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DESIGN OF A TOOL FOR CALCULATING SHORT-CIRCUIT CURRENT IN SYMMETRICAL UNBALANCED FAULTS IN SUBTRANSIENT TIME. A CONTRIBUTION TO THE PRACTICAL MANUAL FOR STUDENTS OF "MODELING OF ELECTRICAL POWER SYSTEMS" AT TECNM VERACRUZ

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Abstract: At the National Technological Institute of Mexico, Veracruz Campus, in the Electrical Engineering program, the course " Modeling of Electrical Power Systems " is taught in the 7th semester. This course provides electrical engineers with the ability to interpret, represent, calculate, and explain the behavior of loads and power flows in an electrical power system, including analysis under fault conditions, in order to operate them efficiently. It introduces students to the methodological analysis of interconnected electrical power systems to understand load management in normal or transient operation through transmission lines, substations, and electrical power distribution networks. See Figure 1. This research project seeks to address the academic challenges faced by electrical engineering students in learning how to calculate short-circuit currents under symmetrical unbalanced fault conditions in subtransient time. Based on a historical and methodological analysis of calculation tools in electrical power systems, there is a clear need for a teaching resource that facilitates the understanding of these complex concepts and, at the same time, allows students to visualize each step of the calculation procedure. In this regard, the project proposes the creation of an accessible and practical tool in Excel format that contributes to improving accuracy and understanding in the analysis of unbalanced faults.

INTRODUCTION

In the field of electrical engineering, short-circuit analysis plays a fundamental role in the planning, operation, and protection of power systems. Faults that occur in these systems, particularly symmetrical unbalanced faults in the subtransient time domain, can cause serious disturbances that compromise the safety and reliability of the electrical grid.

The study of unbalanced faults in the subtransient time domain—such as single-phase-to-ground, two-phase-to-ground, and two-phase-to-phase faults—presents a particular challenge because these faults generate asymmetrical currents and voltages. To analyze them correctly, it is necessary to break down the system into positive, negative, and zero sequence components, which significantly increases the complexity of the calculations.

The objective of this project is to design an Excel calculation tool specifically geared toward the analysis of unbalanced faults in electrical power systems. This tool seeks to make it easier for students to perform detailed calculations and verify their manual results, providing them with an interactive experience that complements theoretical learning and fosters the development of practical skills.

In this way, it aims to contribute to improving students' academic performance in the subject of Electrical Power System Modeling at TecNM Veracruz, as well as offering a solid foundation for short-circuit analysis in their professional training, due to its contribution to the practical manual for these subjects.

Description of the problem

In the field of electrical engineering, short-circuit analysis is essential to ensure the safety and reliability of power systems. Unbalanced faults, which include single-phase to ground, two-phase to ground, and two-phase faults, represent one of the most complex situations that an electrical system can face.

A calculation tool focused on the analysis of unbalanced faults could provide a solution to this problem, facilitating learning and allowing students to visualize and validate the results of their hand-written calculations. With such a tool, students would not only improve their mastery of the subject, but also develop practical skills that would be useful to them later on.

1. General information about the course

Name of the subject	**Modeling of Electrical Power Systems**
Course code	**ELF-1020**
SATCA[1]:	**3-2-5**
Career	**Electrical Engineering**

Figure 1.- Heading of the subject Electrical Power Systems Modeling

Project approach

Short-circuit analysis is a crucial topic in electrical engineering, especially in the context of unbalanced faults, which include single-phase-to-ground, two-phase-to-ground, and two-phase-to-phase faults. These faults generate asymmetrical currents and voltages in the system, which presents a considerable challenge for their calculation and analysis.

Therefore, there is a need to develop a short-circuit calculation tool for unbalanced faults that facilitates detailed analysis and comparison of results with manual calculations, providing a more solid and accurate basis for students' studies. This tool would contribute to improving the efficiency and accuracy of the learning process and strengthening the academic performance of students in the subject of Electrical Power System Modeling at TecNM Veracruz.

General objective

To design a short-circuit current calculation tool for unbalanced, symmetrical, subtransient faults, allowing students to perform detailed analyses and verify their manual results, contributing to their practical learning and improving their academic performance in the subject of Electrical Power Systems Modeling at TecNM Veracruz.

