SPECTRUM OF ENGINEERING SCIENCES
ISSN (E) 3007-3138 (P) 3007-312X VOLUME 4, ISSUE 3, 2026

RADIAL DISTRIBUTION FEEDER USING ETAP OPTIMIZATION AND ANALYSIS

Muhammad Umar[1], Shehreyar Khan[2], Zaheer Farooq[3], Khalid Rehman[*4]

[1]*Department of Electrical Engineering, University of Engineering & Technology, Peshawar, Pakistan.*
[2,3,4]*Department of Electrical Engineering, CECOS University of IT & Emerging Sciences, Peshawar, Pakistan.*

[*4]khalid@cecos.edu.pk

DOI: https://doi.org/10.5281/zenodo.23056962

Keywords
Load Flow, Short Circuit Analysis, Radial Distribution System, ETAP, Mitigation Technique.

Article History
Received: 01 January 2026
Accepted: 16 March 2026
Published: 31 March 2026

Copyright @Author
Corresponding Author: *
Khalid Rehman

Abstract
To make sure that customers have a steady supply of energy, the electrical distribution system must operate well. Nevertheless, this system has inherent shortcomings due to its vulnerability to environmental disturbances. The distribution network's regular functioning could be better by the presence of symmetrical and asymmetrical fluctuations within these flaws, which leads to service interruptions and a general decrease in system dependability. This research uses a systematic approach to look at potential solutions to these important problems, concentrating on the subtleties of load flow and short circuits in the distribution system. The study includes careful load flow analysis and exact software modelling using ETAP (Electrical Transient and Analysis Programme) to replicate asymmetrical breakdowns. By contrasting the outcomes of mathematical studies with those attained over computer simulations, the research seeks to fully resolve these issues. This comparative approach contributes considerably to the overall resilience and reliability of the electrical system distribution by improving our understanding of distribution system fault occurrences and laying the groundwork for the development of targeted mitigation techniques. The knowledge gathered from this research might lead to improvements in the mitigation of disturbances and the performance enhancement of critical energy facilities.

INTRODUCTION

There are always losses involved in the transfer of electricity from the generating power plants to the end user. The following are the prevalent and pronoun losses associated with the power system Transmission losses and losses from distribution. The distribution losses account for roughly 70% of the overall system losses and play a significant role in the system's deterioration. Given the high levels of these losses, winning attention is required to overcome them. Joule's effect causes power losses in distribution systems, which can account for up to 13% of the power generated [1, 2]. The problems with the economy and the effectiveness of the distribution system are directly impacted by these losses [1]. Transmission and distribution losses in Pakistan account for roughly 19.6% of the total generated. One of the most significant areas of research in electrical power systems is the actual planning of electric distribution networks. Numerous publications on optimal distribution planning have been published recently due to the increased effort and work to reduce system losses. However, despite all these efforts, the important sub-

problem of optimal conductor size selection remains unsolved [4–8]. Several published studies on the best practices for distribution network planning have primarily focused on lowering costs by improving conductor profiles and minimizing losses. However, the increasing rate of load for upcoming years is not reflected in nearly all of these. Furthermore, the majority of articles contain.

A heuristic method that uses a novel sensitivity index in the injection of reactive power is presented in [9], while the selection phase in which the economic criteria, after which use a sensitivity index for the technical selection of conductors is discussed in [10] that search to guarantee an achievable operation of the EDS. Heuristic approaches have the benefit of being resilient and simple to use, although they usually reach a local optimal solution. While some approaches approximate the loads as constant current models, other research examines the linear approximation method for the computation of losses and voltage regulation [11]. One approach to solving the conductor size selection problem using a mixed integer linear model.

