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FEA Simulation of the Propagation of Magnetic Field Waves Strength Inside A 275kV Main-Intake Substation

Omar Farouq Mohd Sawi @ Rahim, Md Noor Ramdon Baharom[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: High voltage main substation is very important for step-up voltage and step-down voltage. The magnetic fields inside high voltage substations have become a concern in recent days due to the high value of the magnetic field can give a bad effect on human health. The objective of this study is to design an FEA simulation model of the typical 275kV main-intake substation, to profile a propagation of magnetic field wave strength produced by the simulation's model and to study the magnetic field strengths measured at a ground level according to a different type of condition and situation. ANSYS Maxwell software has been used to measure the magnetic field in five different areas. This software was used to solve electromagnetic field, eddy current and transient current Within a finite region of space, using appropriate boundary conditions. The researcher would focus on the magnetic field (MF) only since the power delivery value is varied depending on the load demand over time. It is related to the current value carried by the busbars. A higher value could be expected during the peak period. Rapid further development of the distribution area would increase the future load demand, hence would cause the lines (busbars) to carry higher currents. The result of the simulation is showing the magnetic field and was compared between different types of case studies. The result can be concluded that the value of an electric field can change according to conditions and situations. The key findings and outcome from the work would provide valuable information to the authority and the designer/engineer on the matters related to the mentioned modeling of the substation using the Ansys Maxwell software, the FEA magnetic field profiles and analysis of the lines under various working conditions and designs.

Keywords: Magnetic Field, Substation, ANSYS Maxwell Software

**Corresponding author: ramdon@uthm.edu.my*

1. Introduction

High voltage main substation is very important for step-up voltage and step-down voltage. Substations are built at various sites depending on the availability of various resources; however, these places may be close to residential and industrial areas [1]. Inside the perimeter of substations, there is a transmission line and components with different functions for example transformer, disconnect switch, circuit breaker, and lightning arrester. A magnetic field is produced by the current flow at the busbar and inside the equipment. Theoretically, the highest magnetic field is measured at the lowest height of the busbars. A high value is expected at the secondary side of the step-down transformer that is normally carried by the underground cable [2].

The purpose of this study is to simulate the propagation of magnetic field waves produced inside the typical TNB 275kV main-intake substation. Based on the magnetic field value, we may investigate whether a certain quantity of magnetic field has a negative impact on human health and whether the substation region is safe for humans to be there. We also can identify whether it can affect electronic equipment that has a hypersensitive component inside. The research site is in an industrial area with some electronic equipment that is extremely sensitive when exposed to a particular level of EMF radiation [3]. The range of voltage levels for the outdoor substation is between 55kV to 765kV. The importance of the open-air main intake substation is to ensure the clearance and creepage of the conductor within good range to prevent unintentional arching between two conductors. The clearance between the conductor and the ground is also important to prevent shock and decrease the value of the magnetic field above the ground. Examples of outdoor substations in Malaysia are 275kV PMU Tudan Substation, 132kV PMU Seberang Jaya Substation and 33kV PMU Ulu Melaka.

Nowadays, these cases can be quickly worked and investigated by engineers from the use of several Finite Element Analysis (FEA) software existing in the market, such as the COMSOL Multiphysics, Ansys Maxwell, FEMM, ORACLE, etc. There is pros and cons when using measurement device and simulation to calculate magnetic field. For measurement devices, the pros are it was easy to use because only use the meter while the cons are that we can only get one result from the measurement. Next, for simulation, the pros are we can get multiple different results because we can use different types of designs and materials while the cons are, that it is very complex to learn and perform the application [4]. This final year project took a challenge to simulate the magnetic field (MF) profile of the line's busbars in the open-air substation. The work makes use of the busbar arrangement inside the 275kV's Batu Pahat South main intake substation (located at Pura Kencana Batu Pahat) as a site reference model in the simulation. Several case studies are made to investigate the ground-level MF strength under certain working conditions and designs. The objective of this study is to design an FEA simulation model of the typical 275kV main-intake substation, to profile a propagation of magnetic field wave strength produced by the simulation's model and to study the magnetic field strengths measured at a ground level according to a different type of condition and situation. ANSYS Maxwell software has been used to measure the magnetic field in five different areas.

