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IMPROVING FAULT ANALYSIS WORKFLOW: A TABLE- BASED APPROACH FOR PER UNIT EQUIVALENT CIRCUITS IN BASIC POWER ENGINEERING COURSE

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ABSTRACT

Fault analysis is a fundamental subtopic in the Basic Power Engineering course, a core subject within the Diploma in Electrical Engineering (Electronic) curriculum. A critical step in fault analysis involves deriving a per-unit equivalent circuit from a given one-line diagram of a power system network, which typically includes generators, transmission lines, transformers, and motors. Traditional methods for obtaining per-unit values often rely on a top-down calculation approach, which lacks systematic organization and can lead to errors. To address this limitation, this approach introduces a structured table-based method designed to streamline the calculation of per-unit values and the construction of equivalent circuits. This innovative approach guides students to focus on specific zones within the network, promoting clarity and reducing computational errors. Furthermore, the table-based format facilitates easier evaluation for lecturers, as it provides a clear and organized representation of the calculation process. A preliminary evaluation involving eight students demonstrated the effectiveness of the method, with seven students adopting the table-based approach. Among these, four students achieved fully correct solutions, while three made minor errors attributed to carelessness. The findings indicate that the table-based method enhances both student performance and teaching efficiency. These results suggest that the table-based approach enhances both student understanding and teaching efficiency. Future work will focus on refining the method and expanding its application to broader power system analysis topics.

Keywords: *Per unit equivalent circuit, fault analysis, power engineering, table-based method, power system*

INTRODUCTION

Fault studies are a critical area of focus in power system analysis. This subject was included in the Basic Power Engineering course under the Diploma in Electrical Engineering (Electronic). Data obtained from fault studies is typically utilized for accurate relay settings and coordination (Hadi Saadat, 2004). The power system network is commonly represented in a simplified and standardized format, where a single line is used to depict all three phases of the actual three-phase power system.

This approach is widely adopted in electrical engineering to streamline the visualization and analysis of complex power systems (Chapman, 2002). The one-line diagram, also referred to as a single-line diagram, serves as a concise and efficient graphical representation of the entire power system network. An example of such a representation is illustrated in Figure 1.

The one-line diagram typically includes critical technical details that are vital for system analysis and operation. These details often encompass the ratings of electrical machines, such as generators and transformers, which specify their capacity and operational limits. Furthermore, the diagram may also indicate the power consumption of loads or the power supplied by sources, offering a comprehensive snapshot of the system's operational parameters.

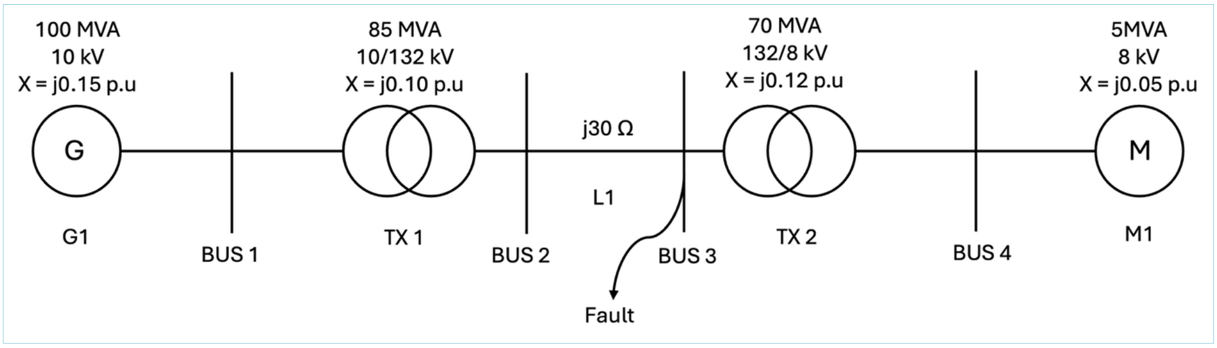

Figure 1.: Single-line diagram for a power system network

Given that the power system network operates on a three-phase basis, one of the most effective and efficient methods for analyzing such a network is to convert it into a per-unit equivalent circuit. The per-unit system is a normalized system of representation that simplifies the analysis of complex power systems by expressing electrical quantities, such as voltage, current, and impedance, as dimensionless ratios relative to predefined base values (Chapman, 2002). One of the key advantages of utilizing the per-unit system is that it eliminates the complications arising from voltage level changes introduced by transformers. This simplification is particularly significant in large-scale power systems, which typically include numerous transformers at various voltage levels.