Hypothesis

The Excel calculation tool designed for short-circuit current analysis in unbalanced faults facilitates the comparison of results with traditional calculations performed by hand, allowing students to visualize the detailed procedure that leads to these results and providing a practical and accurate reference that improves their understanding and accuracy in the analysis of faults in electrical systems, contributing to their learning through their practice manual.

Theoretical framework; Background

Power system analysis is a key discipline in electrical engineering, and within this, the calculation of short-circuit currents has always been fundamental to ensuring the protection, safety, and stability of electrical networks.

Historically, the calculation of fault currents was done manually, which involved a number of significant technical challenges. Engineers had to solve complex equations that modeled the behavior of the system during a fault, which required a deep understanding of the properties of individual components, such as generators, transmission lines, and transformers. These devices required accurate data on the current levels they had to interrupt in the event of a fault, which led to short-circuit calculation methods that included specific protection parameters.

Thus, short-circuit current analysis was adapted to provide protection devices with the data necessary to operate effectively and prevent damage. The introduction of international standards and norms, such as those of the IEEE (Institute of Electrical and Electronics Engineers) and IEC (International Electrotechnical Commission), established uniform methodologies for calculating fault currents. These standards allowed engineers in different parts of the world to work with a common methodological basis, facilitating the implementation of protection practices in various network configurations.

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The transition to the use of computational tools in fault analysis was largely driven by the emergence of programs designed specifically for power systems, as described in "Computer Methods in Power System Analysis" by G. W. Stagg and A. H. El-Abiad. These computational tools made it possible to solve large impedance and admittance matrices with great speed and accuracy, eliminating human error and the time-consuming nature of manual methods.

With the advent of computers and specialized software, power system analysis underwent a profound transformation. As electrical networks grew in size and complexity, engineers began to rely on advanced programs that automated calculations and allowed them to model entire power systems, incorporating not only the physical characteristics of each component, but also the dynamic conditions that arise in the event of a fault.

This methodological change was especially useful for calculating unbalanced faults, which involve the interaction between different sequence components and require exhaustive mathematical treatment. Reference books such as Grainger and Stevenson's "Power Systems Analysis," updated to include these computational tools, highlight the importance of using specialized software for electrical system analysis and describe computational methods as an indispensable alternative for fault calculation.

Today's networks, with multiple generation points and diverse interconnected sources, require advanced methodologies for fault analysis that allow engineers to address the added complexity of generation variability.

Today, electrical engineers have advanced simulation tools, such as ETAP, DIgSILENT PowerFactory, and other specialized programs, that allow them to perform accurate simulations of power systems under various operating and fault conditions.

These programs, by incorporating sequence component theory and matrix calculation methods, greatly simplify the process and allow accurate results to be obtained in a short time. However, the use of these programs does not eliminate the importance of understanding the theoretical concepts that underpin fault analysis, as established in the works of Stevenson and Grainger and Stevenson.

The use of tools such as Excel, although more basic than specialized programs, represents an accessible and practical solution in the academic environment.

Excel's ability to structure calculations in an automated and visual way allows students and professionals to implement calculation models that break down currents into their sequence components, facilitating a deeper understanding of unbalanced fault analysis.

, and referential conceptual framework

This research project is based on fundamental concepts of electrical power system analysis, focusing on the study of faults and the calculation of short-circuit current under unbalanced fault conditions. The main concepts are listed below in alphabetical order.

The reference framework of this research establishes the theoretical, technological, regulatory, and educational foundations that support the development of the project.

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Design of a tool for calculating short-circuit current in symmetrical unbalanced faults in subtransient time. A contribution to the practical manual for students of “Modeling of electrical power systems” at TecNM Veracruz. This section contextualizes the problem addressed, analyzing the state of the art, the academic and institutional environment, relevant regulations, and current technological trends.

Service connection	Educational Tool
Admittance	Impedance
Feeder	Fault Modeling
Power Systems Analysis	Electrical Power System Modeling
Bus	Motor
Motor configuration	Sequence Networks
Transformer configuration	Zero Sequence
Short-circuit current	Negative Sequence
Short Circuit in Electrical Systems	Positive Sequence
Zero-sequence connection diagram	Electrical Power Systems
Balanced Fault	Simulation and Computational Analysis of Faults
Two-Phase Fault	Sequence Component Theory
Two-Phase Ground Fault	Subtransient Time
Unbalanced Fault	Transformer
Fault in Power Systems	Single-line diagram
Single-Phase to Ground Fault	

Theoretical and Methodological Foundations

Fault analysis in electrical systems is a central topic in electrical engineering, since asymmetry conditions in systems significantly affect their performance and stability. This analysis requires the use of sequence component theory, a tool that breaks down the currents and voltages of a system into three components: positive, negative, and zero. These components allow for more accurate modeling and analysis of fault conditions, which is essential to ensuring the safety and reliability of electrical systems.