To minimize loss and improve the voltage level at each bus in the distribution feeder, this paper describes the practical planning of a distribution system by selecting the best conductors in radial distribution networks. The results of the Power flow study of various conductors in the Electrical Transient Analyzer Program (ETAP) are compared with the growing rate of loads to present a novel method of optimal conductor selection for each section of an 11kV radial distribution network. A distribution feeder's load flow is studied by building the feeder using various conductor types. Real and reactive power flows, ampere flows, and power losses for various conductor types are compared, taking into account both the cost of conductors and the cost of losses. Based on these comparisons, the best conductors are chosen for the various feeder sections. ETAP software is used for the distribution feeder power flow study. because it is the most effective electric power flow analysis tool on the market right now, capable of performing voltage drop calculations and power flow analysis with precise and dependable results. There are numerous built-in features, such as:

- Equipment evaluation Automatically
- Warnings and alerts summary
- Analyzer results for Load Flow
- Intelligent Graphics (more user-friendly)

Distribution software has been developed to test unbalanced three-phase distribution. These programs use different frequency techniques and range from several developments to some assumptions [1]. There are many methods to carry out this solution, but they have advantages and disadvantages concerning computation speed, the criterion of convergence, and the memory Computed and simulated. Contrarily, non-technical losses are due to things like covert connections, meter fraud, inaccurate readings, and insufficient energy management procedures [2]. Load flow is a very important factor for analyzing distribution systems. Since there are many radiology distribution networks today, it is difficult to manually get streaming solutions there are various challenges in load flow calculation due to the increasing addition of voltage regulators and in penetration of generation. Adding the models into the current algorithms' distribution load flow just exacerbates the issue. The network's stability is increased and its poor meshing in the radial distribution system is achieved in many cases thanks to the connections that have been established. In an unbalanced distribution, these Algorithms of power flow need to be considered in the network of all three phases. Following categories of distribution load flow with a brief review as under [3-4].

- Voltage Regulators
- Dispersed generation
- Unbalanced and composite loads
- Radial and Weakly Meshed Systems

An essential tool for power system studies, load flow analysis enables effective energy transmission and excellent service quality. It calls for the use of iterative approaches, real-time data for simulations, and software like ETAP. The study aids in network performance assessments [5-6] and system upgrades by considering system

efficiency, line resistance, load distribution, and voltage restrictions. [7-8]

Materials and Methods

The city-II feeder at a 132kV substation is the subject of this case study. Different fault circumstances, including Line-Ground (LG), Line-Line-Ground (LLG), and Line-Line (LL) faults, were simulated using the ETAP program. The investigation considered the substation's single-line diagram (SLD) and the related ratings. The generation of short-circuit faults allowed for the measurement and comparison of fault values to theoretical calculations. The goal of the investigation was to confirm the accuracy of the ETAP simulation and find any inconsistencies between the measured and theoretical values. These disparities can be the result of erroneous data entry, flawed modeling, or other variables that affect how well the substation performs when there is a breakdown. The knowledge gathered from this case study could help to improve the substation's protection and coordination strategies as well as the data quality, modeling, and overall reliability of the power system.