2. Methodology

This section will discuss the method and elaborates on all the work progress used to measure the Electromagnetic Field at the area of the 275kV main intake substation. The explanation of the Ansys Maxwell Software that is used to simulate and generate the magnetic field around the research area. Various types of methods will be used for this project. This project will be completed in the overall manner described in the flowchart and step by step.

2.1 Project Framework

To complete this project, the process will follow the path of the flowchart. All the progress and flow of the project will be done according to the flowchart shown in Figure 1. Each step in the flow chart must be analyzed in order to acquire promising outcomes. The standard 275kV main substation in Malaysia will be studied according to the project title. From the flow chart, there are parts which are Part 1 and Part 2. In part 1, the studies of relevant project information for example study about an electromagnetic field, 275kV main intake substation and etc. The studies are for literature review for the project. The aim of the literature review is to collect more data in order to gain information for the project's aim. For part 2, the starting of the simulation progress. The software is to simulate the model of 275kV substation and analyzing from the result’s gain.

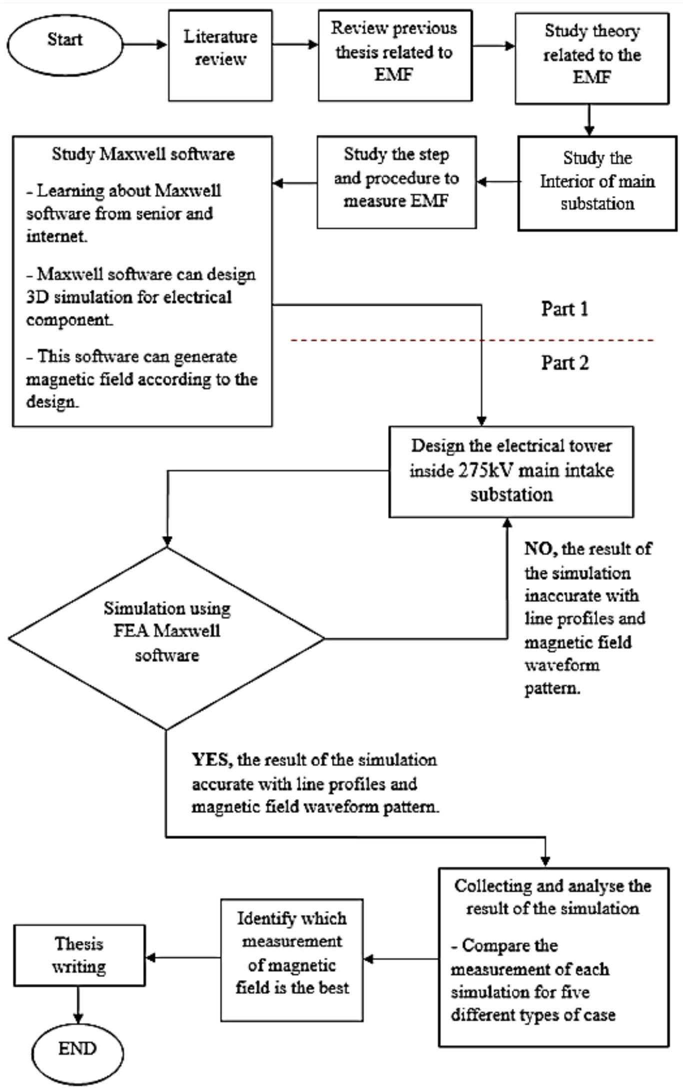

Figure 1: Flow Chart of the Project.