In this sense, pedagogical theory supports the development of teaching tools that combine theory and practice in an accessible way. Approaches such as meaningful learning and constructivism emphasize the importance of providing students with interactive learning environments that allow them to apply abstract concepts to concrete problems. This project responds to these needs by designing an Excel tool that automates short-circuit current calculations in unbalanced faults, breaking down each step of the process to facilitate understanding and validation of the results.

State of the art

In the current state of technology, advanced computational tools such as ETAP, DIgSILENT PowerFactory, and PSCAD have revolutionized the analysis of electrical systems, enabling accurate simulations of complex networks. These tools, while effective, are primarily designed for the professional arena and present barriers to their use in educational settings due to their high cost, technical complexity, and computational requirements.

In contrast, more accessible programs such as Microsoft Excel offer a viable alternative in the academic field. Excel allows the integration of formulas, graphs, and automations that facilitate the learning of advanced concepts, making it especially useful for students in training.

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Academic and institutional context

TecNM Veracruz is an educational institution recognized for its focus on the comprehensive training of engineers capable of solving the technical challenges of the electrical industry. As part of its academic offerings, the Electrical Power Systems Modeling course seeks to equip students with the theoretical and practical tools necessary to analyze, model, and optimize electrical networks under normal and fault conditions. This subject, being directly related to the analysis of faults in power systems, plays a crucial role in the preparation of future electrical engineers.

This project, which consists of a calculation tool developed in Excel, responds to this educational need by providing an accessible and easy-to-use resource. The tool not only facilitates complex calculations, but also breaks down the process into steps that students can follow and understand. By using a widely known platform such as Excel, the project adapts to the resource limitations of educational institutions and allows both students and teachers to adopt the tool without requiring a steep learning curve.

Furthermore, the implementation of this tool is designed to enhance the educational experience by providing practical examples and interactive exercises. This allows students to visualize how currents and voltages break down into positive, negative, and zero sequence components, understanding how these interact under fault conditions. In this way, the project not only contributes to better academic performance, but also fosters a deeper and more practical understanding of electrical power systems, aligning with the educational objectives of TecNM Veracruz.

From a regulatory standpoint, the research is based on international standards such as those established by the IEEE, which regulate fault analysis in electrical systems. These standards provide clear guidelines on how to calculate short-circuit currents and design protection systems, ensuring that the project's methods and results are aligned with industry best practices.

Among the relevant standards are:

- IEEE 141 (Recommended Practice for Electric Power Distribution for Industrial Plants): Provides detailed guidelines for the analysis of distribution systems.
- IEEE 399 (Brown Book): Addresses electrical system studies, including fault analysis.

The proposed tool aligns with these standards, ensuring that the calculations performed are consistent with industry best practices. This not only reinforces its academic relevance, but also prepares students to apply knowledge aligned with professional demands.

Expected impact

The tool developed in this project has the potential to generate a significant impact in both academic and professional settings. By providing an interactive environment for performing short-circuit current calculations in unbalanced faults, the project contributes to:

- Improve student academic performance by simplifying and visualizing complex concepts.

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- Strengthen students' preparation to face technical challenges in the workplace.
- Provide an innovative resource that can be replicated in other areas of electrical systems analysis.

METHODOLOGY

Population

The target population for this research comprises the student community of the Electrical Engineering program at TecNM Veracruz, specifically those enrolled in the Electrical Power Systems Modeling course in the seventh semester, according to the program's curriculum.

This sector represents a key point due to its need to acquire practical skills in fault analysis and discover its different uses, since, without knowing how each type of fault affects an electrical system, the measures required within the country's National Electrical Code ( ) are not currently followed when it comes to short-circuit studies, and the protection system developed is often inadequate.

