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Development and Analysis of Load Flow for a Distribution Feeder Using ETAP-A Case Study Investigation

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Abstract

This Paper uses the ETAP to study load flow analysis on an 11 kV distribution feeder, Data on load including KVA, KVAR, and KW, is gathered from a power distribution firm. Modeling the load flow diagram both before and after the high tension (HT) line is the main goal. In load flow analysis, the Newton-Raphson method—which is renowned for its precise and robust convergence properties—is used to identify transformer overloads, pinpoint specific areas with under voltage and overvoltage conditions at different bus points, calculate real and reactive power losses throughout the network, and evaluate the overall power factor. For better understanding and interpretation, the results were graphically shown such has power factor versus load, KVAR flow versus bus IDs, and kW losses versus loading conditions. The distribution network's performance was clearly shown by these visualizations, which also highlighted important areas that needed attention in order to increase dependability and efficiency. Finally, the project was successfully simulated and analyzed in the ETAP software, and the load flow analysis on an 11kV distribution feeder was done using the Newton-Raphson method. This method provided insightful information about power losses, transformer overloads, and voltage irregularities, and it greatly improved the electrical distribution networks, optimization and reliability.

Keywords: *Voltage regulation, 11KV feeder, ETAP, ACSR conductor, NR Method*

1. Introduction

The increasing integration of renewable energy sources and advanced power flow analysis techniques in modern distribution networks has led to extensive research in stochastic modeling, load flow analysis, fault detection, and AI-based optimization. Goudappanavar and Jangamshetti (2020) proposed a stochastic power flow analysis for unbalanced distribution networks incorporating Small Wind Turbine Generators (SWTG) and Solar Photovoltaic (SPV) clusters, providing insights into system uncertainty management. However, real-time validation on actual distribution networks remains unexplored. Garces (2016) introduced a linearized three-phase load flow approach to simplify computational efforts in power distribution systems, yet its adaptability under high DER penetration remains untested. Kole and Chakrasali (2018) examined voltage regulation in an 11kV distribution feeder through a practical case study, but it lacks consideration of renewable energy integration and storage impact. In the domain of fault detection, Goudappanavar et al. (2021) proposed a method based on the rotor angle behaviour of diesel generators to identify fault-prone areas in distribution networks, though its applicability to microgrids with high renewable energy penetration remains a gap. Farooq et al. (2017) analyzed load flow characteristics of an 11kV feeder with and without distributed generation (DG), highlighting its impact on voltage stability, but without sensitivity analysis for varying DG penetration levels. Goudappanavar and Jangamshetti (2025) explored AI-based phase

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identification techniques to facilitate DER integration, offering a novel solution yet lacking comparative studies against traditional phase identification methodologies. Soni et al. (2015) utilized ETAP for designing an 11kV distribution system, demonstrating its practicality in real-world scenarios but omitting reliability assessment and fault tolerance analysis. Similarly, Natkar and Kumar (2015) presented a 220/132 kV substation design using ETAP, yet without an evaluation of how renewable energy sources impact stability and performance. Vijayvargiya et al. (2016) conducted a comparative study of various load flow methodologies across different bus systems, but did not consider probabilistic load flow approaches under DER uncertainties. In the field of energy storage control, Atur et al. (2017) proposed a novel control algorithm for small wind turbine generator storage systems, though further research is needed to explore hybrid energy storage integration. Lastly, Goudappanavar and Jangamshetti (2020) analyzed high-tension voltage regulation in radial distribution networks, but the study lacks dynamic simulations under fluctuating load conditions. These studies collectively contribute to advancements in distribution network optimization, renewable energy integration, and AI-driven energy management. However, there remain significant research gaps in real-time validation, probabilistic modeling, hybrid energy storage strategies, and AI-based power flow solutions, highlighting the need for further investigations in smart grid technologies. (Figure 1)