2.2 Research of 275kV Substation Design

There are multiple types of substations in Malaysia for example 275kV, 132kV, 33kV and etc. [5]. The researcher must investigate the magnetic field in the 275kv main inlet substation for this Final Year Project’s investigation. This research was carried out on a variety of platforms, including the internet, and it also went to the substation area to analyze the design of the electrical substation area. The researcher recognized the dimensions and measurements of the structure inside the electrical substation with exact measurements such as the height and length of the busbar based on the study findings from the internet and site visits in the electrical substation area. Accurate assessment of the electrical substation structure is critical to ensuring that the final results of the electric field generated by the ANSYS Maxwell software are accurate and meet the study's objectives. The study enables researchers to sketch and design structures in electrical substations using precise measurements. Figure 2 shows the sketch of the exact measurements from the side view while Figure 3 shows the sketch of the exact measurements from the top view ware made with AUTOCAD software. This electrical substation sketch drawing is intended to be used as a reference while performing simulations in the ANSYS Maxwell application to ensure correct measurements. Both figures also show the area measured which is zone A1, A2, B1, B2 and Under Busbar.

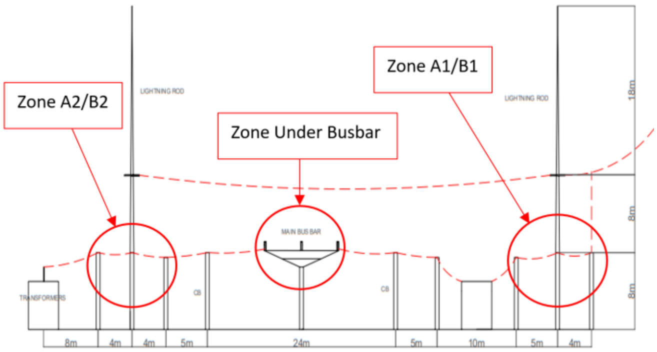

Figure 2: The sketch of the main intake substation from the side view.

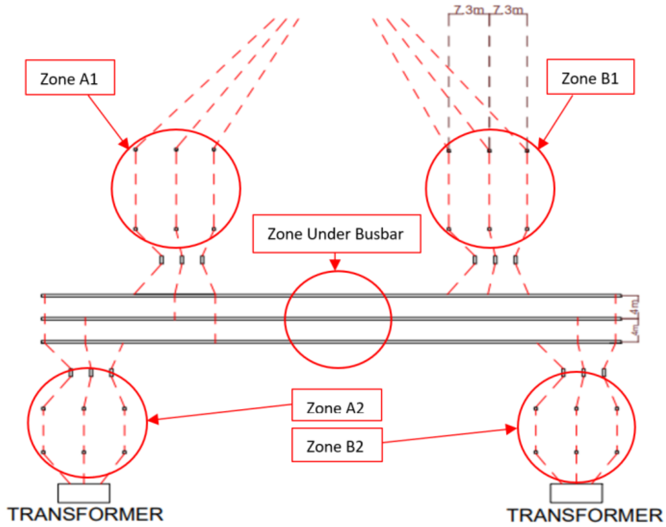

Figure 3: The sketch of the main intake substation from the top view.

2.3 Flow Chart for 3D ANSYS Maxwell Design

For 3D ANSYS Maxwell simulation, the design must be according to the dimensions from the substation structure's sketching. The steps for building this simulation are nearly identical to those for 3D maxwell design. The step for the 3D Maxwell design is shown in Figure 4. Before starting the simulation, insert a 3D Maxwell design with inserting (meter) and solution type (magnetostatic). The next move is to design a 3D model of a high voltage of substation by using multiple types of material which are copper, soil, steel, aluminum and ceramic. All the material is used to create a design of substation for example insulator, ground, conductor and pole. Then, enter the parameters and apply material properties, limits, and excitation to the project. The material of the conductor is aluminum while the insulator uses ceramic as material. After that, create a box for boundaries with the material of air and soil. After creating the 3D design, inject 2500A of current through the conductor. Next, create a plate in 5 different areas for measurement of the magnetic field which at zone A1, A2, B1, B2 and under the busbar. On the plate, create a meshing plate to make sure the value of the magnetic field is accurate according to the value of the current and the material of the conductor. After completing all the steps above, specify the mesh operation and check to validate to ensure the design is correct without error. Finally, run the simulation and it will create color contour of the magnetic field and graph.

