Design of Radial Distribution System to Study Load-Flow and Short Circuit Analysis Using ETAP Software

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Abstract: This work's analysis provides information on fault analysis and load flow studies, which help to understand how radial distribution networks operate both in normal and emergency circumstances. The research explores optimization methods, describing capacitor placement, transformer size, and feeder reconfiguration in order to lower losses and increase system efficacy. Moreover, the work looks at reliability-focused maintenance techniques, stressing the need of predictive maintenance and condition monitoring in raising the dependability of radial distribution networks. Modern electrical power networks depend heavily on their radial distribution system, which effectively and dependable distributes electricity to customers. Many radial distribution system-related topics are covered in detail on this website, including analytical methods, optimization processes, and dependability enhancement strategies. Power flow, voltage control, and losses in radial networks are investigated in this paper under a range of operational situations. The last and crucial stage of a power system, the electrical distribution system makes sure that customers have a steady supply of electricity. Regrettably, because it is often neglected and exposed to environmental risks, our distribution network has a number of problems. Our distribution feeder is rigorously analyzed for load flow and short-circuits in order to overcome these challenges and find and fix problems. The main topics of this study are the load flow and short-circuit analysis of a radial distribution feeder, which is mostly constructed with (ETAP). The final and crucial part of a power system, the electrical distribution system ensures that consumers receive an uninterrupted and steady supply of electricity. Our distribution feeder undergoes a rigorous and cautious process to address these issues front on because of the uncontrollable nature and susceptibility of our network to environmental hazards. This paper delves deeply into the issues of short-circuiting and load flow in radial distribution feeders. Both symmetrical and asymmetrical faults are thoroughly investigated by mathematical computations and ETAP simulations; the results of the software simulations are contrasted with those of the mathematical analysis. These discoveries will definitely influence the development and management of our system and point us in the direction of workable and practical solutions.

Keywords: Asymmetrical Faults, Load Flow, Power Distribution System, Short Circuit Analysis, Symmetrical Faults

1. Introduction
1.1. Background and Motivation

Several energy sources are used in the production and consumption of electricity, all of which add to the enormous amounts of power required to meet the needs of modern society. The stability of the economy is seriously threatened by the fine balance between cheap electricity and growing prices of technological equipment. Because of the focus on offering high-quality, reasonably priced services, utilities have purposefully reduced system costs, operating and maintenance costs, and real estate values. As it guarantees that power is available and reasonably priced for consumers, this quest of cost efficiency is essential in reducing economic downturns [1].

Radial distribution systems in electrical power distribution refer to shared infrastructure that provides power from a single source to several end consumers or loads. The system has a radial design with linked feeders extending out to service certain regions or user groups. A "radial" setup is one in which closed loops are not created and the central source flows only one direction to the consumers. An awareness and optimization of such distribution networks is necessary to provide a dependable and efficient power supply to meet the different demands of communities and enterprises [2].

There are several parts of electricity power, and each one makes a big contribution to our energy consumption. Significant issues endangering the stability of the economy have surfaced in the last few decades, such the growing cost of technology and the availability of power. The issue touches both homes and businesses. This issue needs a whole approach to be resolved. One key element is the requirement to provide first-rate service at affordable costs. Advancement of economic development and stability is impossible without striking this dangerous balance [3].
Specializing on offering services at reasonable costs could be advantageous in a number of ways [4]. Less maintenance and operating costs first and foremost ensure efficient use of resources, allowing for investments in important areas like infrastructure and innovation. Furthermore, more affordable housing is made possible by reduced real estate costs, which raises general affordability [5]. On its path from power plants where it is produced to users, electricity is unavoidably lost, mostly as transmission and distribution losses. Among them, distribution losses account for about 70% of the total system loss. The entire system is greatly impacted by these losses, which also substantially compromise the energy distribution [6]. Considering their huge scope, effectively lowering these losses will take a lot of effort.