This project is based specifically on unbalanced faults (single-phase to ground, two-phase between lines, and two-phase to ground), which are essential for the design of the ground grid and the sizing of the bare cable, It therefore contributes to the training of students in theoretical and technical concepts related to electrical power systems, so that future engineers, for whom the deliverables are intended, graduate with the skills required to ensure safety in electrical networks.

This work corresponds to a development study, as its purpose is to design an educational tool in Excel format for calculating short-circuit currents in unbalanced, symmetrical faults in subtransient time.

The project can even be classified as applied research, as it seeks to offer a practical and specific solution to the educational needs of students of the subject Modeling of Electrical Power Systems at TecNM Veracruz.

This research is aimed at improving academic performance by introducing teaching resources that integrate theory, practice, and technology into a single learning process. In this way, it is hoped that students will not only improve their technical skills but also develop critical competencies for their professional performance in the analysis and design of electrical systems.

Description of the resource

This project is based on a comprehensive resource that combines a computational tool in Excel format and a user guide manual, specifically designed to facilitate the analysis of short-circuit currents in unbalanced, symmetrical, subtransient faults. This set of resources aims to provide students with a practical and educational tool that simplifies complex calculations and reinforces their theoretical and practical learning.

The Excel tool allows automated calculations to be performed using predefined formulas, breaking down currents into positive, negative, and zero sequence components. Its design includes a structured interface for entering electrical system parameters such as voltages, impedances, and system configuration.

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Additionally, it incorporates graphics that allow the corresponding system diagrams to be visualized, facilitating understanding. This tool also includes sections dedicated to validating manual calculations, offering students a means to check the accuracy of their procedures and strengthen their confidence in applying these concepts.

Data collection procedure

The data collection procedure will be carried out in two phases:

1. **Initial testing**: The tool will be validated with a pilot group of students who will simulate unbalanced fault scenarios using manual calculations and the Excel tool. Observations will be recorded on ease of use, understanding of results, and time required to complete tasks.
2. **Final evaluation**: A questionnaire will be administered to gather students' opinions and feedback on the effectiveness of the tool in the learning process. A comparison will also be made between the results obtained with the tool and the calculations performed manually to evaluate its accuracy and usefulness.

This project required a rigorous process of gathering theoretical, technical, and practical information to ensure the accuracy, functionality, and applicability of the resources designed: the Excel calculation tool and the user manual.

This procedure was carried out in several stages, each aimed at collecting specific data that would allow for the development of a comprehensive resource adapted to the educational needs of students in the Electrical Power Systems Modeling course at TecNM's Veracruz campus.

In the first stage, a comprehensive review of technical and regulatory literature was conducted. Among the main sources used were fundamental texts such as "Power Systems Analysis" by Grainger and Stevenson, "Elements of Power System Analysis" by W.D. Stevenson, as well as reference standards such as IEEE 141. These sources made it possible to establish the theoretical basis necessary for calculating short-circuit currents in symmetrical unbalanced faults in subtransient time, providing the key equations and basic parameters for structuring the tool.

Subsequently, the electrical parameters and practical scenarios that would be used as the basis for the calculations were defined, since this tool is limited to a single type of single-line arrangement.

These included nominal operating voltages, positive and zero sequence impedances (since the negative sequence is considered equivalent to the positive sequence, an approximation that can be used in small-scale scenarios such as this one), and system configurations such as grounded star and delta connections.

Based on this data, a representative electrical network scenario was designed, which was then used to develop practical exercises that served as examples in other spreadsheets in the same tool file, following the same procedure detailed in the manual.

In the third stage, simulations were carried out in specialized software, such as ETAP, to validate the accuracy of the theoretical and manual calculations. The simulations were essential for comparing the results obtained manually with those provided by advanced computational methods, adjusting the formulas when necessary to ensure consistency.

These simulations also made it possible to identify potential errors in the initial development and establish strategies for their correction, which were incorporated into the structure of the tool.

Once the calculations were validated, the calculation tool was structured in Excel. This stage included the creation of an interface organized into clear sections: one for data entry, where basic parameters such as voltages, system configurations, data on elements such as cable gauge and distance, equipment power, among others, are entered; another for intermediate calculations, where the necessary formulas were integrated to first organize the single-line data in a table from which to obtain what was required to convert the system to PU; then, to break down the currents into positive and zero sequence components; and finally, a section for final results, where the single-phase to ground, two-phase to ground, and two-phase between lines fault currents are displayed. This design allows users not only to obtain accurate results, but also to understand the calculation process and analyze the results obtained , providing a layout that allows them to easily locate the steps in the user manual.

