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Distribution System Survey and Analysis: A Case Study of Kathmandu University

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Abstract

Load flow analysis helps to understand a power system's voltage profile and power flow distribution, enabling the identification of potential issues such as overloading and under-voltage conditions. Fault analysis ensures reliability and safety by understanding and mitigating abnormal conditions in electrical distribution systems. Together, they contribute to efficient operation, equipment protection, and overall system reliability. This paper presents a load flow and fault analysis of the Kathmandu University distribution system. Starting from the careful study of the power usage of the Kathmandu University distribution system then followed by the load flow analysis employed in the Dig Silent Power factory software, critical insights into the system's performance were unveiled. Additionally, fault analysis within the simulated distribution system provides valuable data to enhance the understanding of the different patterns of currents for the various types of faults that occur at different locations of the Kathmandu University distribution system. This study provides a comprehensive understanding of the Kathmandu University distribution system. It identifies potential issues that can help to make the Kathmandu University power system more reliable and efficient in the future.

Keywords: Load Flow, Fault, Bus, Distribution system, Newton-Raphson, Dig silent power factory

1. Introduction

Power flows from a generating station to the load in a power system through various network branches. Electrical power systems often encounter load-related issues that can severely impact the system's reliability and disrupt customer access to electricity. The flow of active and reactive power is known as load flow or power flow. Load flow analysis is a crucial tool for understanding how electricity moves and ensures a balanced distribution in a power system. Load flow studies use mathematical methodology for calculating bus voltages, phase angles, and active and reactive power flows across various system branches. Load flow analysis is a crucial tool for understanding how electricity moves and ensures a balanced distribution in a power system. The great importance of load-flow analysis is in the planning of the future expansion of power systems as well as in determining the best operation of existing systems. Also, the system can be analyzed and simulation results can be studied before any new change in the existing system without affecting the original system.

Usually, a power system operates under balanced conditions with all equipment carrying normal load currents and also the bus voltages inside the prescribed limits. This condition can be disrupted because of faults within the system. short circuit fault current is many times larger than the normal current. A short circuit is simply a low-resistance connection between the two conductors supplying electrical power to any circuit. This results in an excessive amount of current flow in the power systems through the path of low resistance and may even cause the power source to be destroyed and cause more heat and fires. The fault analysis of a power system is needed to provide information for the choice of switchgear, size of conductors, setting of relays, finding the rating requirements of other power equipment, and confirming system stability.

The researcher of (O. A. Afolabi, n.d.) compares numerical methods and conducting simulations on IEEE 9-Bus, IEEE 30-Bus, and IEEE 57-Bus systems, the authors suggested that the most effective and reliable among the three load flow methods is the Newton-Raphson method because it converges fast and is more accurate. By discussing the application of Newton-Raphson's technique, the authors of (Braide, 2022) offer potential solutions to improve electricity supply to the Choba community, highlighting the technique's role in addressing voltage instability, power losses, and transformer overloading. The load flow analysis is done to evaluate the performance of the Auchi distribution network under maximum loading conditions and assess the impact of a capacitor bank on voltage levels, power losses, and network stability is described in (H. Amhenrior, 2023). load flow analysis of 30 30-bus HVAC system performed by the authors of (Gupta, 2022) using the Newton-Raphson Technique to analyze the power flow in the system with the HVDC link, which is transformed into equivalent active and reactive powers at the rectifier and inverter buses. The authors of (al., 2023) highlight the limitations of traditional techniques and validate the effectiveness of their methodology through virtual tests, demonstrating accurate fault detection and localization. Typically, load flow analysis involves considering constant active and reactive power. However, with modern loads being highly sensitive, their behavior depends upon both voltage and frequency (Mubeen, 2014) The potential of the method of phase coordinates as a flexible and powerful alternative to traditional transformation methods for analyzing unbalanced polyphase network problems is described in (Saleh, 1980).

In electrical power distribution systems, the nature of power flow varies based on the specific configuration and characteristics of the distribution network. Power flow within a distribution system is influenced by factors such as feeder configurations, transformer settings, load distribution, and the presence of distributed energy resources. Understanding the nuances of power flow in electrical distribution systems is essential for designing resilient and efficient networks that can adapt to evolving energy landscapes. Despite numerous researches carried out on load flow and fault analysis in different power systems, no study has yet been conducted on the Kathmandu University distribution system. Therefore, this paper presents a load flow analysis and a fault analysis of the Kathmandu University distribution system.

