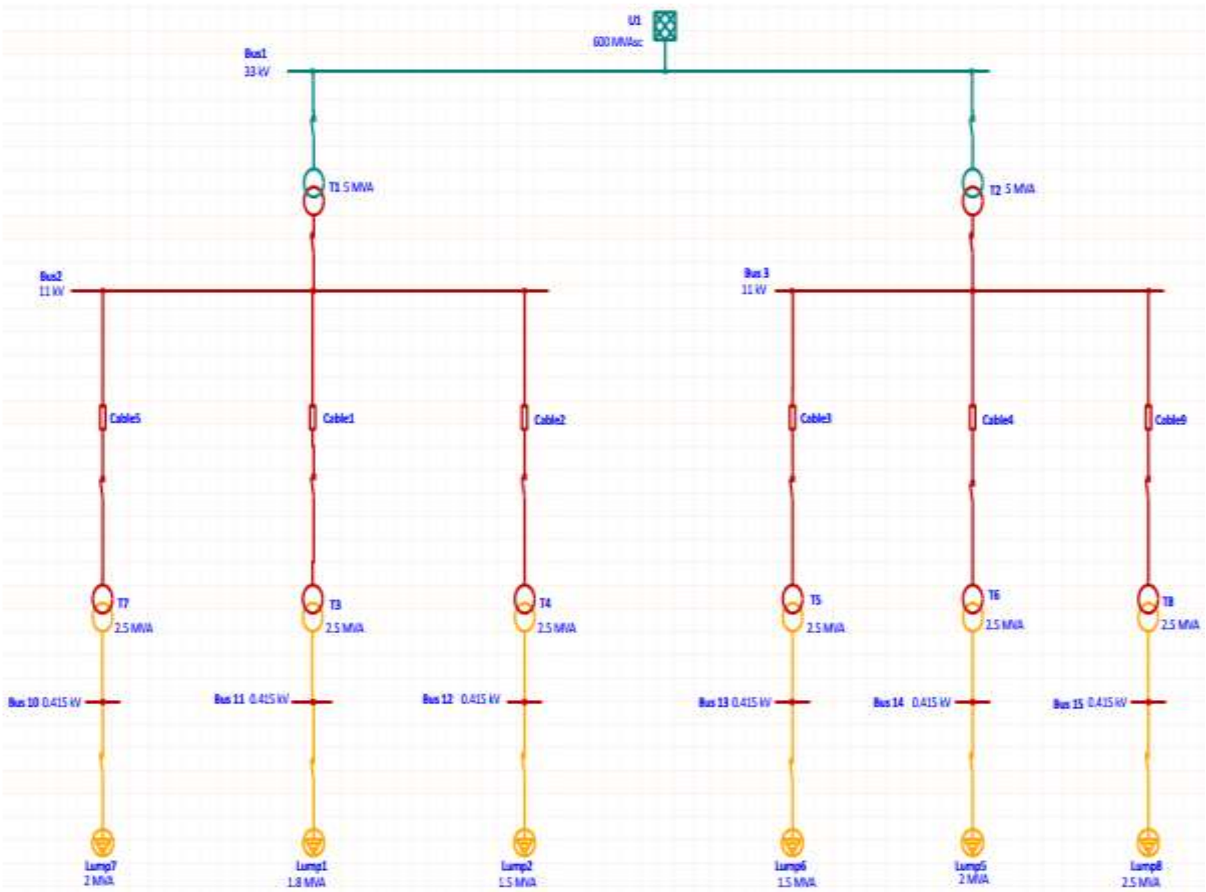

Fig 4.11.Single line diagram of 33/11kV substation design on ETAP software

- Power Grid (G_1):-

The power grid is used to provide a supply to the step-down transformer (33/11 kV)[17].

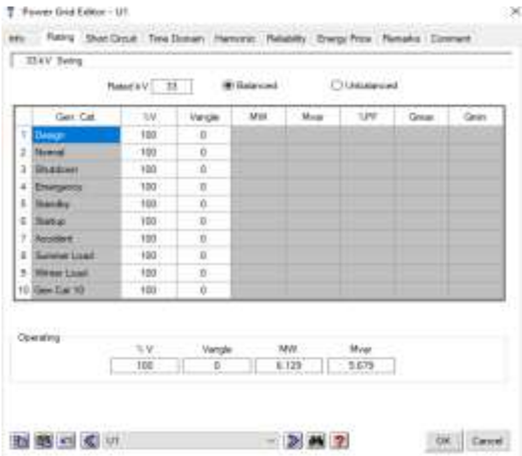

Fig.4.1. Ratings of utility power supply

The swing mode is selected for power grid. The rated voltage is 33 kV input and output is 11 kV and swing mode is considered for 33 kV bus. The short circuit calculation is also determine for the utility power supply[17].