At the same time, the user manual was developed to serve as a guide, acting as an indispensable complement to the Excel tool. This manual includes theoretical explanations of the fundamentals of short-circuit current calculation and describes the practical examples solved step by step in the Excel tool, allowing students to apply the concepts they have learned. It also describes in detail how to use the tool, ensuring that it is accessible even to users with basic knowledge of the subject.

Finally, comprehensive testing of the designed resources was carried out. These tests consisted of applying the tool and manual to simulated scenarios that are normally used for the subject of Electrical Power Systems Modeling, verifying that the results obtained were consistent with manual and theoretical calculations.

The Excel tool and user manual are designed to adapt to the academic needs of students, contributing significantly to their theoretical and practical training, as well as to the requirements necessary for their graduate profile, training engineers who master the specific subject and are capable of replicating it in the workplace.

This is confirmed by tests carried out on a small group of students who voluntarily agreed to participate, both those enrolled in the course and those who will soon be taking it.

Statistical information management procedure

The statistical information management in this project was designed to validate the functionality and accuracy of the Excel calculation tool, as well as to evaluate its usefulness as an educational resource in the subject of Electrical Power Systems Modeling.

This procedure was structured in several stages, ranging from data collection and organization to analysis and graphical representation, with the aim of ensuring reliable results aligned with the project's objectives.

First, data was collected from various sources. This included values obtained from manual calculations of short-circuit currents in symmetrical unbalanced faults in subtransient time ( ), results generated by simulations in specialized software such as ETAP, and values calculated automatically using the Excel tool.

The statistical analysis of the data focused on two main aspects: validating the accuracy of the results obtained using the tool and comparing its efficiency in relation to manual and advanced computational methods. To do this, key indicators were calculated, such as the percentage error between the results obtained manually and those generated by the Excel tool.

This percentage of error made it possible to evaluate the accuracy of the calculations performed with the tool in comparison with traditional methods and simulations performed in specialized software. In addition, the average time required to perform the calculations manually was analyzed in comparison with the time required using the tool, highlighting the improvement in efficiency that it provides.

The graphical representation of the data was another fundamental element in this procedure.

The Excel tool developed played a dual role in this procedure. On the one hand, it automated the complex calculations required for short-circuit current analysis, significantly reducing the time required and minimizing human error.

In addition to the technical analysis, a qualitative evaluation was included based on the application of practical exercises designed to be solved with the tool and the manual as part of the testing phase by the participating students. These exercises were reviewed to ensure that the instructions were clear and that the results generated by the tool were easily interpretable by the students.

This process allowed for the identification of possible adjustments to the structure of the tool and the content of the manual, ensuring that both resources fulfilled their educational objective.

Ultimately, the statistical analysis of the information not only validated the results obtained with the tool, but also provided a solid basis for justifying its implementation as part of the subject's practical manual.

The analyzed data demonstrated that the Excel tool is accurate, efficient, and accessible, making it a valuable resource for the practical learning of concepts related t r the analysis of electrical power systems, facilitating the acquisition of such knowledge by students who find the subject difficult or have not had their first approach to it.

To ensure a comprehensive analysis, the variables and data to be collected have been clearly defined. In the case of qualitative variables, these include the level of student satisfaction with the tool, their opinion on its ease of use, and their perception of its impact on their understanding of the analysis of symmetrical unbalanced faults.

These variables allow us to capture the subjective experiences and opinions of users. On the other hand, quantitative variables include the time spent performing manual calculations versus automated calculations with the tool, the percentage of error in the results obtained using both methods, and the frequency of correct answers in exercises before and after using the tool. These variables provide an objective framework for evaluating the performance and efficiency of the developed resource.

Data collection will be carried out using a structured questionnaire administered to students who use the tool. This instrument will collect both qualitative and quantitative data, providing detailed information about their user experience and the educational impact. In addition, the results of specific academic activities involving manual calculations and the use of the tool will be collected. This data will be essential for analyzing the error rate and execution times, offering a direct comparison between traditional methods and the designed tool.

Furthermore, comparisons will be made to identify differences in the error rate before and after using the tool, which will allow its impact on academic performance to be determined.