This paper is composed of four major parts. The preceding section focuses on the fundamental method of load flow analysis using Newton Raphson's method followed by section 3 which provides a detailed analysis of load flow and fault analysis results. The last section provides the conclusion of the paper.

2. Methodology

The foundation for solving performance equations in computer-aided electrical power system analysis, such as load flow analysis, is a numerical analysis that addresses algebraic simultaneous equations. To initiate load flow analysis, the initial step involves constructing the Y-bus admittance using input data related to transmission lines and transformers.

Newton-Raphson method is an iterative technique that transforms a set of non-linear simultaneous equations into a set of linear simultaneous equations by utilizing Taylor's series expansion, with the terms limited to the first approximation. Widely employed in load flow analysis, the Newton-Raphson method stands out for its robust convergence characteristics compared to alternative approaches. Additionally, its reliability is notable, as it can successfully address cases that may lead to divergence when employing other popular methods. The method's efficiency is contingent on the proximity of the assumed value to the solution; closer proximity results in quicker convergence, while greater distance may extend the convergence time. This iterative load flow method is extensively used for solving nonlinear equations. By using this method, the real and reactive power is given by (Saadat, 1999):

$$\left[\Delta P_2^{(k)} \ \vdots \ \frac{\Delta P_n^{(k)}}{\Delta Q_2^{(K)}} \ \vdots \ \Delta Q_n^{(k)}\right]$$
$$= \left[\frac{\partial P_2^{(k)}}{\partial \delta_2} \cdots \frac{\partial P_2^{(k)}}{\partial \delta_n} \frac{\partial P_2^{(k)}}{\partial |V_2|} \cdots \frac{\partial P_2^{(k)}}{\partial |V_n|} \ \vdots \ddots \vdots \vdots \ddots \right. \qquad \text{(Equation 1)}$$
$$\vdots \ \frac{\partial P_n^{(k)}}{\partial \delta_2} \cdots \frac{\partial P_n^{(k)}}{\partial \delta_n} \frac{\partial P_n^{(k)}}{\partial |V_2|} \cdots \frac{\partial P_n^{(k)}}{\partial |V_n|} \frac{\partial Q_2^{(K)}}{\partial \delta_2} \cdots \frac{\partial Q_2^{(K)}}{\partial \delta_n} \frac{\partial Q_2^{(K)}}{\partial |V_2|} \cdots \frac{\partial Q_2^{(K)}}{\partial |V_n|}$$
$$\left. \vdots \ddots \vdots \vdots \ddots \vdots \ \frac{\partial Q_n^{(K)}}{\partial \delta_2} \cdots \frac{\partial Q_n^{(K)}}{\partial \delta_n} \frac{\partial Q_n^{(K)}}{\partial |V_2|} \cdots \frac{\partial Q_n^{(K)}}{\partial |V_n|}\right] \left[\Delta \delta_2^{(k)}\right.$$
$$\left. \vdots \ \Delta \delta_n^{(k)} \ \Delta V_2^{(K)} \ \vdots \ \Delta V_n^{(k)} \right]$$

The distribution system of the KU was investigated as part of the distribution network survey, focusing on the distribution network from a distribution transformer located behind the Multipurpose Hall. Surveys were carried out on the loads of various buildings within KU. The radial system of the Kathmandu University distribution system was examined. The line is partitioned from the distribution box situated near KU TTC, and it is further subdivided into three sectors. One sector extends to the turbine testing lab, while another extends to Block 8 via the admin and library. Similarly, another line extends to another distribution box located near KUmess. From that distribution box, the line is further divided into two regions, with one extending to the KU Boys Hostel and the other to the staff quarter. The load has been done based on the initial load survey of the mentioned blocks as well as through observation of the energy bill of Kathmandu University. From the survey, the following information is gathered.