Fig.4.2. Ratings of Short circuit and Short circuit impedance

Assumptions, for (3-Phase) short circuit ratings:-

MVAsc	X/R	kAsc
600	10	10.497

Table 4.1. Short Circuit Ratings

For, calculation of short circuit impedance we have three formulas i.e.

Positive impedance:- $Z_1 = R_1 + jX_1$.

Negative impedance:- $Z_2 = R_2 + jX_2$.

Zero impedance:- $Z_0 = R_0 + jX_0$.

- Circuit Breaker (CB_1 and CB_2):-

There are two circuit breakers used in this modeling of single line diagram. The circuit breaker is connected to the 33 kV bus. The vacuum circuit breaker is used[7].

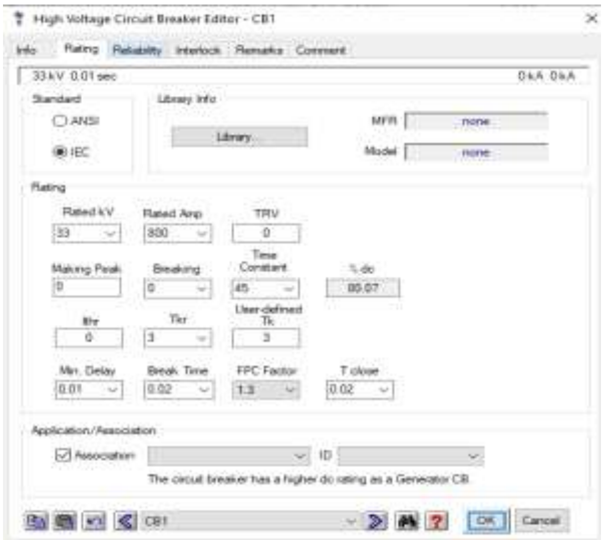

Fig.4.3. Ratings of high voltage circuit breaker (VCB)

A 33 kV vacuum circuit breaker is a protective device used in electric system. It protects system from fault condition[7].
It operates by using a vacuum as the arc-quenching medium[8].

Rated kV	Rated Amp	Standard
33	800	IEC

Table 4.2. Ratings of Circuit Breaker

- Step-Down transformer (T_1 and T_2):-

A transformer is a static device, which converts electric energy from one circuit to another circuit by using electromagnetic induction without changing its frequency *(50 Hz)*[18].

A step down transformer is used for to reduce the high voltage into low voltage level. In this single line diagram a transformer converts 33 kV at primary side and at secondary side is 11 kV[18].

Main parts of transformer:-

- ➢ Primary winding
- ➢ Secondary winding
- ➢ Oil tank
- ➢ Breather
- ➢ Magnetic core
- ➢ Insulation
- ➢ Ventilating ducts (type oil cooling).
- ➢ Primary and secondary voltage terminals[4].

Rated kV	MVA	Standard
33/11	5	IEC

Table 4.3. Ratings of Transformer (33/11 kV)

Fig.4.4. Ratings of Transformer (33/11 kV)

Fig.4.5. Transformer (33/11 kV) Impedance Ratio

Transformer impedance ratio helps to determines[11]:-

- ➢ Voltage profile
- ➢ Short circuit analysis
- ➢ Electric substation stability
- ➢ Load sharing
- ➢ Load flow studies

- Cable *(cable 1 to 6)*:-

Transmission cable is an electrical conductor used to transfer electrical energy from sending station to receiving station. There are two types transmission cables used in electrical system such as[19]:-

- ➢ Under-ground cable
- ➢ Over-head cable

In this modeling the over-head cable is used for transmission. The distance of this cable is 3 km[8]. the aluminum sheath is used in the cable and also, it is open grounded type and the jacket type is XLPE used in the cable. The diameter of the cable is 2 cm and the thickness is 240 mm. The voltage level of the cable is 11 kV[9].