To derive the parameters required for constructing the per-unit equivalent circuit of a power system, a series of calculations must be performed. However, there is no standardized or systematic methodology for performing these calculations. Traditionally, the process follows a top-to-bottom approach, where calculations begin with the determination of base values and proceed sequentially to the computation of per-unit impedances and fault currents. While this method is logically structured, it often poses challenges for students, particularly when they need to revisit earlier calculations to extract necessary information for subsequent steps. This backward referencing can lead to confusion and errors, especially when dealing with numerical values that extend to several decimal places. Such errors can significantly impact the accuracy of the results, making the analysis unreliable

Problem-solving is a critical skill in engineering education, especially in the 21st century. According to (Adeoye & Jimoh, 2023), problem-solving skills have become a necessity to encourage innovation and solve complex problems across any discipline. Their study on the Creative Problem Solving (CPS) model reveals how its six-phase framework provides a robust foundation for processes involving technical problems. This theoretical foundation strongly supports the development of a table-based approach for improving fault analysis workflow, through structured documentation and visual organization of diagnostic information. Other studies conducted by Lai & Hwang (2014) and Shieh & Chang (2014) show that structured problem-solving skills may result in superior outcomes compared to an ad-hoc method.

Building on these foundations, the primary objective of this paper is to introduce a structured and systematic table-based approach for deriving the necessary parameters required to construct the per-unit equivalent circuit of a power system. Unlike the traditional top-to-bottom calculation method, which often lacks organization and can lead to inefficiencies, the proposed table-based approach provides a clear and structured framework for solving the problem. By organizing all calculations within a single table, this method ensures that each step of the process is logically connected and easily traceable, thereby reducing the likelihood of errors and carelessness. This is particularly beneficial when dealing with complex numerical values that extend to multiple decimal places, as the tabular format minimizes the risk of misplacing or miscopying data.

Furthermore, the table-based approach offers significant advantages for both students and educators. For students, it simplifies the learning process by providing a visual and organized representation of the calculations, making it easier to follow the sequence of steps and verify intermediate results. For lecturers and instructors, this method streamlines the evaluation process, as all calculations are consolidated in a single, coherent format. This not only enhances the clarity of the solution but also facilitates more efficient and accurate marking, saving time and reducing the potential for oversight. By adopting this structured approach, the paper aims to improve the accuracy, efficiency, and educational effectiveness of per-unit calculations in power system analysis.

METHODS

The table-based approach was designed to offer a structured, systematic, and efficient methodology for calculating per-unit values in power system networks and constructing the equivalent circuit necessary for fault analysis. This approach employs a tabular framework that organizes the calculation process into distinct, sequential steps, ensuring clarity and logical progression throughout the analysis. The structure of the table is adaptable, with the number of columns corresponding to the number of zones present in the power system network. As such, the table's dimensions are dynamic and will vary depending on the specific configuration of the power system being analyzed.

Each row within the table is dedicated to a specific parameter, including but not limited to base apparent power, base voltage, base impedance, base current, transformer ratings, and per unit values for each component within a specific zone. This organized arrangement ensures that all critical parameters are systematically calculated and documented, reducing the likelihood of errors and enhancing the overall accuracy of the analysis.

To illustrate the practical application of this approach, Figure 1 and Table 1 provide examples of a power system network comprising three zones, along with the corresponding table-based framework used to calculate the per unit values for the respective system. These figures demonstrate how the tabular method simplifies the process of deriving per-unit values, even in multi-zone power systems, by consolidating all calculations into a single, coherent format.

The table-based methodology is implemented through the following procedural steps:

Step 1: The number of zones is determined by the quantity of transformers within the network, as illustrated in Figure 1. In this example, the network is partitioned into three distinct zones.