Table 1. Survey Results

Total Load	Total Line Length	Conductor Type	Ampacity
97.64KW	1.308KM	DOG	239A
		XLPE	211A

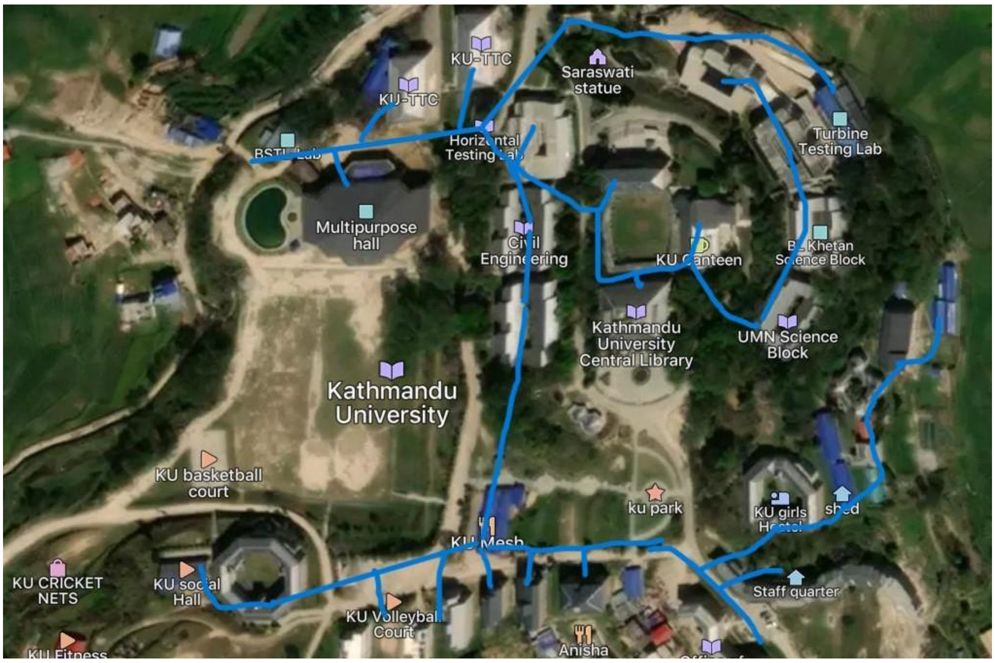

Figure 1. Layout of KU Distribution System

After obtaining all the necessary parameters Load Flow analysis and fault analysis is done in Digsilent Powerfactory software. Every block (which contains electrical load) of the Kathmandu University is defined as a bus in this study.