Fig.4.6. Cable Impedance Ratio

- ➢ Voltage:- 11 kV
- ➢ Operating Current:- 400 Amp
- ➢ Loading factor :- 100%

Fig.4.7. Operating Current capacity of cable

- Step-Down Transformer (T_3 to T_8):-

A transformer is a static device, which converts electric energy from one circuit to another circuit by using electromagnetic induction without changing its frequency *(50 Hz)*[11].

A step down transformer is used for to reduce the high voltage into low voltage level[14]. In this single line diagram a transformer converts 11 kV at primary side and at secondary side is 0.415 kV[15].

Transformer impedance ratio helps to determines:-

- ➢ Voltage profile
- ➢ Short circuit analysis
- ➢ Electric substation stability
- ➢ Load sharing

Fig.4.8. Ratings of Transformer

(11/415 kV)

Rated kV	**MVA**	**Standard**
11/0.415	2.5	IEC

Table 4.4. Ratings of Transformer (11/415 kV)

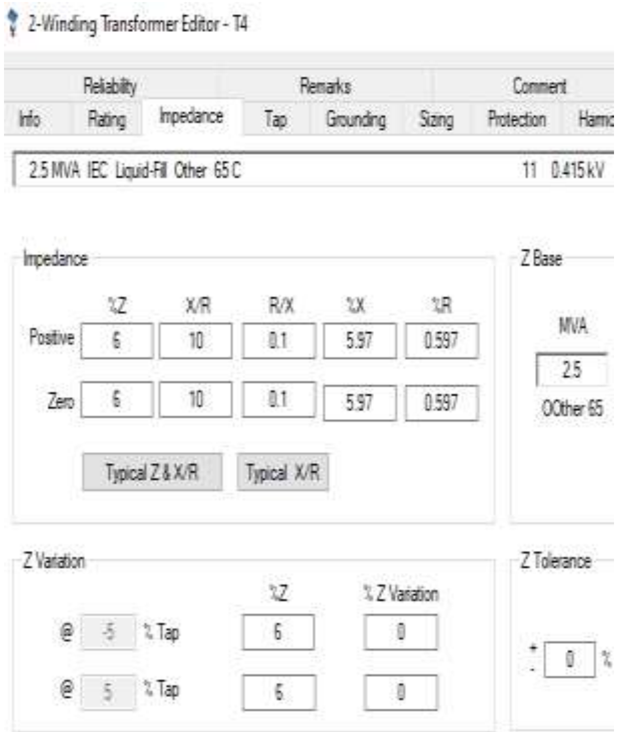

Fig.4.9. Transformer (11/415 kV) Impedance Ratio

- Contactors:-

The Contactor is used in power system for open or close electric loads. Contactor allows to circuit open and close automatically by using electromagnetic operation. It improves system reliability it makes system more efficient due to manual and automatic operation[20].

In single line diagram contactor is connected in the series with the loads i.e. it helps to reduce fault condition occurs on load side[14].

- Load *(assume)*:-

In the single line diagram there are six lumped loads connected to the substation[7].

The lumped is the combination of all loads and it used in single line diagram for load flow analysis, power flow analysis and short circuit analysis. Examples of lumped load:- Houses, Shops, industrial load and etc[21].

4.2 Single Line Diagram Design:-

The single line diagram is very important for electrical power system. It helps to reduce complex system into simplified single line system. It helps to clearly show main components used in power system for example[22]:-step-up and step-down Transformer, insulators, conductors, cables, relay section, battery backup section and towers and etc[11]. The very important factor is to calculate the line impedance and losses to determine the power loss in the system[23].

Fig 4.10.Case of 33/11 kV substation located at rohinkhed

This 33/11kV substation consists power grid or transmission line, two transformer, circuit breaker, contactor, insulators, cables and also, loads[24]. The power grid *33kV* is connected is connected to transformer through circuit breaker[25]. It converts *33kV into 11kV* it is connected through circuit breaker, contactor and it is connected in parallel with each transformer. Then, the 11 kV bus is connected to the step down transformer through the cables and circuit breakers *(vacuum circuit breaker)*[8]. Thus, the loads are connected thorough 0.415 kV bus[5].

The single line diagram helps to analyze the power flow and losses occurs in the system[26].