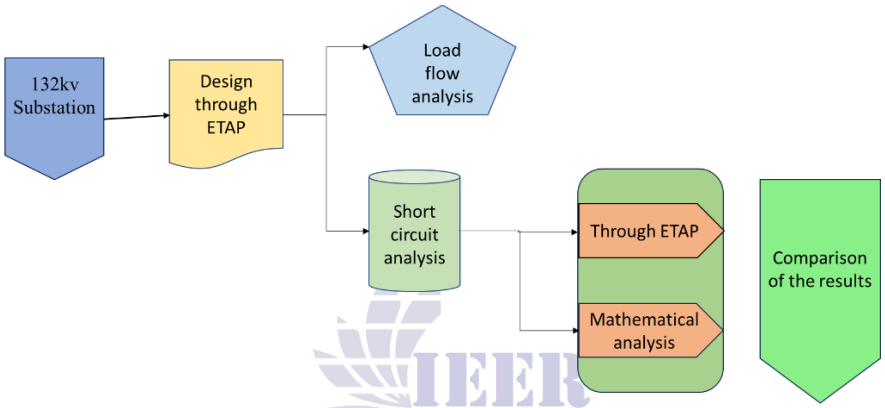


Figure 1: **Design methodology of the case study**

The load flow analysis offers a snapshot of the feeder's load flow under typical circumstances. It entails researching a variety of elements, such as cables and buses. Each wire or cable that joins two buses also has a load attached to it. Planning, running, and maintaining a system all depend on this data. In system planning, load flow analysis aids in identifying future load growth locations and supports infrastructure expansions or improvements. Additionally, it aids in selecting the best sites for substations or new-generation units to reduce losses and improve system dependability. Load flow analysis aids in-the-moment decision-making, ensuring that the power system can satisfy demands while maintaining stable voltage levels. Operators may adjust generator outputs and control devices to ensure system stability and dependability by evaluating power flows and voltages at different buses. To detect possible problems, such as overloads on lines or transformers, voltage violations at buses, or reactive power limit breaches at generators, load flow analysis is useful. Preventative actions may be performed to avert equipment failure or system outages by recognizing these problems beforehand. The data collected after simulation through ETAP relates to a power system's network of 215 buses and 80 lines. The table may be used to study the network's power flow, voltage stability, and fault analysis. The total connected load on the network is 3000 kW. The single line diagram of the feeder that is designed and analyzed in the ETAP software has a total of 32 sections each section has a length of 1000m so the total length of the distribution lines is 32km. Distribution transformers connected to the feeder are 23, and the total load connected is 8,050kVA Fig. 1 shows the design and load flow study of an 11kV distribution feeder in ETAP which also shows the names given to buses.

Short Circuit Analysis

Short circuit analysis is provided in radial distribution systems. The distribution system also becomes significantly more mobile. With more complicated security devices installed, these devices can be remotely configured as needed with every change in the network, but the chance of a flaw in the distribution system still exists. The process suggested in this paper finds the short circuit current taking a load into account in the system. Customarily a short circuit study of power systems overlooks loads in the system [6]. Normally, only the path to the position of the root failure is examined. The reason why loads were forgotten is that it is considered that loads have very little effect on the short circuit current.

IEER
Institute for Excellence in Education & Research

Figure 1: Buses

Table 1: Simulation of Feeder data

Cable/Line	Connected Bus ID		
Load Identification Lines	Using Bus Number	In reference to bus Number	Load Connected in Kilo Watt
Lines 1-2	1	2	195
Lines 2-4	2	4	192
Lines 4-6	4	6	189
Lines 6-9	6	9	179
Lines 9-11	9	11	183
Lines 11-13	11	13	174
Lines 13-15	13	15	171
Lines 15-17	15	17	169
Lines 17-19	17	19	167
Lines 19-24	19	24	162
Lines 24-26	24	26	159
Lines 26-28	26	28	155
Lines 28-30	28	30	151
Lines 30-32	30	32	132
Lines 32-34	32	34	123
Lines 34-36	34	36	120
Lines 36-38	36	38	119
Lines 38-40	38	40	116
Lines 40-41	40	41	8
Lines 40-51	40	51	106
Lines 51-52	51	52	5
Lines 51-60	51	60	100
Lines 52-54	52	54	3
Lines 54-46	54	56	3
Lines 41-43	41	43	0.72
Lines 43-45	43	45	0.72
Lines 60-61	60	61	2
Lines 60-65	60	65	97
Lines 65-67	65	67	93
Lines 67-68	67	68	0.66
Lines 67-70	67	70	0.66
Lines 70-71	70	71	78
Lines 71-74	71	74	4
Lines 71-75	71	75	6
Lines 75-78	75	78	5
Lines 75-220	75	220	0.64
Lines 78-80	78	80	4
Lines 80-84	80	84	3
Lines 70-86	70	86	78
Lines 86-87	86	87	3
Lines 87-89	87	89	1
Lines 86-91	86	91	3