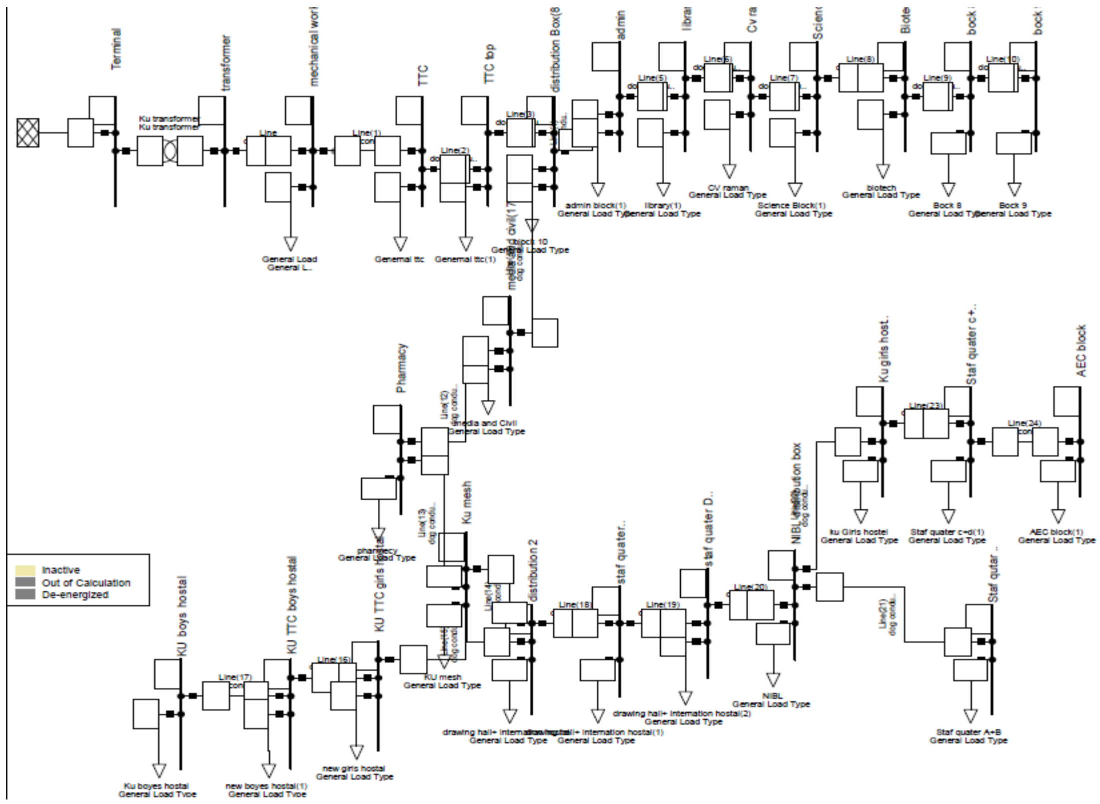

Figure 2. KU distribution System in Digsilent Powerfactory

3. Result and Analysis

3.1 load flow results

From the load flow of the Kathmandu University distribution system following voltages were found in the respective locations in the system.

Table 2. Voltage profile of KU Distribution System

Location	Voltage(pu)	Location	Voltage(pu)
Mechanical Workshop+ TTCB2	0.981575	KU Mess	0.95835
TTC	0.973275	KU TTC Girls Hostel	0.94425
TTC top	0.970125	KU TTC Boys Hostel	0.942725
Admin block	0.9659	KU Boys Hostel	0.941975
Library	0.96285	Staff quarter E	0.94085
CV Raman	0.961875	Staff quarter D7	0.9421
Science Block	0.9599	NIBL distribution box	0.93755
Biotech	0.9578	Staff quatre A	0.9365
Bock 8	0.956325	KU Girls Hostel	0.93415
Bock 9	0.955675	Staff quarter c+d	0.933675
Media and Civil	0.95545	AEC block	0.93365
Pharmacy	0.9611		

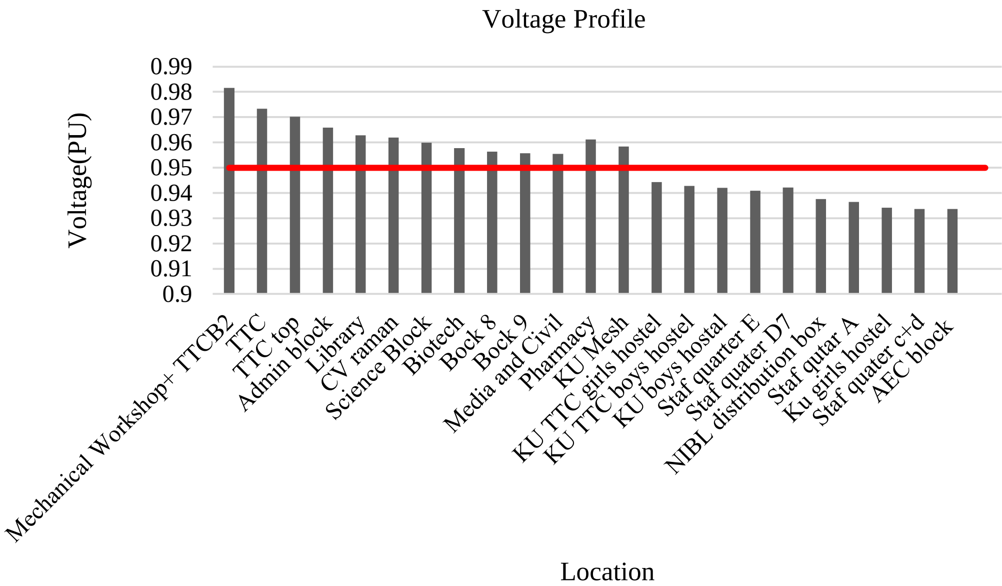

Figure 3. Bar Chart of Voltage Profile

The above voltage profile bar chart explains that the load nearest to the distribution transformer has a voltage nearest to the rated voltage while as the distance is being increased and more loads are being added to the radial system the voltage at the farthest location is low. Here the nearest location is Mechanical Workshop+TTCB2 and the farthest location is AEC Block. The Highest voltage available is at the Mechanical Workshop+TTCB2 which is 0.981575pu while the lowest voltage available is at the AEC Block which is 0.93365pu and the region from Ku mess to AEC block is operating at under voltage condition at the time of peak load.

From the load flow of the Kathmandu University distribution system following conductor currents were found in the respective locations in the system.