2. Methodology

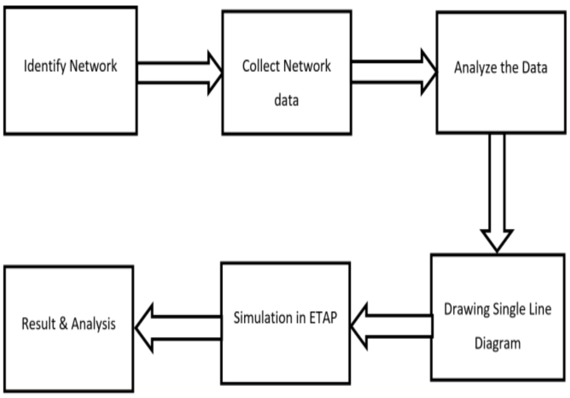

Figure 1 Block Diagram

The block diagram of the proposed work is shown in Fig. (2.1). The methodology followed in this study consists of the following key steps.

2.1. Data Collection

Gather real-time data from the power distribution firm, including:

- Load parameters (Voltage, KVA, KVAR, KW)
- Feeder configurations and specifications
- Transformer ratings and locations
- Bus ID mappings and network topology

2.2. System Modeling in ETAP

- Develop a single-line diagram of the 11kV distribution feeder in ETAP.
- Input collected data into the ETAP model, including load values and transformer parameters.
- Define the network components (buses, transformers, feeders, and loads).

2.3. Load Flow Analysis Using Newton-Raphson Method

Implement the Newton-Raphson method for load flow calculations due to its accuracy and convergence efficiency.

Compute the following key electrical parameters:

- Voltage levels at each bus
- Real and reactive power flow (KW & KVAR)
- Transformer loading conditions
- Total real and reactive power losses

Identify critical points such as overvoltage, under voltage, and transformer overloads

2.4. Graphical Representation and Result Analysis

Generate graphical outputs for better interpretation, such as:

- Power factor versus load
- KVAR flow versus bus IDs
- KW losses versus loading conditions

Analyze the performance of the distribution network based on the obtained results.

Highlight weak points in the network that require optimization

3. Methods Adopted for Load Flow Analysis

In a load flow study, the power flow of an

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interconnected power system is numerically evaluated. Three approaches are being used for load flow analysis: the Newton-Raphson method, the Gauss-Siedel method, and the Fast-Decoupled method. The number of acquired iterations has been utilised to compare the three load flow techniques. Of the three methods, the Newton-Raphson method is more precise and provides better results with fewer repetitions than the other two.The Fast Decoupled technique is the fastest of all the approaches, but because it relies on assumptions for speedy calculation, it is less accurate than the Gauss-Siedel method, which is straightforward and easy to use but requires more time (more iterations) as the number of buses increases.

Table 1 **Rating of Test Feeder**

Component	Type	Rating (KVA)	Primary voltage (KV)	Secondary Voltage (KV)
Transformer	Transformer 1	50	11	0.4
	Transformer 2	25	11	0.4
	Transformer 3	25	11	0.4
Bus	**Type**	**Load (HP)**	**Type of Load**	
	Bus3	60	IP Sets	
	Bus5	30	IP Sets	
	Bus7	30	IP Sets	
TX line length	**Type**		**Length in km**	
	Line1		15km	
	Line2		0.1km	
	Line3		0.1km	
Cable	**Type**		**Length in m**	
	Cable 1		10	
	Cable 2		5	
	Cable 3		5	

The Gauss-Seidel approach is inferior to the Newton-Raphson method theoretically. It is discovered to be a more effective approach for high power systems. This strategy is thought to be among the most frequently used techniques for determining the system's roots. Additionally, it demonstrates that the procedure is quadratically convergent as we get closer to the root. The linearized link between tiny changes in active and reactive power (ΔP and ΔQ) and voltage angle ($\Delta\delta$) and voltage magnitude (ΔV) is provided by the Jacobian matrix. (Figure 2)

$$P_p = \sum_{q=1} n V_p |V_q| |V_{pq}| \cos(\theta pq + \delta q - \delta p)$$

$$Q_p = \sum_{q=1} n \ |V_p| |V_q| |V_{pq}| \sin(\theta pq + \delta q - \delta p)$$

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} J \end{pmatrix} \begin{pmatrix} \Delta \partial \\ \Delta |V| \end{pmatrix}$$