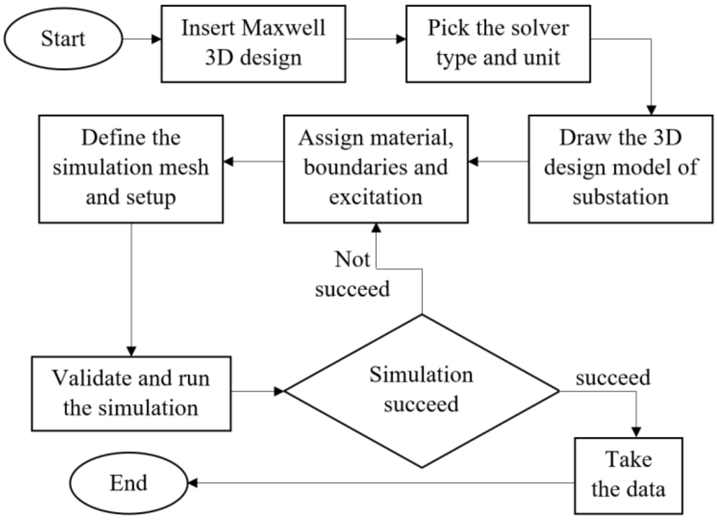

Figure 4: Simulation flowchart for 3D Maxwell design.

2.4 Characteristics of the Design high Voltage 275kV Substation

Figure 5 shows the illustration design for the conductor inside the high voltage 275kV main intake substation. It also shows the area will be measured at the high voltage main intake substation. The design is according to the typical design of a high-voltage substation. The height of the conductor is constant for the busbar due to the busbar is hard and solid material while the height of the wire is not constant because the material is flexible. The average height of the conductor inside the substation is between 8 meters to 6 meters. The figure shows there are areas for busbar and wire which are areas 1 and 2 respectively.

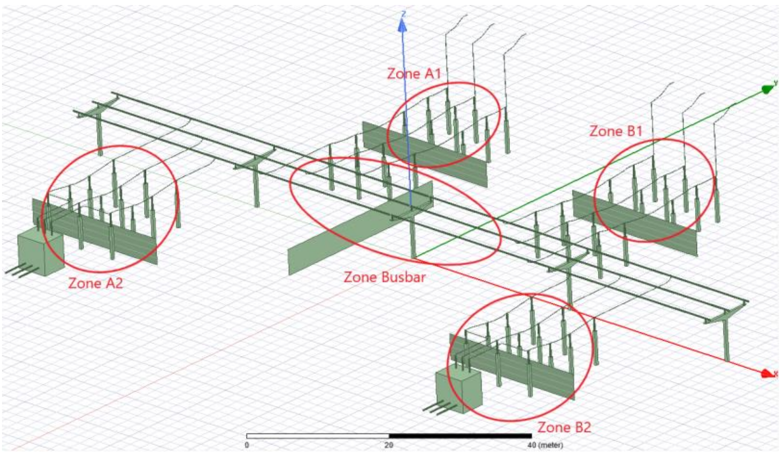

Figure 5: Illustration design of conductor inside high voltage 275kV main intake substation.

Based on Table 1, it shows the height of the conductor based on the standard design of a high voltage substation. The area of the substation has which is for busbar and wire. Area 2 is for busbar and Area 1 is for wire.

Table 1: Height of conductor based on standard design of high voltage substation.

Conductor Height based on High Voltage Substation	Area 1	Area 2
Maximum Height	7.5 meter	8 meter
Minimum Height	6 meter	8 meter

2.5 Case Study of This Study

There are five cases with different situations to investigate the value of the magnetic field at Batu Pahat's substation. The case and situation of these studies shown below:

- Magnetic field strength at the ground level (0 meter)
- Magnetic field strength at different size busbar
- Magnetic field strength with different types of grounding material
- Magnetic field with different heights of wires and busbars
- Magnetic field strength profiles when one circuit OFF

3. Results and Discussion

This section is about the result of the project simulation. It will examine and perform a simulation of the electromagnetic field produced underneath or below the busbar of the 275 kV main intake substation. The design for 3D has been carried out in this project. By using ANSYS Maxwell software, the data of the outcome will be examined for the magnetic field under the conductor is more accurate and easier to detect. The result will show one case study which is magnetic field strength with different types of grounding material. The measurement area will be only measured at zone B2 and the height of the measurement will be discussed at 2 meters above the ground only due to average human height.