Table 3. Conductor Current

Location	Current(A)	Location	Current(A)
Transformer-Mechanical workshop	148.69	Distribution Box -Media and Civil	83.4
Mechanical workshop-TTC	143.79	Media and civil-Pharmacy	80.14
TTC-TTC Top	137.26	Pharmacy-KU mess	76.87
TTC Top-Distribution Box	130.73	KU mess- Distribution Box 2	75.56
Distribution Box -Admin	40.8	KU mess- KU TTC Girls Hostel	24.11
Admin- Library	34.27	KU TTC Girls Hostel- KU TTC Boys Hostel	21.67
Library-CV Raman	31	KU TTC Boys Hostel- KU Boys Hostel	16.33
CV Raman- Science Block	22.87	Distribution Box 2-Staff Quarter F	41.65
Science Block -Biotechnology	19.6	Staff Quarter F- Staff Quarter D7	38.39
Biotechnology-Block 8	16.33	Staff Quarter D7- NIBL Distribution Box	35.12
Block 8-Block 9	6.53	NIBL Distribution Box-KU Girls Hostel	21.23
Transformer-Mechanical workshop	148.69		
Staff Quarter C+D-AEC Block	1.63	KU Girls Hostel-Staff Quarter C+D	8.17

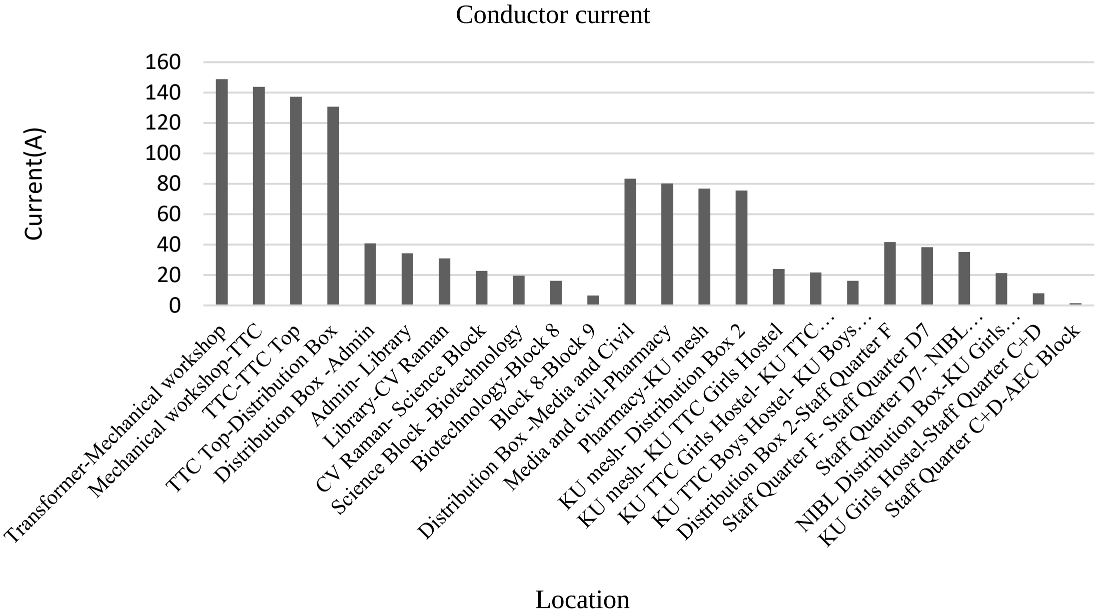

Figure 4. Bar chart of Conductor Current

From the conductor current bar chart, the conductors that are nearer to the distribution transformer have a higher value of current than the conductor at the farthest end. The highest value of load current is at the line Transformer-Mechanical Workshop which is 148.69A while the lowest value of load current is at line Staff Quarter C+D-AEC Block which is 1.63A. From the load flow of the Kathmandu University distribution system following line loadings were found in the respective locations in the system.

Table 4. Percentage of Loading of conductor

Location	%Loading	Location	%Loading
Transformer-Mechanical workshop	62.22	Distribution Box -Media and Civil	34.9
Mechanical workshop-TTC	60.16	Media and civil-Pharmacy	33.53
TTC-TTC Top	57.43	Pharmacy-KU mess	32.16
TTC Top-Distribution Box	54.7	KU mess- Distribution Box 2	31.62
Distribution Box -Admin	17.07	KU mess- KU TTC Girls Hostel	10.09
Admin- Library	14.34	KU TTC Girls Hostel- KU TTC Boys Hostel	9.06
Library-CV Raman	12.97	KU TTC Boys Hostel- KU Boys Hostel	6.83
CV Raman- Science Block	9.57	Distribution Box 2-Staff Quarter F	17.43
Science Block -Biotechnology	8.2	Staff Quarter F- Staff Quarter D7	16.06
Biotechnology-Block 8	6.83	Staff Quarter D7- NIBL Distribution Box	14.69
Block 8-Block 9	2.73	NIBL Distribution Box-KU Girls Hostel	8.88
Transformer-Mechanical workshop	62.22		
Staff Quarter C+D-AEC Block	0.68	KU Girls Hostel-Staff Quarter C+D	3.42