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} \partial P/\partial \delta & \partial P/\partial |V| \\ \partial Q/\partial \delta & \partial Q/\partial |V| \end{pmatrix} \begin{pmatrix} \Delta \partial \\ \Delta |V| \end{pmatrix}$$

4. Simulation of 11 Kv Distribution Feeder in ETAP

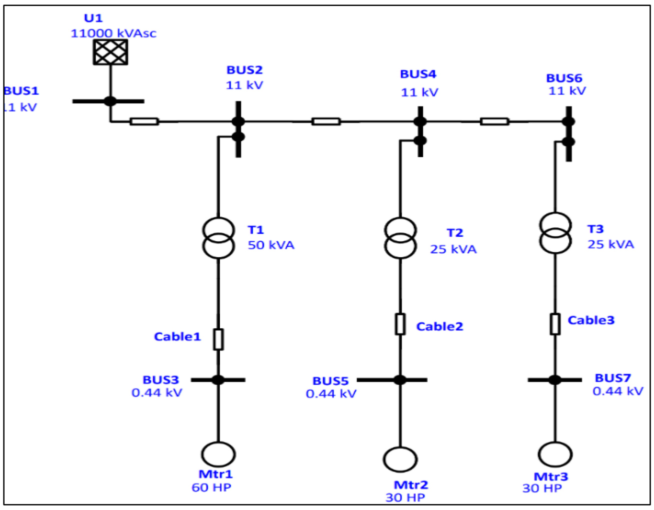

Figure 2 **One-Line Diagram of 11 KV Feeder Using ETAP Before High Tension**

The power system that supplies electricity to 11 KV Buses 1 and 2 is shown in Figure 2 Transformer 1 is connected to Bus 2. Bus3's electricity will be utilised by the load since it is linked to it. The hyperlink between Bus 1 and Bus 2 is a transmission cable. A transformer, on the other hand, has access to a cable. (Figure 3)

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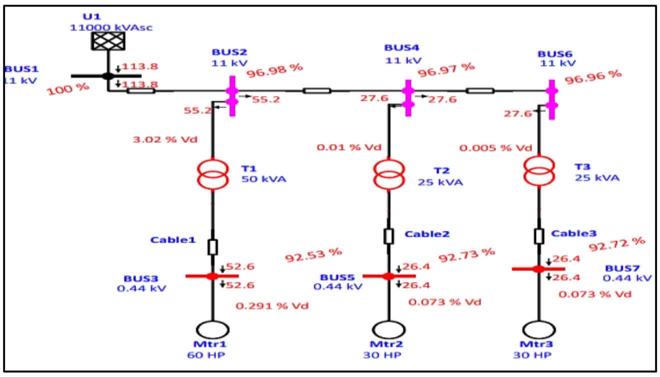

Figure 3 **Load Flow Analysis of 11 KV Feeder using ETAP Before High Tension**

Fig 3 Represents simulation of 11 KV distribution feeder which indicates buses (2, 4, 6) that are marginally stable, buses (3, 5, 7) that are in critical condition, and transformers (1,2 3) are overloaded.

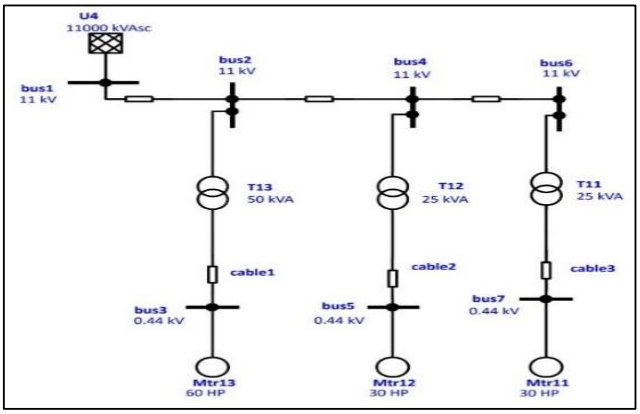

Figure 4 **One-Line Diagram of 11KV Feeder Using ETAP After HT**

Table 2 **Voltage Profile**

BUS ID	Before HT voltage	After HT voltage
BUS 1	100	100
BUS 2	96.98	96.34
BUS 3	92.53	91.86
BUS 4	96.97	96.33
BUS 5	92.73	92.05
BUS 6	96.96	92.79
BUS 7	96.32	92.72

