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PROTECTION-ORIENTED POWER SYSTEM STUDIES FOR THE ELECTRICAL NETWORK

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Abstract: This thesis presents the power system analysis of an electrical network using ETAP software to evaluate steady-state performance, fault levels and protection coordination. Adaptive Newton–Raphson techniques are applied to assess the reliability, safety and operational effectiveness of the system. The electrical network is modelled in ETAP to analyze voltage profiles, fault current levels and relay coordination. Load flow analysis confirms that bus voltages remain within permissible limits and equipment operates within rated capacities. Short circuit analysis determines fault current levels for equipment verification, while protection coordination studies ensure selective operation of relays and circuit breakers with proper primary and backup protection. The study concludes that the electrical network operates reliably and efficiently under normal operating conditions. Further studies such as motor acceleration and transient stability analysis can also be performed to evaluate the dynamic performance and stability of the system.

Keywords: Power System Analysis, Protection Coordination and ETAP Modelling.

INTRODUCTION

Electrical power systems play a vital role in ensuring reliable and continuous operation of modern facilities. Proper analysis of electrical networks is essential to maintain system stability, safety and operational efficiency under various loading conditions. Power system studies such as load flow, short-circuit and protection coordination analysis are widely performed to evaluate the performance and reliability of electrical systems.

ETAP software provides an effective platform for modelling, simulation and analysis of complex electrical networks. Load flow analysis is used to determine voltage profiles, power flow and equipment loading under steady-state conditions. Short-circuit analysis helps in identifying fault current levels and verifying equipment interrupting capacities. Protection coordination studies ensure proper operation of relays and circuit breakers for selective fault isolation and reliable system operation. This study focuses on the analysis of an electrical network using ETAP software to assess system performance, protection reliability and operational safety under normal operating conditions.

OBJECTIVE

i. To evaluate the steady-state performance of the electrical network using load flow analysis in ETAP.
ii. To determine fault current levels and verify equipment performance.
iii. To perform protection coordination studies for selective operation of relays and circuit breakers to ensure reliable system protection.

STUDY ON LOAD FLOW ANALYSIS

Load flow analysis is an important study used to determine the steady-state operating condition of an electrical power system. It calculates bus voltages, voltage angles, active power, reactive power and power flow through various components of the network. The analysis helps in identifying voltage drops, overloaded buses and system losses under normal operating conditions.
In ETAP, each bus represents a connection point where electrical components such as generators, transformers, loads and feeders are interconnected. Bus details include voltage magnitude, voltage angle, active power demand, reactive power

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demand and loading condition. These parameters are used to verify whether the bus voltages remain within permissible limits and whether the connected equipment operates safely within rated capacities.

The Adaptive Newton–Raphson method is used in this study due to its high accuracy and fast convergence characteristics. The load flow results help in maintaining system stability, improving power distribution and ensuring reliable operation of the electrical network.

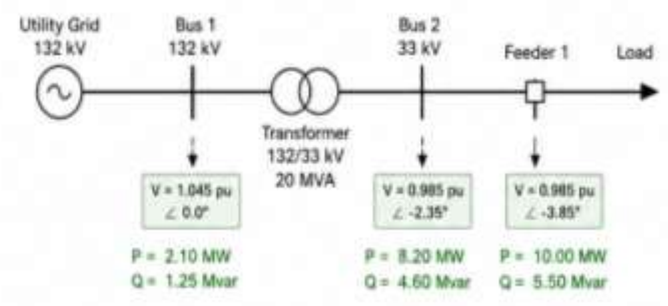

Figure 1.1 Study on load flow analysis

STUDY ON SHORT CIRCUIT ANALYSIS

Short circuit analysis is performed to determine the fault current levels in an electrical power system under abnormal operating conditions. It is an important study used to evaluate the capability of electrical equipment to withstand and interrupt fault currents safely. The analysis helps in selecting suitable ratings for circuit breakers, relays, transformers and other protective devices as shown in figure 1.2.

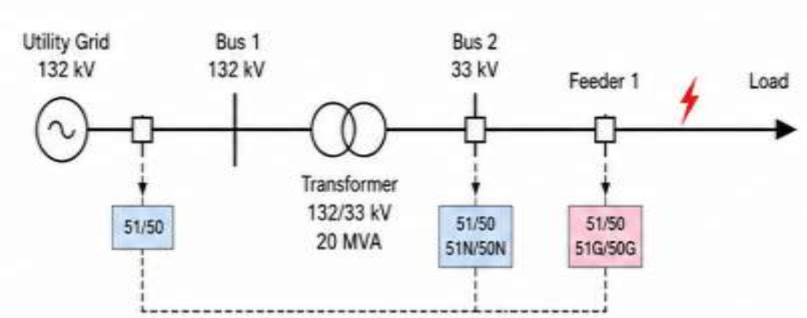

Figure 1.2 Study on short circuit studies

In ETAP, short circuit studies are carried out to calculate fault currents at different buses in the electrical network. Among various fault types as shown in figure 1.3, the three-phase fault is considered the most severe symmetrical fault condition, producing the maximum fault current in the system. Therefore, three-phase fault analysis is widely used as the basis for relay coordination studies and circuit breaker setting calculations.