Furthermore, comparative graphs, such as bar or line graphs, will be created to show the evolution of academic performance and calculation errors before and after implementing the tool. These visualizations will facilitate understanding of trends and the impact of the tool on student learning.

The interpretation of the statistical results will allow for an evaluation of the tool's effectiveness in terms of reducing calculation time, improving the accuracy of results, and the perceived impact on learning.

Finally, the presentation of the results will include a clear and visual summary of the analyzed data using tables, graphs, and detailed descriptions. This presentation will not only facilitate the interpretation of the findings but will also serve as the basis for the study's conclusions. Additionally, a discussion section will be included to analyze the implications of the results in the academic and professional fields, highlighting how the use of the tool and the manual contribute to practical learning in the subject of Electrical Power Systems Modeling.

Results obtained and discussion

This project is expected to have a significant impact on the academic training of Electrical Engineering students at TecNM Veracruz, particularly the Excel calculation tool for those currently studying the subject of Electrical Power Systems Modeling.

The tool developed in Excel is designed to directly address academic needs and contribute to the practical understanding of concepts related to the analysis of short-circuit currents in unbalanced, symmetrical, subtransient faults.

One of the main expected results is that this tool will allow students to gain a deeper understanding of the steps necessary to perform detailed short-circuit current calculations.

This will help students understand how currents and voltages are broken down into positive and zero sequence components, significantly improving their ability to visualize and apply these concepts in practical scenarios.

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Figure 2. Cover of the user manual.

In addition, a tangible improvement in students' academic performance is expected. By allowing them to compare the results obtained through manual calculations with those generated by the tool, students will be able to identify common errors and correct them more efficiently.

As a result, an increase in grades obtained in practical assessments and greater confidence in their ability to perform electrical system analysis are expected.

Another key result of the project is the integration of this tool into the subject's practical manual, which will represent a significant contribution to the institution. This manual will include not only the tool itself, but also practical guides, interactive exercises, and solved examples to help students apply theoretical concepts in real-world situations.

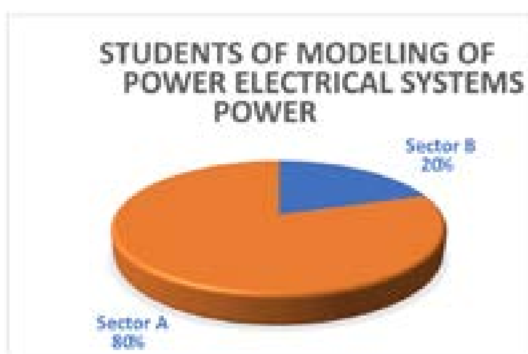
This contribution to the practical manual will not only enrich the existing academic material, but will also become a replicable standard that will benefit future generations of students, providing a valuable resource for learning about electrical power systems.

These skills include the ability to interpret results, analyze failure scenarios, and propose effective solutions, which are essential competencies in today's electrical industry. In this way, the project contributes to closing the gap between academic training and the demands of the labor market.

Finally, the tool is expected to be successfully validated during its implementation in the classroom. Testing with students will not only confirm its functionality and accuracy but also provide valuable feedback for adjustments and improvements.

In addition, by reducing the time required to perform complex manual calculations, the tool will allow students to focus more on critical analysis and interpretation of results, maximizing the educational impact.

Graph 1 below shows the results obtained after testing with the small group of students taken:



Graph 1. Test results for a group of students.

According to the graph, 80% of the students currently enrolled in the course

"Modeling of Electrical Power Systems" at the TecNM campus in Veracruz (Sector A) were able to use the tool efficiently, achieving the expected result and significantly improving the time spent calculating these faults.

On the other hand, 20% (Sector B) had complications in the development, requiring the user manual to use the tool in the manner for which it is designed.

It is expected that the user manual, in conjunction with the Excel tool, will have a significant impact on a group of students who have not yet taken the Electrical Power Systems Modeling course, preparing them to more easily address the theoretical and practical concepts related to unbalanced, symmetrical, subtransient faults.

This group represents a key population for evaluating the user manual's capacity as an introductory resource, designed to facilitate the learning of advanced concepts from earlier stages than those planned in their academic training.