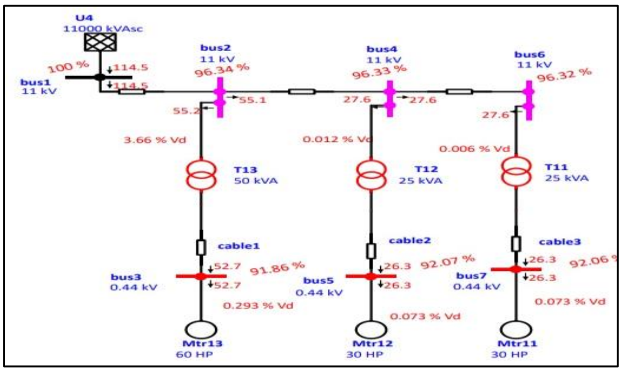

Figure 5 **Load Flow Analysis of 11 KV Feeder Using ETAP After HT**

5. Result and Analysis of Load Flow

A voltage profile is a graphical illustration of the voltage intensity along a transmission or distribution network that shows the variations in voltage levels at different points from the power source to the load. Voltage typically decreases with increasing distance from the electrical source due to factors such as inductance, line resistance, and varying load demands (Figure 6)

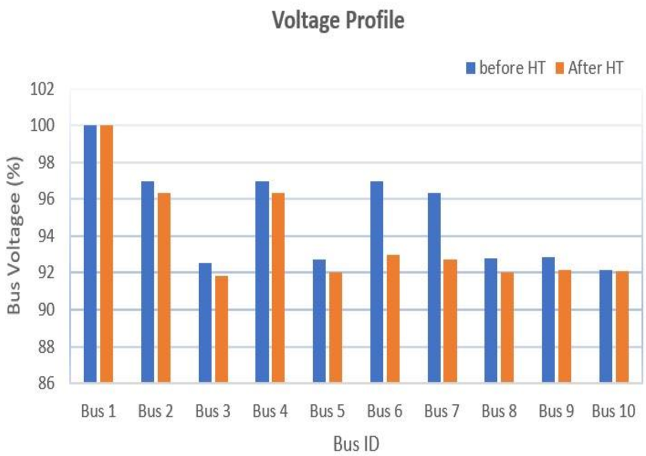

Figure 6 **Voltage Profile for Before and After HT Line**

How the system's power factor changes with varying loads is displayed in a above graph. A measurement of electrical power production called the power factor is the ratio of real power (KW) to perceived power (KVA). 100%, or a power factor of 1, denotes perfect efficiency. Actually, when the system load increases, the power factor tends to improve up to a certain point

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as given in Fig.5. Because reactive power—either inductive or capacitive—dominates at light loads, the power factor is typically smaller. As the load grows, so does the percentage of real power, improving the power factor. But once the system reaches its peak, more loading may cause the power factor to drop if the system is overworked or if inductive loads—like motors—dominate without sufficient compensation as in table.3.

Table 3 Branch Result

Bus Id	Kvar Flow	ID No	KW Losses	Loading
Bus 2	27.72	C1	0.182	89.1
Bus 3	27.72	c1	0.184	89.7
bus 3	14.01	C2	0.0227	44.6
Bus 5	14.01	c2	0.0231	44.9
bus 5	14	C3	0.0228	44.6
Bus 7	14.01	c3	0.00231	44.9
bus 7	30.17	L1	0.0042	0
Bus 2	15.08	L2	0.001	0
Bus 4	62.49	L4	2.5	0
Bus 1	15.1	L11	0.0017	0
bus 4	30.19	L12	0.0066	0
bus 2	61.69	L13	3.96	0
Bus 1	29.87	T1	1.44	110.3
Bus 8	15.08	T2	0.719	110.4