One problem is the magnitude of these losses and their consequences. High distribution losses cause internal system inefficiencies that waste necessary energy resources [7]. Additionally jeopardizing the long-term economic sustainability of the entire energy supply chain are these losses. Both customers and electricity producers bear a financial cost from these inefficiencies, which raises prices and reduces overall effectiveness.

The distribution with regard to distributors changes with time. A relationship exists between distributors and specific load kinds. Thus, different sites in the electrical system can be investigated for voltage, current, active and reactive power, and power coefficients [8]. Encouraging sensible energy use and increasing knowledge of the need of energy efficiency can significantly reduce distribution losses [9]. Stressing the importance of energy conservation at every scale, from single residences to industrial complexes, can help to halt these losses and create space for a more effective and sustainable energy distribution system [10, 11]. Thus, it is critical to realize the seriousness of this problem and implement comprehensive measures to substantially lower these losses and give everyone access to a future of more reasonably priced and environmentally friendly energy. Fixing this issue will need the application of creative solutions and deft interventions. Modern technological investments, such as smart grids and upgraded metering systems, could enhance energy distribution monitoring and management, leading to more efficient operations and reduced losses [12]. Reducing losses caused by outdated or malfunctioning equipment can be accomplished with routine maintenance and infrastructural improvements.

The mouse flow has to be computed to assess the static performance of power systems during development, design, and operation [13]. Flow surveys can be performed with computer programs made especially for simulation. Software known as ETAP (Electric Transient Analyzer Program) was created to mimic an electrical network.

It provides totally integrated software solutions for optimum and other problems in electrical engineering [14]. From small power systems to large ones, any business can tailor its modular functionality to suit their requirements. We are able to design underground channel systems (UGS), three-dimensional cable systems, and one-line diagrams (OLDs). ETAP is employed for analysis. Any bus in the system has an approach for load flow studies. Determining the system’s sensitivity to changes in power demand, conductor length, and the distribution transformers’ combined capacity is the aim [17, 18]. They are used to make sure that the transmission and distribution system for moving power from the generator to consumers is dependable, stable, and cost-effective. A load flow study’s primary goal is to determine if all of the buses' voltages fall within the prescribed ranges and whether the reactive power transfer is fair in order to guarantee that customers receive services of a high enough caliber [19]. For the design, development, and administration of power systems, calculations of load flows are required to evaluate their static performance. To accomplish load flow studies, software tools designed specifically for simulation activities might be employed. The last phase of distribution is the distribution system, during which the buyer’s supply is controlled by an electrical network. With distribution feeders, the load is not always linked [20]. Distribution feeders link many sorts of loads. Therefore, all can be investigated by load flow analysis. The amount and location of the load are also necessary for the design of distribution feeders. Newton-Rapson and Goss-Siddle investigated the use of load flow technology, creating the optimal method model, and modeling the approaches used in load flow solutions [21]. The beginning situation must serve as the foundation for a better simulation. The model must be predicated on current data in order to correctly portray the current scenario. The anticipated outcome may be seen when ETAP is employed for analysis. Any bus in the system has an adjustment point for the weak regions across the overall design. This type of system employs separate feeders that are exposed to radiation from a single power plant and only distribute to distributors at one end. The radial topology demonstrates that the system is devoid of rings and that each bus only has one branch leading to the source [22]. Despite being the most straight forward and affordable arrangement, it is not a secure network configuration. This method is frequently used in areas that are heavily inhabited. With this power distribution mechanism, the energy is moved from the main bus to the other buses, where it is divided once more. The radial topology illustrates both the absence of rings in the system and the fact that each bus has a single branch that goes to the source [23].
1.3. Contribution

For electricity, concessionaires may provide power to customers, but a number of requirements must be met to solve difficulties with size, economy, and the environment. The initial stage, known as production, involves the creation of energy at massive power plants that are isolated from all loads. The second stage is the transmission process, which is completed with the assistance of several devices including transformers, overhead transmission lines, and subterranean cables. Moving the generated electricity to the system’s last step of distribution involves an expensive component called transmission [24].