3.1 Parameter and material of The Design in Simulation for 3D Design

This design will use multiple different parameters and materials. The input current and output current for this design is 2500A. The diameter of the wire is 0.02862m while the diameter of the busbar is 0.2m. The maximum height of the conductor is 8m while the minimum height of the conductor is 6m. the material for this design is aluminum for the conductor, ceramic for the insulator and steel for the post. For the grounding, the material will use multiple types of material according to the case studies of measurement of magnetic field strength with different types of grounding material. The material is soil, copper and steel.

3.2 Case Study - Magnetic field strength with different types of grounding material

The observation in this study is to measure the magnetic field under a substation with three different types of grounding material which are soil, steel and copper. The magnetic field readings will be compared between three different types of grounding material. Each reading will be designed separately to make the result accurate. This study will prove whether the material of grounding will affect the value of a magnetic field or not. The result of this design may help engineers or contractors to create efficient substations with a low value of a magnetic field in the future. Figure 6 shows the example result for the magnetic field contour color plot of a high voltage substation.

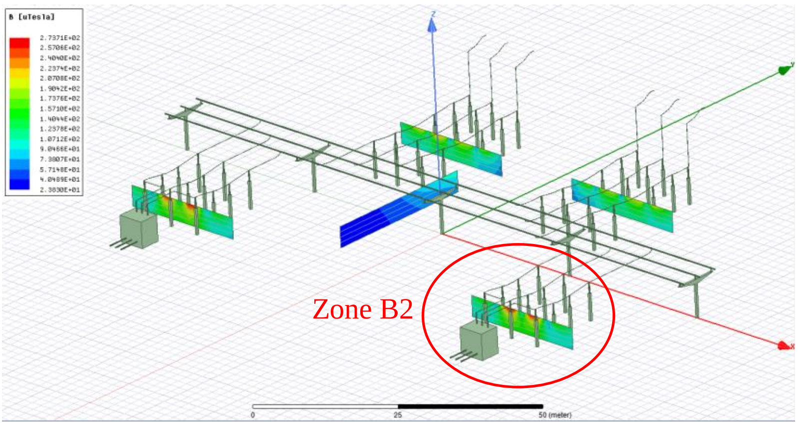

Figure 6: Magnetic field plot under high voltage substation.

3.2.1 Situation 1 – Soil Grounding Material

The observation in this situation is to measure the magnetic field under the substation with soil grounding. This design has been made based on an actual high voltage substation with 2500A current injection. The measurement value of the magnetic field will be measured at zone B2. Figure 7 shows the graph of the magnetic field produced under a high voltage substation by using soil material as grounding. The measurement was taken at a height of 1 meter, 2 meters, 3 meters and 4 meters above ground, and the length of measurement is 24 meters. There is one result of simulation which is at zone B2 that has a different value of magnetic field radiated under.

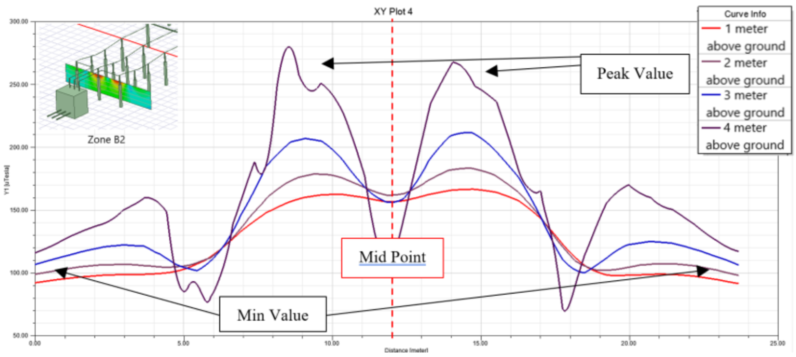

Figure 7: Magnetic field plot under high voltage substation at zone B2.