Lines 91-93	91	93	72
Lines 93-95	93	95	70
Lines 95-97	95	97	52
Lines 95-106	95	106	10
Lines 97-99	97	99	4
Lines 106-130	106	130	9
Lines 130-132	130	132	7
Lines 132-134	132	134	5
Lines 95-149	95	149	52
Lines 134-137	134	137	4
Lines 149-151	149	151	51
Lines 151-153	151	153	50
Lines 153-155	153	155	4
Lines 155-158	155	158	3
Lines 158-160	158	160	2
Lines 153-162	153	162	44
Lines 162-165	162	165	42
Lines165-167	165	167	42
Lines167-168	167	168	25
Lines 167-172	167	172	5
Lines 172-174	172	174	2
Lines 177-186	177	186	22
Lines 167-177	167	177	25
Lines 167-178	167	178	9
Lines 178-182	178	182	6
Lines 182-184	182	184	6
Lines 186-190	186	190	19
Lines 190-191	190	191	5
Lines 191-193	191	193	4
Lines 193-195	193	195	3
Lines 190-199	190	199	13
Lines 199-202	199	202	13
Lines 201-203	201	203	12
Lines 203-207	203	207	9
Lines 201-209	207	209	7
Lines 209-211	209	211	5
Lines 211-213	211	213	3
Lines 213-215	213	215	2

However, this hypothesis is not always sufficiently accurate in the distribution system. This article proposes modelling beyond the path of the failure and considering the loads both in the short circuit current calculations and in current circumstances analysis. Sometimes the load on the transmission line increases and the network is faulty. The very common and well-known faults linked with power radial distribution systems are: Three-phase faults (Symmetrical faults) Line to ground faults, Line-to-line faults Double line to ground faults (Unsymmetrical faults)

Whenever a short circuit takes place in a power scheme, the magnitude of the faulty current is very high as compared to the current stream that is emitted into the radial power distribution system. It is essential to make symmetrical and asymmetric analysis of the power of the network to determine the magnitude of the fault current of these faults and errors, to choose the appropriate ratings of the power system [4-18] we discuss here the line impedance called sequence impedance. There are three sequence impedances. Each component of the power system provides impedance to different phase sequence components of current that may not be the same. For example, the impedance provided by any equipment to positive tracking current will not necessarily be the same as that provided for negative sequence current or zero tracking current. Thus, in unsymmetrical error calculations, each piece of equipment will have three values of impedance one comparable to each succession current. [9-10] Positive sequence impedance Negative, sequence impedance, zero sequence impedance.

A positive sequence's building blocks are a trio of magnitudes, each of which is 120 degrees out of phase with the others.

$$Z_1 = r_a + (X_a + X_d)\mathrm{i} \quad (1)$$

$$R = \frac{\delta L}{A} \quad (2)$$

$$X_a(f, GMR) = 1.032\left(\frac{f}{60}\right) log\left(\frac{1}{GMR}\right) \frac{\Omega}{miles} \quad (3)$$

$$X_d(f, D_{eq}) = 1.032 log\left(\frac{D_{eq}}{1ft}\right) \frac{\Omega}{miles} \quad (4)$$

$$D_e(f, \rho) = 20\sqrt{\frac{\rho}{f}} ft.Hz \quad (5)$$

The Negative sequence impedance can be calculated. Three phases, each rotated by 120 degrees and containing phase sequences in opposition to the starting phases, are equivalent to negative trace elements.

$$Z_2 = r_a + (X_a + X_d)\mathrm{i} \quad (6)$$

$$R = \frac{\delta L}{A} \quad (7)$$

$$X_a(f, GMR) = 1.032\left(\frac{f}{60}\right) log\left(\frac{1}{GMR}\right) \frac{\Omega}{miles} \quad (8)$$

$$X_d(f, D_{eq}) = 1.032 log\left(\frac{D_{eq}}{1ft}\right) \frac{\Omega}{miles} \quad (9)$$

$$D_e(f, \rho) = 2160\sqrt{\frac{\rho}{f}} ft.Hz \quad (10)$$

To calculate the Zero sequence impedance, we use the following calculations, The elements of a zero sequence have three identical phases with no dislocations between them. Impulse zero impedance may be easily calculated with the help of the guidance tables. Information on X_a and X_d, as well as tables for directors, are provided. The return effects of land may be increased by including more re and X_e. Z1 is the positive sequence resistance, which is the resistance offered by the corresponding circuit to a current flowing in a positive sequence. Negative relay resistance (Z2) and zero relay resistance (Z1) respectively refer to the resistance carried by a device for negative and zero sequence currents (Z0). [13]

$$Z_0(r_c, f, D_e, GMR) = (3.r_c + \frac{0.00477}{Hz}.f + 1j\frac{0.01397}{Hz}.log(\frac{D_e}{GMR})).\frac{\Omega}{Mile} \quad (11)$$

Line to Ground Fault

When there is one line in contact with the ground due to pregnancy or environmental hazards shown in the figure 2, this error occurs in L-G. When an error occurs from one line to the ground in a three-phase radial distribution network, extending in the form of an equilateral triangle, the power system is disconnected. Suppose that only peripheral voltages and single currents can be measured, the value of the defect position examination and the value of the contact examination.