The power network and the final user are connected by the electrical distribution system, is the most important component of the power system. Unavoidable losses occur along the route that electrical power travels from where it is produced in power plants to where it is consumed, most notably in the form of transmission and distribution losses. One of these, distribution losses, accounts for a large portion nearly 70% of the whole system loss [25]. These losses are a significant problem for the distribution of energy and have a significant impact on the entire system. Given their huge scope, it is imperative to put a lot of effort into successfully lowering these losses. For the goal of modeling an electrical network, a software program known as ETAP (Electric Transient Program for Analysis) was created. For electrical engineering, it provides fully integrated software solutions for arc, short circuit, load flow, transient stability, coordination relay, optimal power flow, and other applications. Businesses using power systems, small and large, can alter their modular functionality to suit their requirements. GIS schedules, three-dimensional grid systems (GCS), current high-time coordination and optional graphs, one-line diagrams (OLDs), subterranean channel systems (UGS), and three-dimensional cable systems may all be created using ETAP [26].

2. Materials and Methods

The Electric Transient and Analysis Program (ETAP) is a complete and specialist software tool for the design, analysis, and simulation of electrical power networks. It is widely used by engineers and scientists employed in the industrial sectors as well as in the fields of electrical engineering, power generation, transmission and distribution. ETAP provides a large number of features and capabilities for the efficient and dependable operation of power systems [8]. Radial distribution systems are networks of electrical power distribution that distribute electricity to several end users or loads from a single source, such as a substation. With each branch serving a specific area or clientele, the electricity in this system travels through a network of linked feeders and branches out in a radial manner [3]. "Radial" configurations are those in which consumers receive electricity just from a central source in one direction, without forming a full loop.

2.1. System’ Mathematical Description

With ETAP, users may build detailed and accurate models of electrical power systems. Generators, transformers, circuit breakers, relays, motors, and loads are just a few of the system components that users can represent in the software.

2.2. Load Flow Analysis

The steady-state operating conditions of the power system are helped to be determined by the load flow analysis that ETAP does. Calculated are voltages, currents, fluxes of active and reactive power, and system losses.

2.3. Short Circuit Analysis

The program makes short circuit situations in the power system able to be analyzed. The amount of fault currents and the efficiency of the protective mechanisms depend on this research.

2.4. Protective Devices Coordination

Relays, circuit breakers and fuses are among the protective devices that ETAP helps to coordinate. Working in the right sequence, the protective devices are ensured by good coordination, which also helps to detect problems and reduce downtime.

2.5. Integration and Reporting

ETAP allows the integration of many modules and provides comprehensive reports together with graphical representations of the results of the analysis. This helps engineers decide how to build and run the power system.

3. Mathematical Formulation

3.1. Line to Line Fault

When two wires come into touch, line-to-line faults, sometimes referred to as asymmetrical faults, result. A line-to-line fault is an electrical problem that occurs when two wires in a multiphase electrical system come into direct contact with one another or L-L fault occurs [24].

A phase-to-phase fault is another name for this kind of failure. By avoiding the load impedance, this type of failure results in a short circuit between the damaged phases [14]. Conductor corrosion, insulation failures, and other electrical system problems can all lead to phase-to-phase disturbances.

\[
\bar{I}_0 = \frac{1}{3} (\bar{I}_R + \bar{I}_Y + \bar{I}_B) = \frac{1}{3} \bar{I}_R \tag{1}
\]

\[
\bar{I}_1 = \frac{1}{3} (\bar{I}_R + a\bar{I}_Y + a^2\bar{I}_B) = \frac{1}{3} \bar{I}_R \tag{2}
\]

\[
\bar{I}_2 = \frac{1}{3} (\bar{I}_R + a^2\bar{I}_Y + a\bar{I}_B) = \frac{1}{3} \bar{I}_R \tag{3}
\]

\[
\bar{I}_3 = \frac{1}{3} (\bar{I}_R + a\bar{I}_Y + a^2\bar{I}_B) = \frac{1}{3} \bar{I}_R \tag{4}
\]