Table 2 shows the data result of the magnetic field for soil grounding material measured 2 meters above the ground. The height of the measurement will be discussed is 2 meters above the ground only due to the average human height. Zone B2 shows there were two peak values of the graph due to the conductor that has a current flow. The highest value of the magnetic field is 182.45µT shows that the conductor is near that can trigger the value of the magnetic field while the minimum value of the magnetic field is 98.56µT at the end left of the graph because the conductor is far from the measurement. The value of the magnetic field in the middle of the measurement is 161.12µT.

Table 2: The value of magnetic field measured 2 meters above the ground for soil grounding material.

Part	Magnetic Field at Zone B2 (µT)
Highest magnetic field	182.45
Lowest magnetic field	98.56
Magnetic field in mid	161.12
Magnetic field at left end	98.56
Magnetic field at right end	99.45

3.2.2 Situation 2 – Steel Grounding Material

The observation in this situation is to measure the magnetic field under the substation with steel grounding. This design has been made based on an actual high voltage substation with 2500A current injection. The measurement value of the magnetic field will be measured at zone B2. Figure 8 shows the graph of the magnetic field that is produced under a high voltage substation by using steel material as grounding. The measurement was taken at a height of 1 meter, meterser, 3 meters and 4 meters above the ground, and the length of measurement is 24 meters. There is one result of simulation which is at zone B2 that has a different value of magnetic field radiated under.

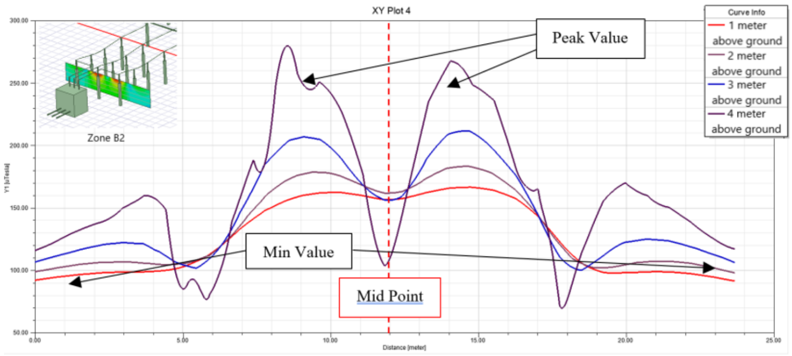

Figure 8: Magnetic field plot under high voltage substation at zone B2.

Table 3 shows the data result of the magnetic field for steel grounding material measured 2 meters above the ground. The height of the measurement will be discussed is 2 meters above the ground only due to the average human height. Zone B2 shows there were two peak values of the graph due to the conductor that has a current flow. The highest value of the magnetic field is 105.99µT shows that the conductor is near that can trigger the value of the magnetic field while the minimum value of the magnetic field is 39.73µT at the end right of the graph because the conductor is far from the measurement. The value of the magnetic field at the middle of the measurement is 90.54µT.

Table 3: The value of magnetic field measured 2 meters above the ground for steel grounding material.

Part	Magnetic Field at Zone B2 (µT)
Highest magnetic field	105.99
Lowest magnetic field	39.73
Magnetic field in mid	90.54
Magnetic field at left end	61.72
Magnetic field at right end	39.73

3.2.3 Situation 3 – Copper Grounding Material

The observation in this situation is to measure the magnetic field under the substation with copper grounding. This design has been made based on an actual high voltage substation with 2500A current injection. The measurement value of the magnetic field will be measured at zone B2. Figure 9 shows the graph of the magnetic field that is produced under a high voltage substation by using copper material as grounding. The measurement was taken at a height of 1 meter, 2 meters, 3 meters and 4 meters above the ground, and the length of measurement is 24 meters. There is one result of simulation which is at zone B2 that has a different value of magnetic field radiated under.