Resistance can be calculated by equating the stable sinusoidal stream state of the circuit. So we can find out the error under the measurement standards, because of the measurement errors, especially the measurement error of the phase. [7-10].

$$\vec{If} = \frac{3\overrightarrow{E_R}}{\overrightarrow{Z_1}+\overrightarrow{Z_2}+\overrightarrow{Z_0}} \quad (12)$$

I_f - 1.22kA

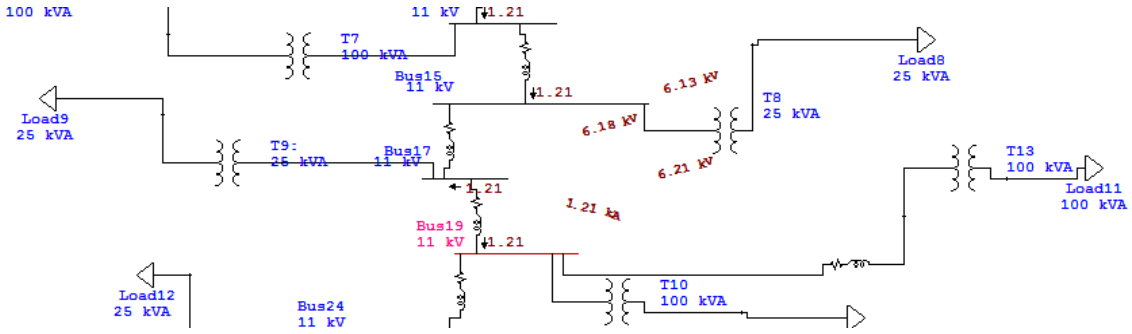


Figure 2: The part feeder where the line to ground fault is generated through ETAP

Double line to ground fault

Double-phase faults, which arise from the contact or short-circuiting of two lines, are classified as Unsymmetrical faults with a likelihood of occurrence ranging from 5 to 15% shown in figure 3. The possibility of a single-line problem becoming a double line-to-ground error emphasises how important it is to find and fix errors quickly. Fixing these bugs requires a team of experts to take a methodical approach that involves going around the network as a whole. The MVD power line fault tracking technique described here focuses on tracking faults from double phase to ground. This complex process entails figuring out the earth's linear circuit resistance, a number that is correlated with the separations between each fault [14–15]. This methodical technique makes it possible to compute these errors, guaranteeing mitigation strategies are implemented.

$$\vec{I}_F = \vec{I}_b + \vec{I}_c$$
$$V_b = V_c = \vec{I}_F * Z_f$$
$$\vec{V}_0 = \vec{V}_1 = \vec{V}_2 = \frac{\vec{V}_a}{3}$$
$$\vec{I}_a = \vec{I}_0 + \vec{I}_1 + \vec{I}_2$$
$$\vec{I}_F = 3\vec{I}_0$$
$$\vec{I}_F = \frac{-3\vec{Z}_0}{\vec{Z}_2 + \vec{Z}_0} * \frac{\vec{E}_r}{\vec{Z}_1 + \frac{\vec{Z}_2\vec{Z}_3}{\vec{Z}_2 + \vec{Z}_3}}$$
$$\vec{I}_F = \frac{-3\vec{Z}_0 * \vec{E}_r}{\vec{Z}_0 * \vec{Z}_1 + \vec{Z}_0\vec{Z}_2 + \vec{Z}_1\vec{Z}_2} \quad (13)$$
$$\vec{I}_F = 1.958kA$$