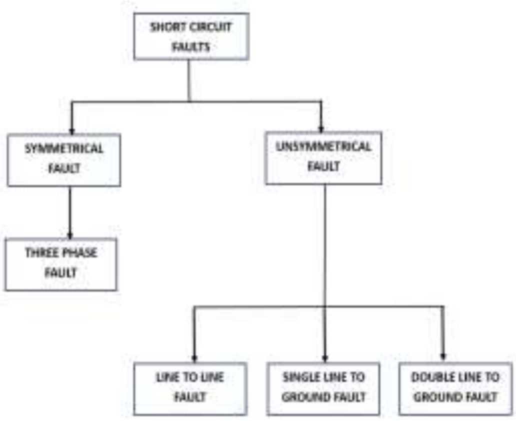

Figure 1.3 Types of fault studies

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The obtained fault current values are used to verify circuit breaker interrupting capacities and to determine appropriate relay pickup settings and time coordination characteristics. Proper evaluation of three-phase fault levels ensures selective operation of protective devices, reliable fault isolation and protection of equipment from thermal and mechanical damage. Short circuit analysis also improves the overall safety, stability and reliability of the electrical network.

STUDY ON RELAY COORDINATION

Relay coordination study is performed to ensure selective and reliable operation of protective devices during fault conditions in an electrical power system. The main objective of relay coordination is to isolate only the faulty section of the network while maintaining uninterrupted supply to the healthy sections. Proper coordination between relays and circuit breakers improves system reliability, stability and equipment protection.

In ETAP, relay coordination analysis is carried out by evaluating relay characteristics, pickup current settings and operating time sequences for different fault conditions. The study mainly uses three-phase fault current values obtained from short-circuit analysis as the basis for determining relay and circuit breaker settings. Primary protection devices are designed to operate first, while backup protection devices operate with a time delay in case of primary protection failure. Time Current Characteristic (TCC) curves are used to verify proper coordination between relays and circuit breakers. The analysis ensures that protective devices operate selectively without unnecessary tripping of healthy feeders as shown in figure 1.4. Relay coordination studies help in minimizing equipment damage, reducing outage duration and improving the overall safety and reliability of the electrical network.

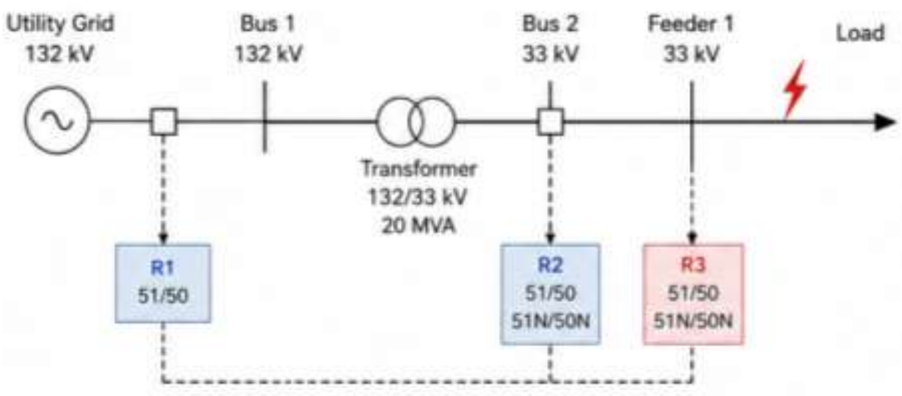

Figure 1.4 Study on relay coordination

RELAY FUNCTIONS USED IN ETAP PROTECTION COORDINATION

Relay Function	Relay Name	Operating Principle	Main Application
50	Instantaneous Overcurrent Relay	Operates instantly when current exceeds pickup value without intentional time delay.	Protection against severe short-circuit faults and high fault currents.
51	Time Overcurrent Relay	Operates with inverse time characteristic; operating time decreases as fault current increases.	Feeder protection and backup overcurrent protection.
50N	Instantaneous Neutral Overcurrent Relay	Detects high neutral current due to earth faults and operates instantly.	Fast neutral and earth fault protection.
51N	Time Neutral Overcurrent Relay	Provides time-delayed protection based on neutral current magnitude.	Coordinated earth fault and neutral protection.
50G	Instantaneous Ground Fault Relay	Detects ground fault current and trips without time delay.	Rapid ground fault isolation and equipment protection.
51G	Time Ground Fault Relay	Operates with inverse time delay for ground fault currents.	Coordinated ground fault protection in electrical systems.
67	Directional Overcurrent Relay	Operates only for fault current flowing in a specified direction.	Protection of interconnected systems, ring networks and parallel feeders.