\[
\bar{V}_R = 0 \text{ and } \bar{I}_0 = \bar{I}_1 = \bar{I}_2 \tag{5}
\]
The conductor experiences an (LG) fault when it comes into contact with either the neutral conductor or ground. Eighty percent of the time, line-to-ground issues will arise. When one of the conductors in a multi-phase electrical system makes direct contact with the ground or a grounded item, it causes an electrical defect known as a phase-to-ground fault, sometimes referred to as an L-G fault. One of the phase conductors is short-circuited to the ground in such a problem. The majority of problems in power systems are phase-to-ground faults.

\[
\begin{align*}
\overline{I}_0 &= \frac{1}{3}(\overline{I}_R + \overline{I}_Y + \overline{I}_B) = \frac{1}{3}\overline{I}_R \\
\overline{I}_1 &= \frac{1}{3}(\overline{I}_R + a\overline{I}_Y + a^2\overline{I}_B) = \frac{1}{3}\overline{I}_R \\
\overline{I}_2 &= \frac{1}{3}(\overline{I}_R + a^2\overline{I}_Y + a\overline{I}_B) = \frac{1}{3}\overline{I}_R \\
\overline{I}_0 &= \overline{I}_1 = \overline{I}_2 = \frac{1}{3}\overline{I}_R \\
\overline{E}_R &= \overline{I}_1 Z_1 + \overline{I}_2 Z_2 + \overline{I}_0 Z_0 + \overline{V}_R \\
\text{As } \overline{V}_R &= 0 \text{ and } \overline{I}_0 = \overline{I}_1 = \overline{I}_2 \\
\overline{E}_R &= \overline{I}_0(\overline{Z}_1 + \overline{Z}_2 + \overline{Z}_0) \\
\overline{I}_0 &= \frac{\overline{E}_R}{\overline{Z}_1 + \overline{Z}_2 + \overline{Z}_0} \\
\overline{I}_R &= 3\overline{I}_0 = \frac{3\overline{E}_R}{\overline{Z}_1 + \overline{Z}_2 + \overline{Z}_0} \\
\overline{I}_Y &= 0 \text{ And } \overline{I}_B = 0
\end{align*}
\]

### 3.2. Line to Ground Faults

The conductors balance or fail to balance, depending on the area's energy demands, spanning a vast area of 22.465 kilometers. Throughout the procedure, we painstakingly examined the needs and made room for a sizable infrastructure that included 100 distribution transformers that were carefully placed along the feeder. Every transformer was positioned with great attention to optimize voltage distribution and management. It takes these transformers to reduce the main 11 kV power supply to levels suitable for local use. The estimated 6,915 kVA total connected load of the feeder also reflects the varied demographic of energy users in the area. Through suitable simulation of this load with the ETAP tool, we made sure that the system was built to effectively manage the current needs while allowing for possible future growth. We improved the single-line diagram and ensured the stability and dependability of the system under a range of operating situations by using the sophisticated capabilities of ETAP, like load flow analysis, short circuit analysis, and protective device coordination (Fig. 2 (a,b)). A thorough harmonic analysis made possible by the program also ensured that any harmonic problems—which are frequently brought on by non-linear loads—were found and successfully fixed.

### 5. Results and Discussion

Using the software ETAP, we laboriously produced the single-line schematic for the current 11 kV CANTT 2 feeder, which we obtained from the Subdivision Office Bannu 1. Analysing important features throughout the design phase was essential to building a reliable and efficient electrical distribution system. One 1500 MVA (Megavolt-Ampere) power grid served as the integration point for the whole electrical system. A unit of measurement called MVA is used to indicate apparent power, which is the sum of real power (measured in watts) and reactive power (measured in VARs) in an AC circuit. The distribution lines were carefully built to meet the area's energy demands, spanning a vast area of 22,465 kilometers. A feeder simulation is a procedure used in electrical systems by engineers and researchers to simulate and examine the movement of energy across a network. The goal of this particular simulation was to ascertain the losses that occurred during the transfer of electricity. The results showed an over-feeder loss of 2.84,606, which pointed to the system's inefficiencies. 6915 kVA (Kilovolt-Ampere) was the measured total connected load, or the total power consumption of all the equipment and devices connected to the system. Rabbit conductors were utilized in order to transmit this power. These conductors balance strength and conductivity with their composition of one steel strand and six aluminum strands. These conductors had a diameter of 3.3528 mm.