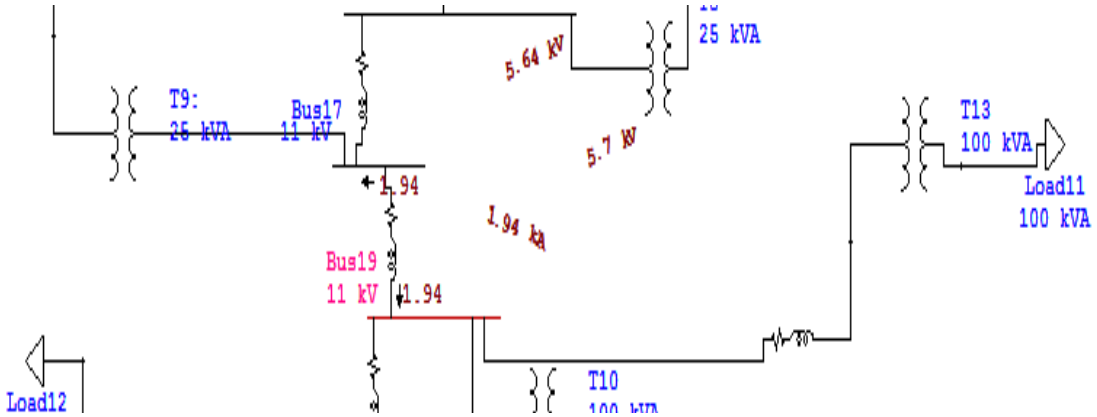


Figure 3: The part feeder where the double line to ground fault is generated through ETAP

Line-to-Line Fault

A fault state occurs when two lines converge and collide, giving birth to a line-to-line fault. Because of the cancellation effect between the positive and negative sequence currents in this case, the output current registers as zero shown in figure 4. The total output magnitude is zero as a result of the colliding currents cancelling each other out [6]. This specific fault type highlights how important it is to comprehend how sequences interact when doing fault analysis since the opposing currents help to prevent net current flow in the system when a line-to-line fault occurs.

$$I\vec{f}=\frac{-i\sqrt{3}*\vec{E}_R}{Z\vec{1}*Z\vec{2}} \qquad (14)$$

I_{f1}=0.88kA, I_{f2}=-0.88kA

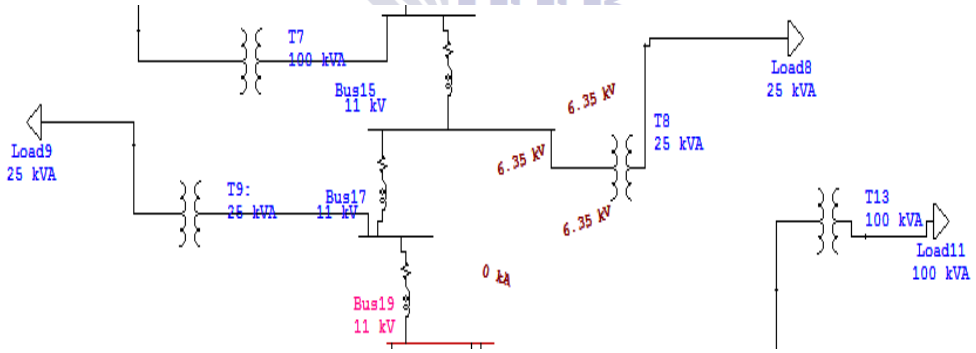


Figure 4: The part feeder where the line-to-line fault is generated through ETAP

Conclusion

Within a power system, electrical distribution is essential to providing electricity to users. It is important to analyse and optimise this distribution to guarantee a dependable and effective supply of power. For load flow and short circuit investigation, the Electrical Transient and Analyzer Programme (ETAP) is a priceless resource. A numerical investigation of the dynamics of electric power flow, load flow analysis looks at actual power, reactive power, voltage angles, and other AC power parameters at each bus under steady-state circumstances. This thorough research provides insights into the behaviour of the power distribution network, which helps with system design and operation.