This single line diagram represents the 33/11kV substation design on ETAP software[16]. It includes power grid or transmission line, two transformer, circuit breaker, contactor, insulators, cables and also, loads[17]. The power grid *33kV* is connected is connected to transformer through circuit breaker[21]. It converts *33kV into 11kV* it is connected through circuit breaker, contactor and it is connected in parallel with each transformer[22]. Then, the 11 kV bus is connected to the step down transformer through the cables and circuit breakers *(vacuum circuit breaker)*[27]. Thus, the loads are connected thorough 0.415 kV bus[23]. The single line diagram helps to analyze the power flow and losses occurs in the system[22]. ETAP software allows system easy visualization of the electrical power system and it is real time operation system *(RTO)*[5]. It makes system more reliable. In the single line diagram there are six lumped loads connected to the substation[24]. The lumped is the combination of all loads and it used in single line diagram for load flow analysis, power flow analysis[12].

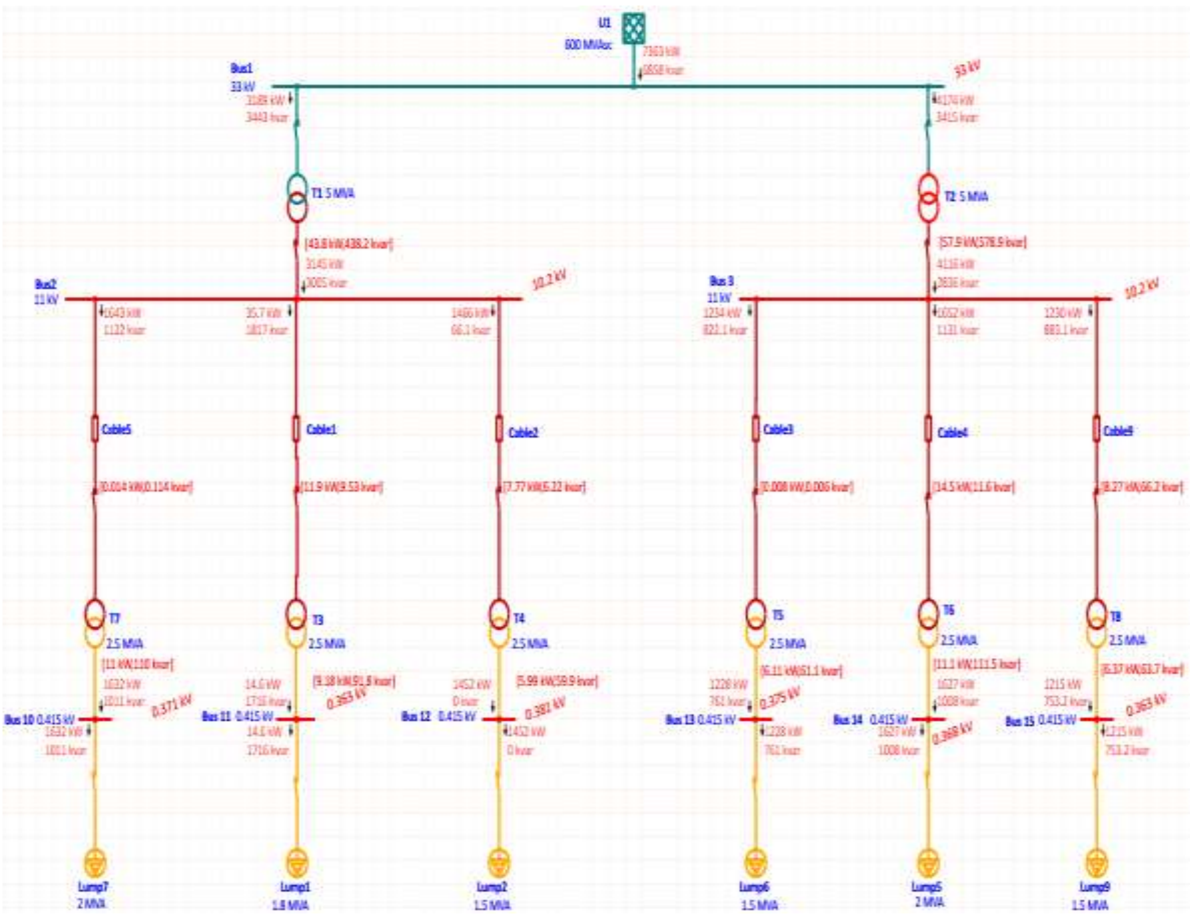

Fig 4.12. Single line diagram of 33/11kV substation design on ETAP software

4.3 Load Flow Analysis and Short Circuit Analysis:-

Load flow analysis determine the bus voltage, real power and reactive power in the form of *(kW+kVAR)*, Losses, loading and over-loading capacity of transformer[25]. The short analysis determines the fault analysis and fault current analysis on various buses. The short circuit analysis helps to improve system reliability[2]. It determines ratings of circuit breaker and also other components such as transformers and other protective devices[26].

Load flow analysis performed by using ETAP software[2]. It helps to calculate the power loss and voltage magnitude calculation. This analysis helps to determine the steady state analysis of the system[1].

The load flow analysis calculate some parameter such as:- Voltage magnitude, real power and reactive power *(kW+kVAR)*[27]. Power loss of transmission line and also over-loading of transformer[4]. ETAP software helps to analyze this parameter in real time operation system *(RTO)*[28].

- Voltage Magnitude:-

Voltage magnitude is point of voltage at particular point in the electrical system without determine its phase angle[29]. The voltage magnitude is very important factor in the load flow studies[23]. The voltage magnitude determines the voltage within normal operating condition, voltage drop and also it determines the power system is in normal operating condition[8].