Conclusions can be drawn from the loading of the table and graph, such as determining the amount of current flowing through the conductor and assessing the conductor's ability to withstand further additions of current. According to barchart transformer- Mechanical workshop has the highest percentage of line loading which is 62.22% while Staff Quarter C+D -AEC Block has the lowest percentage of line loading which is 0.68%. The conductor connecting the transformer-mechanical workshop of Kathmandu University is overloaded and may require reconductoring in the future. Similarly, the underloaded conductors can be better utilized by connecting additional loads into them.

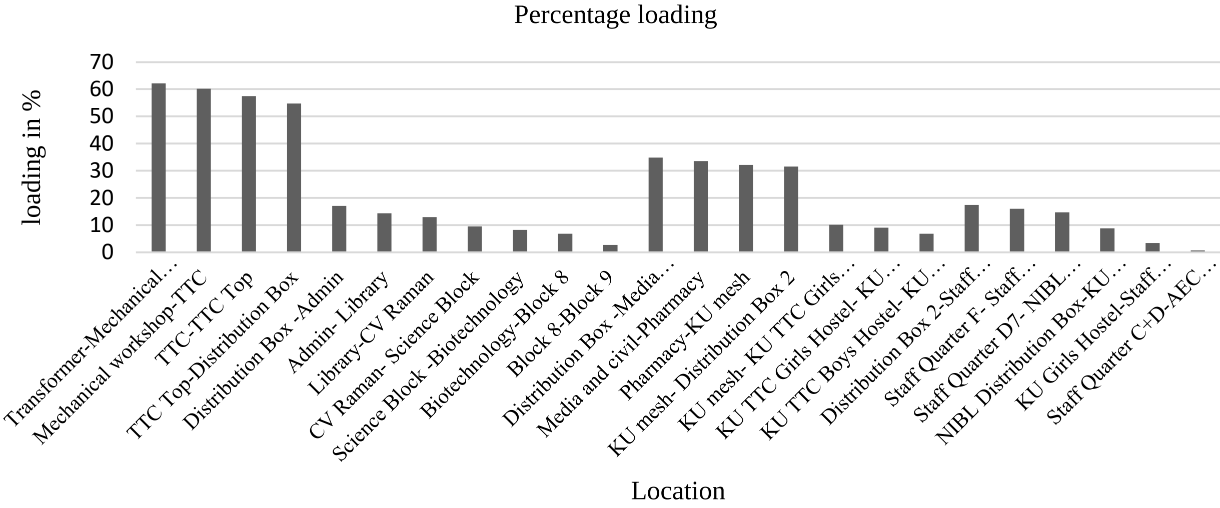

Figure 5. Bar Chart of Line Loading

3.2 Faults Analysis Results

For the fault analysis of the Kathmandu University distribution system, different four types of faults are simulated on different six locations of the distribution system and the value of fault current is obtained as:

Table 5. Values of Fault current at different locations

Location	Type	Current (kA)	Location	Type	Current (KA)
Block 9	Three phase short circuit	1.50	Staff Quarter A	Three phase short circuit	1.25
	Single line to ground fault	1.47		Single line to ground fault	1.03
	Double line to ground fault	1.51		Double line to ground fault	1.04
	Line to line fault	1.3		Line to line fault	0.91
AEC Block	Three phase short circuit	1.2	Boys Hostel	Three phase short circuit	1.42
	Single line to ground fault	1.01		Single line to ground fault	1.4
	Double line to ground fault	1.02		Double line to ground fault	1.41
	Line to line fault	0.96		Line to line fault	1.27
TTC	Three phase short circuit	5.30	Admin	Line to line fault	2.76
	Single line to ground fault	5.26		Three phase short circuit	3.18
	Double line to ground fault	5.27		Single line to ground fault	3.15
	Line to line fault	4.59		Double line to ground fault	3.17

By observing the different fault currents we could differentiate between the normal operating current and the current after the faulted condition. From the bar chart of fault current, the fault current is high in the line which is nearer to the distribution transformer while the line which is at the farthest end of the distribution transformer has a low fault current.