Being a crucial component of the electrical infrastructure, the distribution system is vulnerable to environmental risks, which can result in symmetrical and unsymmetrical problems. With the aid of programmes like ETAP, mathematical analysis and simulations are

carried out in order to comprehend and fix these errors. A number of fault situations are painstakingly simulated, such as Line to Ground, Double Line to Ground, and Line to Line failures. After that, the outcomes of software simulations and mathematical studies are compared to provide a thorough assessment of how the distribution system reacts to various failure scenarios and to make mitigation techniques more feasible.

REFERENCES

Jangra, Jatin, and Shelly Vadhera. "Load flow analysis for three phase unbalanced distribution feeders using Matlab." *2017 2nd International Conference for Convergence in Technology (I2CT)*. IEEE, 2017.

Chaubey, Piyush, et al. "Robust power system stabilizer based on static output feedback approach to enhance power system stability." *Energy Procedia* 158 (2019): 2960-2965.

Abdel-Akher, Mamdouh, Khalid Mohamed Nor, and Abdul-Halim Abdul-Rashid. "Development of unbalanced three-phase distribution power flow analysis using sequence and phase components." *2008 12th International Middle-East Power System Conference*. IEEE, 2008.

Kumar, R. James Ranjith, and Amit Jain. "Load flow methods in distribution systems with dispersed generations: A brief review." *2015 1st Conference on Power, Dielectric and Energy Management at NERIST (ICPDEN)*. IEEE, 2015.

Abdel-Akher, Mamdouh, Khalid Mohamed Nor, and AH Abdul Rashid. "Improved three-phase power-flow methods using sequence components." *IEEE Transactions on power systems* 20.3 (2005): 1389-1397.

Soni, C. J., P. R. Gandhi, and S. M. Takalkar. "Design and analysis of 11 KV distribution system using ETAP software." *2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*. IEEE, 2015.

Czumbil, L., et al. "Analysis of load flow and short-circuit issues in a retrofitted 110/20 kV Romanian substation." *2017 14th International Conference on Engineering of Modern Electric Systems (EMES)*. IEEE, 2017.

Sreelatha, P. N. K., J. Praveen, and V. Kamaraju. "Effect of unsymmetrical faults on distribution lines with different line X/R ratios and voltage restoration using DVR with Space vector control." *2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET)*. IEEE, 2012.

Santoso, Surya, et al. "Distance estimation technique for single line-to-ground faults in a radial distribution system." *2000 IEEE Power Engineering Society Winter Meeting. Conference proceedings (Cat. No. 00CH37077)*. Vol. 4. IEEE, 2000.

Zhang, Han, Zhigang Liu, and Siqi Wu. "Sequence impedance modeling and stability analysis of single-phase converters." *2018 21st International Conference on Electrical Machines and Systems (ICEMS)*. IEEE, 2018.

Khakimzyanov, Elmir, Ramil Mustafin, and Pavel Platonov. "Method of fault location for double line-to-earth faults in distribution networks." *Engineering Science and Technology, an International Journal* 19.4 (2016): 1668-1671.

M. M. Legha and M. Mohammadi, "Aging Analysis and Reconductoring of Overhead Conductors for Radial Distribution Systems Using Genetic Algorithm," *Journal of Electrical Engineering & Technology (JEET)*, pp. 1-8, 2014.

M. M. Legha, H. Noormohamadi, and A. Barkhori, "Optimal conductor selection in radial distribution using bacterial foraging algorithm and comparison with ICA method," *WALIA Journal*, pp. 1-8, 2015.

[14] C. Soni, P. Gandhi, and S. Takalkar, "Design and analysis of 11 KV distribution system using ETAP software," in *Computation of Power, Energy Information and Commuincation (ICCPEIC), 2015 International Conference on*, 2015, pp. 0451-0456.

D. Das, D. Kothari, and A. Kalam, "Simple and efficient method for load flow solution of radial distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 17, pp. 335-346, 1995.

Abdulkareem, C. Awosope, H. Orovwode, and A. Adelakun, "Power Flow Analysis of Abule-Egba 33-kV Distribution Grid System with real network Simulations," *IOSR Journal of Electrical and Electronics Engineering*, vol. 9, pp. 67-80, 2014.

IEER
Institute for Excellence in Education & Research