Sr.No	Bus No	Actual Voltage	Voltage Magnitude
1	Bus 1	33 kV	33 kV
2	Bus 2	11 kV	10.2 kV
3	Bus 3	11 kV	10.2 kV
4	Bus 4	0.415 kV	0.371 kV
5	Bus 5	0.415 kV	0.363 kV
6	Bus 6	0.415 kV	0.381 kV
8	Bus 8	0.415 kV	0.375 kV
9	Bus 9	0.415 kV	0.368 kV
10	Bus 10	0.415 kV	0.363 kV

Table 4.5 Ratings of voltage magnitude at various buses

- Active power and Reactive power flow:-

Active power:-

Active power is also known as real power it transfers real power in electrical system from source to load[7]. It transfers the useful power to the fans, heaters, motors, lighting system and other equipment. Active power measured in kW[29].

Where,

P= Active power *(kW, MW and W)*

I= Current *(I)*

V= Voltage *(V)*

Reactive power:-

Reactive power flow represents the power that oscillates between source and reactive components for example:- capacitive components, inductive components. The reactive power is very important for maintain the voltage level and voltage stability[10].

Where,

V= Voltage

I= Current

Q= Reactive Power

Sr.No	Components	Active Power	Reactive Power
1	Utility Power Supply	7363 kW	6858 kvar
2	Transformer 1	43.8 kW	438.2 kvar
3	Transformer 2	57.9 kW	578.9 kvar
4	CB 1	3189 kW	3443 kvar
5	CB 2	4174 kW	3415 kvar
6	CB 3	0.014 kW	0.114 kvar
8	CB 4	11.9 kW	9.53 kvar
9	CB 5	7.77 kW	6.22 kvar
10	CB 6	0.008 kW	0.006 kvar
11	CB 7	14.5 kW	11.6 kvar
12	CB 8	8.27 kW	66.2 kvar
13	Transformer 3	9.18 kW	91.8 kvar
14	Transformer 4	5.99 kW	59.9 kvar
15	Transformer 5	6.11 kW	61.1 kvar
16	Transformer 6	11.1 kW	111.5 kvar
17	Transformer 7	11 kW	110 kvar
18	Transformer 8	6.37 kW	63.7 kvar

Table 4.6 Active and Reactive power flow at various components

- Short-circuit Analysis:-

Short circuit analysis determines the maximum fault current occur in the electrical power system[6]. The short circuit analysis consists various types fault such as L-L *(Line to Line)*, L-L-L-G *(Three Phase Short Circuited with Ground)*, L-L-G *(Two Phase short Circuited with Ground)*[4]. This electrical tool helps analyze the short circuit fault and losses at buses and lines[5].

The short circuit analysis consists various types of fault and this types of fault is used in single line diagram to calculate the maximum fault current[30]. In short circuit analysis it performs L-L *(Line to Line)*, L-L-L-G *(Three Phase Short Circuited with Ground)*, L-L-G *(Two Phase short Circuited with Ground)*[5].