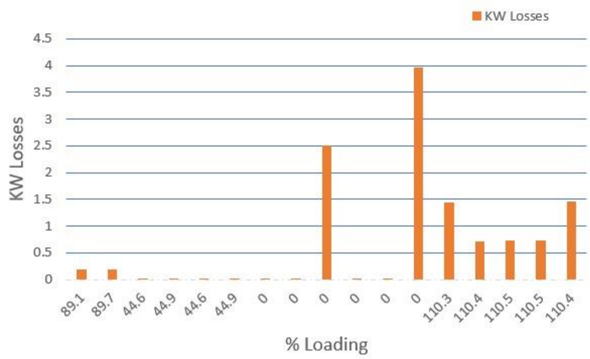

Figure 7 KW Losses V/S %Loading

The network's efficiency and performance are inextricably tied to the relationship between KW losses and system loading as in Fig.5.3. The current flowing through the gearbox and distribution lines increases in tandem with the system's increased loading. Because power losses in the lines are proportionate to the square of the current (I^2R losses), these losses are dissipated as heat, which can cause components to overheat in addition to lowering the system's overall efficiency. The KVAR versus bus number graph as in Fig.6 provides insight into the distribution of reactive power across various buses in a power system. Reactive power is essential for maintaining voltage levels within the network and ensuring the efficient operation of inductive loads, like motors and transformers. The fig.8 shows how much reactive power (in KVAR) is associated with each bus, indicating whether a bus is a source or a sink of reactive power.

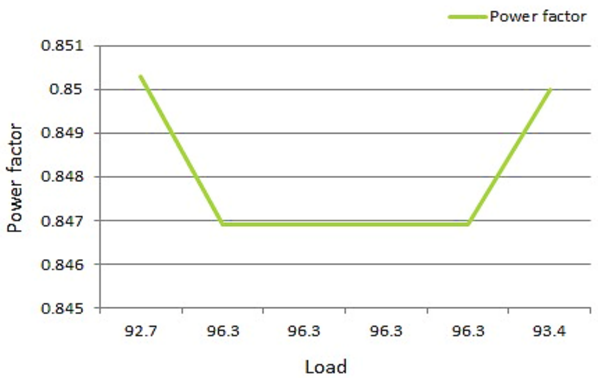

Figure 6 Power Factor V/S Load

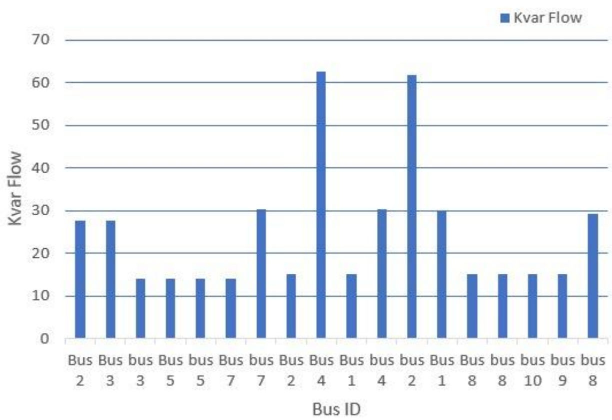

Figure 8 Kvar Losses V/S Bus Id

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Conclusion

In this study, the 11KV Distribution feeder is effectively used to apply the Newton-Raphson method, and ETAP software is used to analyse the data (KW, KVAR, and KVA). To conduct a comprehensive load flow analysis on 11kV distribution feeder, utilizing meticulously gathered data from a government-oriented power company to ensure accuracy. By modeling load flow both after and before high tension (HT) points, A knowledge is gained thorough understanding the system's behavior under various loading conditions. Analysis of data are identified through critical issues such as under-voltage and overvoltage conditions at specific bus points. The graphical representation of key findings, including kW losses versus loading conditions, KVAR flow versus bus IDs, and power factor versus load, provided clear insights into the network's performance and highlighted areas requiring attention for efficiency improvements. The investigation merely detected the power losses and critical voltage abnormalities, but it also provided insightful advice for optimising the system of distribution to greatly increase its efficiency and dependability.

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