\[
\begin{align*}
\overline{E}_R &= \overline{I}_0(\overline{Z}_1 + \overline{Z}_2 + \overline{Z}_0) \\
\overline{I}_0 &= \frac{\overline{E}_R}{\overline{Z}_1 + \overline{Z}_2 + \overline{Z}_0} \\
\overline{I}_R &= 3\overline{I}_0 = \frac{3\overline{E}_R}{\overline{Z}_1 + \overline{Z}_2 + \overline{Z}_0} \\
\overline{I}_Y &= 0 \text{ And } \overline{I}_B = 0
\end{align*}
\]
Figure 1.a. Feeder design in ETAP.

Figure 1.b. Feeder design in ETAP.
Figure 1c. Feeder design in ETAP.

Figure 2a. Load flow analysis of existing feeder.
They are part of the ACSR (Aluminum Conductor Steel Reinforced) family of electrical cables, which are renowned for their strength and endurance. These conductors have an estimated resistance of 0.659 ohms per kilometer, which indicates resistance to the flow of electrical current. The branch connections were sequentially examined by the engineers or researchers in order to further assess the system. This means that they looked at each electrical connection individually to identify the loads connected to each bus. In this context, a "bus" is a shared electrical connection point that is shared by several lines or devices. Knowing the loads at every bus helps engineers to assure efficient power distribution, reduce losses, and optimize the system. Deep insights about the network's behavior are given by these findings. According to the study, the imbalanced feeder showed variations in load distribution among its parts. Further raising questions about the system's dependability and effectiveness was the finding that certain buses were overloaded. The system has to be optimized, hence these issues have to be found. Transformers and other equipment life and effectiveness may be shortened by uneven feeding and inequal stress. By means of the detection of these issues with ETAP simulations, engineers can plan remedial actions.

Uneven feeder distribution and overloaded buses are issues that require a novel approach combining many tactics. One important first step is to look into load distribution changes, which could entail spreading electrical loads among different grid nodes to produce a more balanced system. Transformers can also have their energy distribution improved and the effect of uneven loads reduced using innovative technology updates. Another solution that allows dynamic changes to maintain appropriate voltage levels while preventing overload is voltage control approaches. These complex adjustments help to increase the general reliability, stability, and efficiency of the electrical distribution system.

The suggested improvements, as a strategic road map, provide targeted answers to the problems caused by unequal feeder distribution and packed buses. These findings ultimately offer the way forward for a developing electrical system that satisfies community requirements and supports a safer and more efficient energy distribution network.

6. Conclusion

In this research, we thoroughly examined the existing 11kV CANTT 2 feeder using the powerful ETAP tool; we discovered significant distribution system problems. Uneven feeder load distribution and overcrowding of some buses severely impair the system's dependability and efficacy. We were able to understand a lot about the behavior of the system via long simulations and meticulous statistical and graphic examination of the provided data. If one wishes to establish a reliable and strong power distribution network, these issues must be resolved. Critical equipment components might have their life and efficiency shortened by uneven stress from imbalanced feeds. Buses packed too full put the safety of the equipment and the clients' power supply at risk. Starting with the recognized problems is essential for implementing corrective action. Through careful load changes, transformer modernization, and the installation of efficient voltage-regulating equipment, the system may be improved to increase dependability, stability, and overall efficiency. These preventive measures are needed to provide a steady and long-lasting supply of electricity while effectively meeting the energy needs of the community.
References