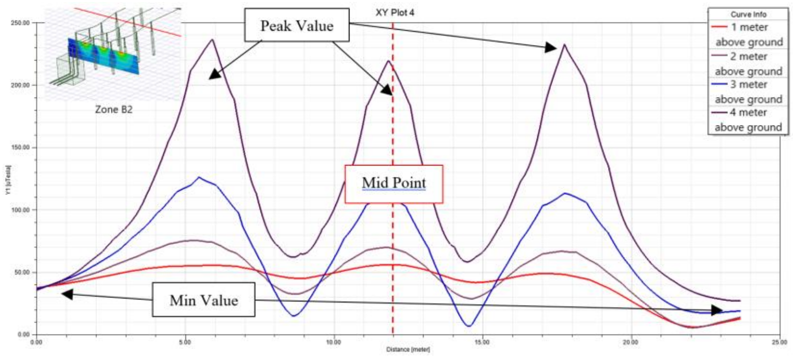

Figure 9: Magnetic field plot under high voltage substation at zone B2.

Table 4 shows the data result of the magnetic field for copper grounding material measured 2 meters above the ground. The height of the measurement will be discussed is 2 meters above the ground only due to the average human height. Zone B2 shows there were two peak values of the graph due to the conductor that has a current flow. The highest value of the magnetic field is 75.71µT shows that the conductor is near that can trigger the value of the magnetic field while the minimum value of the magnetic field is 13.91µT at the end right of the graph because the conductor is far from the measurement. The value of the magnetic field in the middle of the measurement is 69.81µT.

Table 4: The value of magnetic field measured 2 meters above the ground for copper grounding material.

Part	Magnetic Field at Zone B2 (µT)
Highest magnetic field	75.71
Lowest magnetic field	13.91
Magnetic field at mid	69.81
Magnetic field at left end	38.16
Magnetic field at right end	13.91

3.3 Discussions

Table 5 shows the comparison for each situation with a maximum value of the magnetic field. From the result, it can say that soil ground material has the highest value of magnetic field compared to steel and copper. For example, in zone B2 it shows the value of the magnetic field for soil is 182.45µT while copper shows the least value of the magnetic field which is 75.71µT.

Table 5: Comparison of each situation with a maximum value of the magnetic field.

Situation	Maximum Value of Magnetic Field at Zone B2 (µT)
Situation 1 - Soil	182.45
Situation 2 - Steel	105.99
Situation 3 - Copper	75.71

The result of the magnetic field measured for different types of grounding material which is soil, steel and copper shows that the value of the magnetic field was different. The highest value of the magnetic field is for soil grounding material, while the lowest value of the magnetic field is for copper grounding material. The material of grounding will affect the value of the magnetic field due to the conductivity of the material. For example, copper has a low magnetic field because its conductivity is high compared to the soil which has low conductivity. We can say that the material of grounding is very important for the substation to ensure the value of the magnetic field is in low condition. The important of a good grounding system is to offer a low impedance path to the earth for the currents coming from ground faults, lightning rods, surge arresters, gaps, and related devices. It also provides the neutrals of generators, transformers, capacitors, and reactors with a connection to the earth.

4. Conclusion

For this project, the design of the FEA simulation model of the typical 275kV main-intake substation was successfully designed by using Finite Element Analysis (FEA) in ANSYS Maxwell software. The design was according to the actual design of high voltage substations for example at Pura Kencana, Batu Pahat's high voltage substation and Parit Raja's high voltage substation. According to the actual design of a high voltage substation, there are a few parameters that need to be applied for example the size of the conductor, height of the conductor, value of current and material. The value current that has been used is 2500A injected into the conductor. The value of the current will produce a magnetic field. Next, the diameter of the conductor for the wire is 0.02862 meters while for the busbar is 0.2 meters. The diameter of the conductor is according to the previous research. Finally, the height of the high voltage substation ranges between 8 and 6 meters.

Besides that, the 3D design of the substation successfully produced a propagation of magnetic field wave strength. The result of the simulation shows the contour color of the magnetic field and produced a graph for the value of the magnetic field. From contour color, blue color shows the lowest value of the magnetic field while red shows the highest value of the magnetic field. All measurements were taken under a substation in five different areas, with heights of one meter, two meters, three meters, and four meters. This study shows that the objective of this project was successfully obtained. It has been demonstrated that the magnetic field can be lowered by changing the distance between the conductors. Finally, after completing this project, a better understanding of high voltage 275kV main intake substations will be obtained.

Acknowledgement

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