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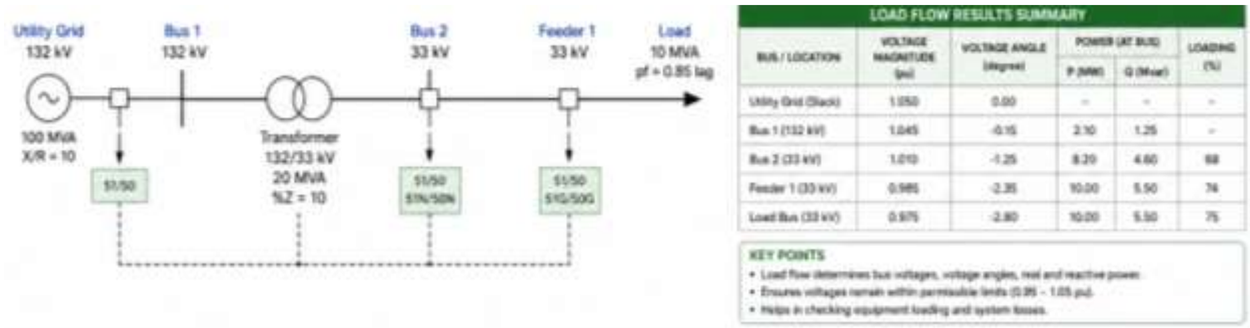
RESULTS AND DISCUSSION

The load flow analysis performed in ETAP confirmed that all bus voltages remained within the permissible operating limits under normal operating conditions. The voltage profile across the electrical network was found to be stable, and the loading of transformers, feeders and buses remained within rated capacities. The obtained results verified proper power flow distribution and satisfactory system performance without any overload conditions as shown in figure 1.5.



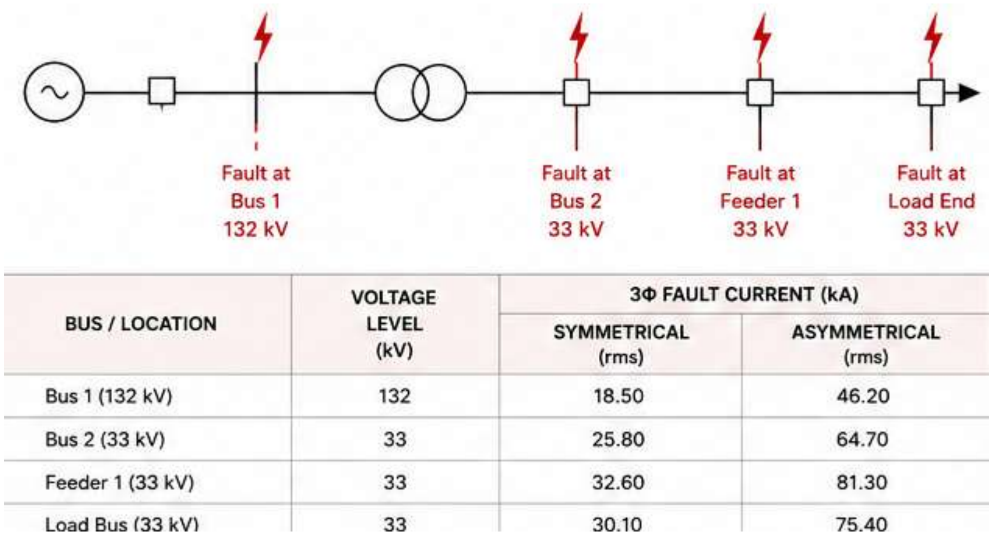
LOAD FLOW RESULTS SUMMARY

BUS / LOCATION	VOLTAGE MAGNITUDE (pu)	VOLTAGE ANGLE (degree)	POWER (AT BUS)		LOADING (%)
			P (MW)	Q (Mvar)	
Utility Grid (Slack)	1.050	0.00	-	-	-
Bus 1 (132 kV)	1.045	-0.15	2.10	1.25	-
Bus 2 (33 kV)	1.010	-1.25	8.20	4.60	68
Feeder 1 (33 kV)	0.985	-2.35	10.00	5.50	74
Load Bus (33 kV)	0.975	-2.80	10.00	5.50	75