Assume, L-L-G *(Two Phase short Circuited with Ground)* fault is occur in bus1 *(33 kV)* it represents the short circuit calculation[13]. It helps to determine the maximum fault current occur in bus 1[3].

Sr.NO	Short-Circuit Bus	Actual Voltage	Short-Circuit Voltage	Fault Type
1	Bus 1	33 kV	10.497 kA	L-L-G

Sr.NO	Short-Circuit Bus	Actual Voltage	Short-Circuit Voltage	Fault Type
1	Bus 1	11 kV	2.678 kA	L-L-G
2	Bus 2	11 kV	2.678 kA	L-L-G

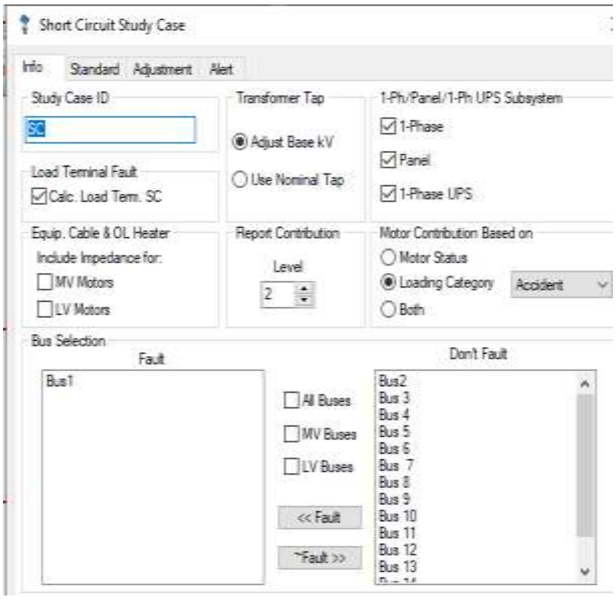

Fig 4.13. Short-circuit calculation of bus 1

Assume, L-L-G *(Two Phase short Circuited with Ground)* fault is occur in bus2 and bus3 *(11 kV)* it represents the short circuit calculation[5]. It helps to determine the maximum fault current occur in Bus1 and bus2[5].

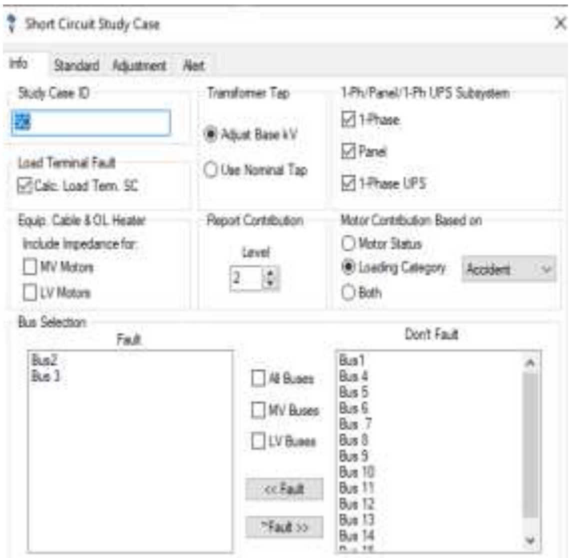

Fig 4.14. Short-circuit calculation of bus2 and bus3

Table 4.8 Short-Circuit calculation of Bus1 and Bus2

Assume, L-L-G *(Two Phase short Circuited with Ground)* fault is occur in bus 10 to bus15 *(11 kV)* it represents the short circuit calculation[12]. It helps to determine the maximum fault current occur in Bus 10 to Bus 15[5].