Step 2: The base apparent power, denoted as ***Sbase***, is typically provided as a reference value. In this example, ***Sbase***
is specified as 150 MVA. It is important to note that ***Sbase*** remains consistent across
all zones. Step 3: The rated capacities of all transformers are recorded according to
their respective zones.
Step 4: The initial base voltage, ***Vbase***, is usually given as a reference. For example, ***Vbase*** is set at 10 kV and is in Zone 1. The base voltages for Zone 2 and Zone 3 are subsequently derived using the prescribed formula presented in Table 1.

Step 5: The base impedance, ***Zbase***, is then computed. In this scenario, since there is only one real impedance value of j30 Ω associated with the transmission line in Zone 2, ***Zbase*** is calculated exclusively for Zone 2.

Step 6: The base current, ***Ibase***, is also determined for Zone 2, given that the fault condition is located within this zone.

Step 7: The per-unit impedance is computed for all components within the power system, categorized by their respective zones. Given that transformers possess two sides, students may select one side of each transformer for the per-unit impedance calculation. In this example, if the primary side of transformer 1 is selected, the per-unit impedance will be calculated for Zone 1, thereby obviating the need for a separate calculation on the secondary side in Zone 2.

Table 1.: Table-based approach for per-unit equivalent circuit

Zones	**1**	**2**	**3**
Sbase (MVA)		150	
Transformer rating (V)	10 k	132 k	8 k
Vbase (V)	10 k	$\frac{132k}{10k}\ x\ 10k = 132k$	$\frac{8k}{132k}\ x\ 132k = 8k$

Z_{base} (Ω)	N/A	$\frac{(132k)^2}{150M} = 116.16$	N/A
Ibase (A)	N/A	$\frac{150M}{\sqrt{3}132M} = 656.08$	N/A
Per-unit impedance	**G1:** $j0.15 \times \left(\frac{150M}{100M}\right) \times \left(\frac{10k}{10k}\right)^2 = j0.225$ **TX1:** $j0.10 \times \left(\frac{150M}{85M}\right) \times \left(\frac{10k}{10k}\right)^2 = j0.176$	**L1:** $\left(\frac{j30}{656.08}\right) = j0.046$ **L1:** $\left(\frac{j30}{656.08}\right) = j0.046$	**TX2:** $j0.12 \times \left(\frac{150M}{70M}\right) \times \left(\frac{8k}{8k}\right)^2 = j0.257$ **M1:** $j0.05 \times \left(\frac{150M}{5M}\right) \times \left(\frac{8k}{8k}\right)^2 = j1.5$

RESULTS AND DISCUSSION

The preliminary study aimed to evaluate the effectiveness of the table-based approach in improving students' ability to perform per-unit calculations and construct equivalent circuits for fault analysis. Out of the eight students enrolled in the Basic Power Engineering course, seven chose to adopt the table-based method, while one student preferred the traditional top-down approach. The solutions were evaluated based on three criteria: accuracy, organization, and clarity.

The results presented in Table 2 indicate that four out of seven students employing the table-based method attained fully correct solutions, reflecting a robust understanding of the process and effective application of the method. Two students demonstrated minor errors, largely attributable to carelessness in the transfer of values between steps; however, their overall workflow was organized and coherent. The remaining student utilizing the table-based method exhibited difficulties in conceptual understanding; however, the structured format proved beneficial, as it facilitated clear documentation and enabled easier error identification. The student employing the traditional approach also arrived at a correct solution; however, their work was less organized and required considerably more effort for evaluation. The table-based approach enhanced the evaluation process for the instructor by providing a logically organized and clearly documented framework for each step.

Table 2. Summary of preliminary results using a table-based approach

Method Used	Number of Students	Fully Correct Solutions	Minor Errors	Conceptual Errors	Organization & Clarity
Table–Based	7	4	2	1	High
Traditional	1	1	0	0	Low

CONCLUSION

The findings of this study indicate that the table-based approach can improve student learning and teaching efficiency in power system fault analysis. The result of four students getting fully correct solutions highlights the effectiveness of this approach in enhancing accuracy and conceptual comprehension. Students who made errors also benefited from the organized workflow, as it facilitated the identification and correction of mistakes more effectively than the traditional disorganized approach. The student employing the traditional method and attaining a correct solution demonstrates that this approach can still produce accurate results when utilized by a competent learner. However, the lack of organization and clarity in their work made the evaluation process more time-consuming and difficult for the instructor.

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