KEY POINTS
- Load flow determines bus voltages, voltage angles, real and reactive power
- Ensures voltages remain within permissible limits (0.95 – 1.05 pu)
- Helps in checking equipment loading and system losses

Figure 1.5 Result for Load flow analysis

The short-circuit analysis was carried out to determine the fault current levels at various buses in the electrical system. Among the different fault conditions, the three-phase fault produced the maximum fault current and was considered as the base condition for protection coordination and circuit breaker setting calculations as shown in figure 1.6. The calculated fault current values were within the interrupting capacities of the installed protective devices, ensuring safe fault clearance and equipment protection.



BUS / LOCATION	VOLTAGE LEVEL (kV)	3Φ FAULT CURRENT (kA)	
		SYMMETRICAL (rms)	ASYMMETRICAL (rms)
Bus 1 (132 kV)	132	18.50	46.20
Bus 2 (33 kV)	33	25.80	64.70
Feeder 1 (33 kV)	33	32.60	81.30
Load Bus (33 kV)	33	30.10	75.40

Figure 1.6 Result for short circuit analysis

Relay coordination studies were performed using Time Current Characteristic (TCC) curves to ensure selective operation of protective devices. The coordination results confirmed proper operating sequence between primary and backup relays with adequate time margins, thereby minimizing unnecessary tripping and improving system reliability as shown in figure 1.7.

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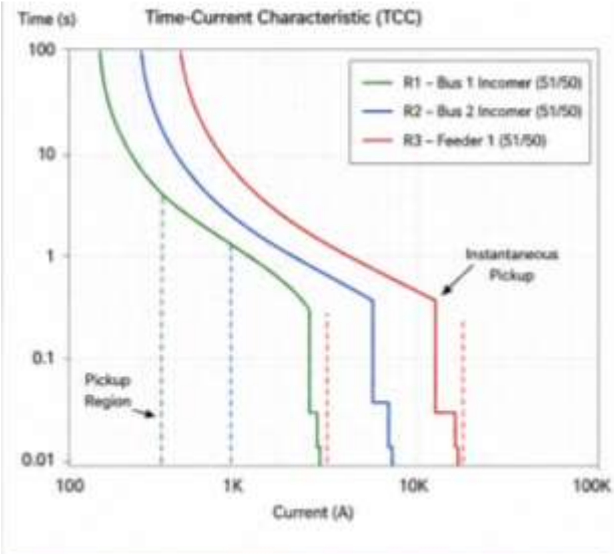

COORDINATION TIME INTERVAL (at 5 x Pickup Current)					
Relay Pair	Primary Relay	Backup Relay	Operating Time Primary (s)	Operating Time Backup (s)	Time Interval (s)
R3 - R2	R3 (Feeder 1)	R2 (Bus 2)	0.23	0.43	0.20 ✓
R2 - R1	R2 (Bus 2)	R1 (Bus 1)	0.43	0.75	0.32 ✓

Figure 1.7 TCC for relay coordination

The relay settings for overcurrent and ground fault protection functions were properly coordinated based on load flow and short-circuit analysis results for the summary of relay coordination as shown in figure 1.8.

RELAY COORDINATION SUMMARY						
Relay ID	Device / Location	CT Ratio	Relay Type	Pickup Current (A)	Time Dial (TMS)	Inst. Pickup Current (A)
R1	Bus 1 Incomer (132 kV)	100/1	OC & EF	600	0.10	6000
R2	Bus 2 Incomer (33 kV)	200/1	OC & EF	800	0.20	8000
R3	Feeder 1 (33 kV)	200/1	OC & EF	1000	0.30	10000

Figure 1.8 Summary for relay coordination

Overall, the ETAP simulation results demonstrated that the electrical network operates reliably and efficiently under steady-state and fault conditions, ensuring improved system stability, protection coordination and operational safety.

CONCLUSION

The power system studies carried out using ETAP software successfully evaluated the steady-state performance, fault behaviour and protection coordination of the electrical network. Load flow analysis confirmed that all bus voltages and equipment loading conditions remained within permissible operating limits, ensuring stable and efficient system operation. Short circuit analysis determined the fault current levels at various buses, with the three-phase fault producing the maximum fault current used for equipment verification and circuit breaker setting calculations.

Relay coordination studies verified the proper coordination between primary and backup protective devices through suitable relay settings and Time Current Characteristic (TCC) analysis, ensuring selective fault isolation and reliable protection of the electrical system. Overall, the study demonstrated that the electrical network operates safely, reliably and efficiently under normal and fault operating conditions.

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