Table 4.8 Short-Circuit calculation of Bus10 and Bus15

Sr. NO	Short-Circuit Bus	Actual Voltage	Short-Circuit Voltage	Fault Type
1	Bus 10	0.415 kV	32.684 kA	L-L-G
2	Bus 11	0.415 kV	30.735 kA	L-L-G
3	Bus 12	0.415 kV	30.735 kA	L-L-G
4	Bus 13	0.415 kV	32.701 kA	L-L-G
5	Bus 14	0.415 kV	30.735 kA	L-L-G
6	Bus 15	0.415 kV	20.973 kA	L-L-G

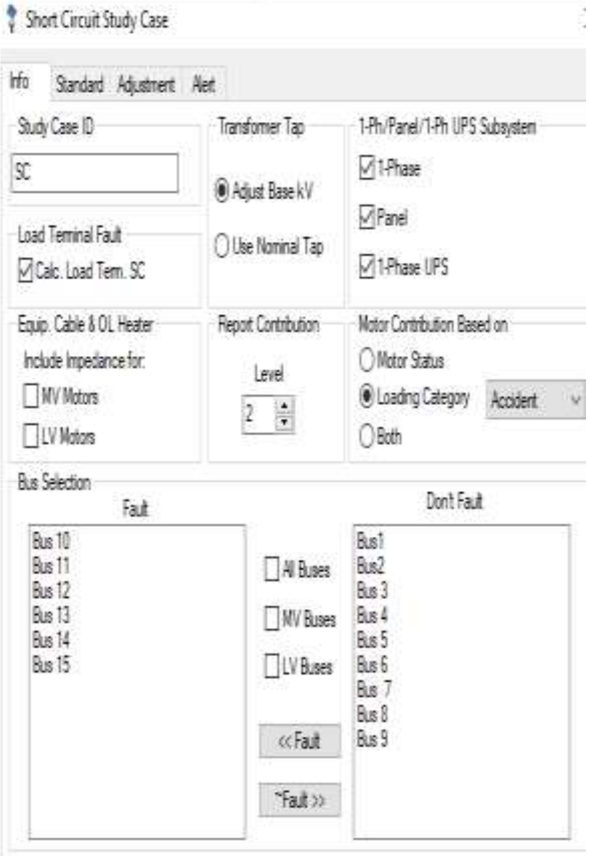

Fig 4.15. Short-circuit calculation of bus 10 to Bus 15

5. Result:-

ETAP software helps to simulate the Single Line Diagram of 33/11 kV substation and also analyze the power system performance by using load flow analysis[11]. Load flow analysis determine the active and reactive power and also determine the power loss and fault analysis[11]. It increases system efficiency and reliability. Due to single line diagram[16].

It reduces fault condition on electrical power system due short circuit analysis it consists various types of fault such as L-L *(Line to Line)*, L-L-L-G *(Three Phase Short Circuited with Ground)*, L-L-G *(Two Phase short Circuited with Ground)*[14]. This electrical tool helps analyze the short circuit fault and losses at buses and lines[10]. It improves system reliability. Thus, ETAP software is very important for analysis of electrical power system by using load flow analysis and short circuit analysis[19].

6. Conclusion:-

The design and analysis of 33/11 kV substation by using ETAP software were successfully complete[20]. Load flow analysis helps to analyze the voltage magnitude, power factor and determine the various types of loss occur in electrical power system[4]. Short circuit analysis helps to determine the faults such as:- L-L *(Line to Line)*, L-L-L-G *(Three Phase Short Circuited with Ground)*, L-L-G *(Two Phase short Circuited with Ground)*[5]. This feature improves system reliability and efficiency[8].

7. Future Scope:-

In the future, the study can be extended by use of various types renewable energy sources. Such as solar energy, wind energy, etc into the substation[10]. Also, use of protection scheme for example:- For further research may include the real time protection system, transient stability analysis and harmonic analysis[12].

Another potential for future scope is the integration of IOT *(internet of things)* system and automation such as SCADA in electrical power system[22]. It makes system real time operation that is real time monitoring system[23]. It improves efficiency of power system and it reduces the fault conditions such as:- L-L *(Line to*

Line), L-L-L-G *(Three Phase Short Circuited with Ground)*, L-L-G *(Two Phase short Circuited with Ground)*[12].

Finally, the development of model can be further expand to involve large model transmission power system and also add more multiple grids. This model expanded by using ETAP software[28].

The main point for future scope is adding of Artificial intelligence and implementation of machine learning *(real time operation system)* in electric power system. It makes system more reliable due to pre-fault finding system, predictive maintenance of power system[30].

8. Acknowledgement:-

The authors would like to express their gratitude to project guide and faculty for their guidance and support the completion of this research paper and design of single line diagram[21]. Thanks are also extended to the collage for providing the important facilities and various sources for the successfully completion this report[21]. The ETAP software greatly help in performing the simulation and analysis of the 33/11 kV substation[23].

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