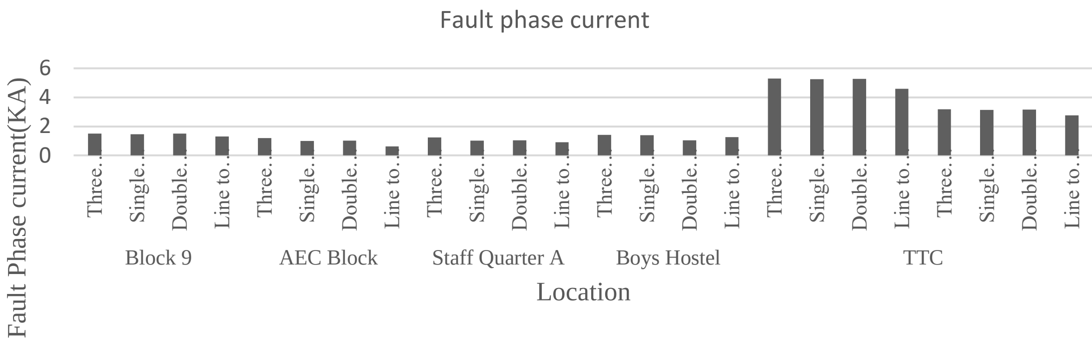

Figure 6. Bar Chart of fault current

3.3 Comparison of actual and simulated voltage profiles

To validate the load flow analysis, the voltage value of three different locations was compared with the actual voltage data obtained (from the actual installed smart energy meters of the D-VA project).

Table 6. Comparison of actual and simulated voltages

Location	Voltage from energy meter (pu)	Voltage from Load Flow (pu)
Biotech	0.9565	0.9578
Civil	0.96086	0.95545
Science	0.96087	0.9599

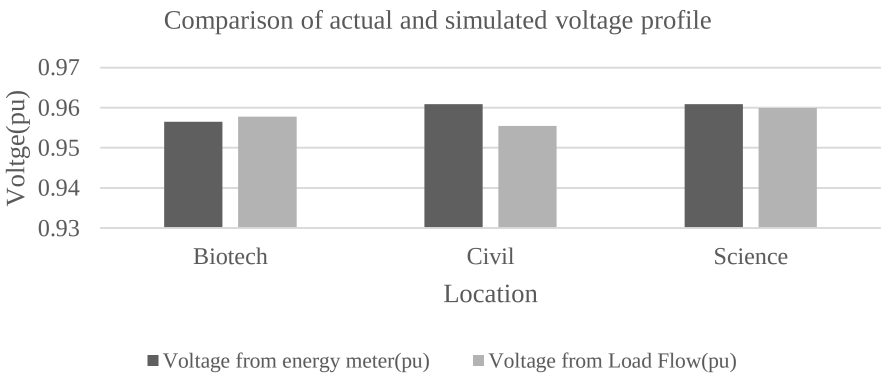

Figure 7. Bar Chart of actual and simulated voltages

Fig.7 shows the comparison between the voltage profile of actual results and simulated results. from this comparison, the data obtained from the load flow analysis and the actual data from the energy meter are quite similar with an error percentage of 0.256.

4. Conclusion

A comprehensive understanding of the Kathmandu University distribution system is provided by this study, and potential issues are identified. From the distribution survey, different parameters like Conductor Type, Line length, total load, and ampacity are determined. Identification of fault current, voltage distribution, line loading, and conductor current is done by observing Load flow analysis and Fault analysis results of the KU distribution network. From the load flow analysis, the highest voltage available is at the Mechanical Workshop+TTCB2 which is 0.981575pu while the lowest voltage available is at the AEC Block which is 0.93365pu. The conductor connecting the transformer- Mechanical workshop has the highest percentage of line loading which is 62.22%. From the fault analysis, the fault current is high in the line which is nearer to the distribution transformer while the line which is at the farthest end of the distribution transformer has a low fault current.

The results obtained from the simulation are compared with the actual data obtained from the energy meter with an average error of 0.256%. Furthermore, the results show that the voltage profiles beyond the KU mess suffer from undervoltage while the conductor connecting the transformer-mechanical workshop can be prone to overloading if further loads are added in this section. In the future, the study may be extended for distribution system planning, fault detection, and prediction of fault type and location.

Acknowledgments

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