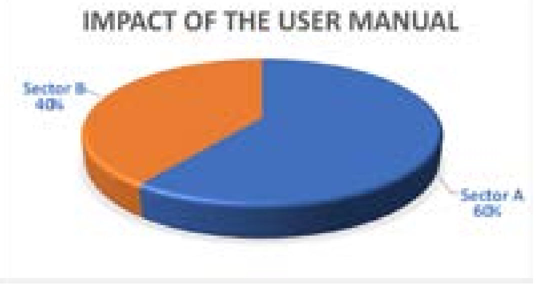
Specifically, it is anticipated that students will effectively understand the theory of sequence components, identifying how fault currents break down into positive, negative, and zero sequence components, and how these concepts apply to the analysis of unbalanced faults.

By carefully reading the manual and completing guided exercises, students are expected to develop skills to perform basic calculations using the Excel tool, even without prior experience in the subject.

A key expected outcome is an increase in the accuracy of students' calculations when comparing the initial results obtained manually with those obtained after using the manual and the tool.

From a qualitative perspective, it is anticipated that students will perceive the manual as an accessible and useful tool, particularly due to its step-by-step explanations, solved examples, and practical exercises. Participants are expected to consider that the manual contributes to a better understanding of the fundamentals of unbalanced fault analysis and improves their confidence in tackling more complex topics in future courses.

Finally, it is anticipated that this initial impact will serve as an indicator of the potential of the manual and tool to be used in introductory courses or as complementary support material, helping students establish a solid foundation before tackling the more in-depth analysis required by the subject of Electrical Power Systems Modeling. This result will reinforce the applicability of the designed resources and their ability to be effectively integrated into different levels of academic training.



Graph 2. Sector "A" and Sector "B" of students who took the test.

The results of the test administered to students who have not currently taken the course "Modeling of Electrical Power Sys-

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tems" and, in turn, have not learned about the importance of topics related to short circuits reveal the impact that developing these skills can have at a stage prior to that considered by the current Electrical Engineering curriculum, since this topic is of utmost importance for the graduate profile and, in general, is not addressed with enough time for all students related to the subject to master it.

In Graph 2, it can be seen that 60% (Sector A) of the students who took the test successfully completed the proposed exercise, even though this was their first encounter with the subject.

On the other hand, 40% (Sector B) faced difficulties in completing the exercise, highlighting the importance of a more thorough analysis of the relevant considerations taken into account with respect to load values (motors).

Based on the satisfaction survey, aspects were identified that need to be explored in greater depth in the user manual in order to make the topic clearer, making it an easily accessible and understandable tool for the entire student community, seeking the most efficient way to develop the topic in order to achieve the expected competencies.

In summary, the expected results of this project include a notable improvement in students' theoretical and practical understanding, an increase in their academic performance, a significant contribution to the subject's practical manual, and a positive impact on their professional preparation.

CONCLUSIONS

Based on the results obtained from tests carried out on students enrolled in the "Electrical Power Systems Modeling" course, as well as those who will soon enroll in the course, it is clear that the tool designed in Excel is truly useful for calculating the short-circuit current of single-phase to ground, two-phase to ground, and two-phase between lines unbalanced faults. It fulfills its function and makes the development of the corresponding equations and the analysis of the concepts applied to them more efficient.

For their part, the students for whom it represented an introduction to the subject of short circuits agreed that it is a very useful tool that facilitates understanding of the subject and, accompanied by the user manual, emphasized its intuitive nature.

It should be noted that this project does not seek to compete with current technological tools for simulating different fault scenarios in various electrical network configurations, but rather to be a complement that offers students of the subject "Modeling of Electrical Power Systems" a value that can be easily used as a reference to confirm their own calculations.

In addition, the manual has been designed to allow students not only to learn how to use the calculation tool in Excel format, but also to develop the detailed procedure that this same spreadsheet carries out to achieve its results.

Based on the IEEE Std. 141 standard, it offers students a tool that they can use not only in the academic field, but also as knowledge acquired for the development of their graduate profile.

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Analysis of the results obtained from tests carried out on a small group of students currently studying the subject at TecNM campus Veracruz shows that the calculation tool is easy to use and accessible to all, unlike current platforms that are not available to the entire student community.

This fact allows for the evaluation of the possible use of the tool designed as an official complement to the subject, so that it can be made available to teachers to implement in their subjects, not limited to "Modeling of Electrical Power Systems," but also to areas that go hand in hand with it in the Electrical Engineering degree program.

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