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Analysis of Electric Potential Distribution in a System without Charge Using Laplace's Equation Approach; Literature Review

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Abstract- Electricity is a fundamental thing in everyday life. When talking about electricity, it cannot be separated from electric charge, electric field and electric potential. In this meta-analysis, the researcher discusses the analysis of the distribution of Electric Potential in a System without charge using the Laplace equation. This topic is related to the electrostatic system used in a static state. This Laplace equation can be solved by two methods, namely the analytical method and the numerical method. The analytical method includesCoulomb's Law, Newtonian Mechanics, basic concepts of electric potential. Which generally use the method of separate variables. However, this method is less effective for complex geometry due to the limitations of boundary conditions.

While numerical methods allow solutions for complex geometries. Numerical simulation is an approach that gives researchers the possibility to analyze the behavior of some phenomena that, due to their complexity, are beyond the scope of classical calculus. The principles of numerical methods include the Finite Element Method (FEM), the Finite Difference Method (FDM) and the Boundary Element Method (BEM). In this meta-analysis, researchers present various research results from previous researchers related to solving the Laplace equation using computer-based numerical methods and analytical methods that are used as comparative materials. All research results from the collected journals provide consistent and identical results, both with the FEM, FDM and even BEM methods.

This meta-analysis was conducted using the Systematic Literature Review approach with the PRISMA technique, where eight selected articles from various journals became the basis for the analysis. The results of the analysis showed that the numerical method provides more practical and accurate solutions than the analytical method, especially in complex geometries. This finding provides an important contribution to the development of electric potential distribution simulations and can be a guideline for researchers in developing further solutions using modern technology. Thus, this meta-analysis can be a basis for the application of numerical methods in the fields of physics and engineering that require in-depth analysis of electric potential distributions.

Keywords: *electric potential distribution, Lalplace equation, numerical methods, analytical methods*

1 Introduction

Physics is an essential science because its concepts are used to explain existing phenomena.[1]. Phenomena related to physics include electricity. For all living things, especially humans, electricity is the most important thing for everyday life. Bright lights, moving fans, even complex electronics that drive modern technology are the benefits of electricity that we feel. But keep in mind that electricity allows many

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widely known physical phenomena to occur, such as lightning, electric fields, and electric currents. So, what exactly is the definition of electricity? Electricity is a property of matter that arises from the presence of an electric charge. Electricity can also be interpreted as the condition of certain subatomic particles, such as electrons and protons, which cause attraction and repulsion of forces between them[2].

In electricity, there is a term known as Electric Potential. This electric potential is of course caused by the presence of a charge that creates an electric field.[3]. In simple terms, electric potential is a concept that describes the ability of an electric field to do work on an electric charge. The distribution of electric potential is an important phenomenon in the study of static electric fields.

Electric potential is defined as the potential energy per unit positive charge. Electric potential can be written as the following equation:

$$V = \frac{U}{Q} \qquad (1.1)[4]$$

In a system without charge ($\varrho = 0$), the distribution of electric potential follows the Lap equation.lace, namely:

$$\nabla^2 V = 0 \qquad (1.2)[3]$$

Laplace's equation is one of the fundamental equations in physics and mathematics used to analyze the distribution of electric potential in an uncharged region. Various literatures show that Laplace's equation is very important in the simulation of electronic devices such as capacitors, transistors, and electrodes, the distribution of electric potential needs to be analyzed to ensure optimal performance and prevent system failure. In geophysics, Laplace's equation is used to model the distribution of potential below the earth's surface, for example in soil resistivity analysis or mineral resource exploration. In addition, Laplace's equation is also relevant in the design of high-voltage insulation systems, where the distribution of electric fields around conductors needs to be calculated accurately to prevent damage or unwanted electrical discharges.

In some real cases, Laplace's equation is difficult to solve using analytical methods. The principles of this analytical method include Coulomb's Law, MechaNewtonian physics, the basic concept of electric potential. Which generally uses the method of separate variables. This analytical method produces exact solutions for simple geometries such as spheres, cylinders or cubes. However, this method is less effective for complex geometries due to the limitations of boundary conditions.

For the above problem, a numerical method is used which allows solutions for complex geometry.[5]. Numerical simulation is an approach that gives researchers the possibility to analyze the behavior of some phenomena that, due to their complexity, are beyond the scope of classical calculus.[6]. The principles of numerical methods include the Finite Element Method (FEM), Finite Difference Method (FDM) and Boundary Element Method (BEM).

The Finite Element Method (FEM) was first introduced in 1950 through the rapid development of technology, especially computer technology. This increase in computer capabilitiesleading to greater possibilities for performing analyses of larger and more complex engineering problems.[7]. Based on several journals reviewed by researchers, it shows that the FEM method is a method with high accuracy and the most flexible solution.

On aIn the 19th century, the Boundary Element Method (BEM) began to develop. This method was first worked on by G. Green to solve physics problems mathematically, which we later know as the Green's function. Since the discovery of the Green's function, many researchers have developed BEM[8]. The advantage of the BEM method is its ability to handle problems for open domains (unlimited). And in 1928, Courant-Friedrichs-Lewy introduced the method of solving the Laplace equation through the Finite Difference Method (FDM) approach.[9]. Where FDM is simpler to implement than FEM, but has limitations in domains with complex shapes or varying material parameters.

Based on what the researcher read and summarized from various journals regarding the Laplace equation in the analysis of electric potential distribution, the researcher will discuss these methods based on the journals that have been read by the researcher. And poured into the form of a meta-analysis. It is hoped that this meta-analysis can contribute to helping further researchers to conduct research.

2 Research Methodology

This study uses a qualitative approach with the Systematic Literature Review method with the PRISMA (Preferred Reporting Items for Systematic Review-Meta Analysis) technique.[10][11].A systematic literature review identifies, evaluates, and interprets research sources by formulating a research problem or topic to be reviewed using literature studies.[12]. The research process is carried out to identify and analyze relevant research.[13]the results are used to answer research questions[11]and provide guidelines for further research[14]. This technique consists of four stages, namely identification, screening, eligibility, and inclusion. The initial stage is identification, searching for articles using the Mendeley and Google Scholar applications based on the keywords "Electric Potential Distribution" and "Laplace equation approach" with article limitations from 2015-2024.

In the initial search with Mendeley and Google Scholar, 365 articles were obtained that matched the keywords, and a filtering stage was carried out. At this stage, all articles were filtered with criteria according to the year limits, namely 2015-2024, as well as the suitability of the title, abstract, and certain topics. The third stage is checking the feasibility of the article content according to the research question "How to solve the distribution of electric potential in the Laplace equation?" and summarized in a data mapping table to be more effective at the analysis stage. In checking the feasibility, it was obtained articles that meet the research criteria so that they can be continued to the inclusion stage. Activities carried out at the inclusion stage include review, analysis of article content, and summary (synthesis) of the review results to describe findings related to the distribution of electric potential through the Laplace equation through analytical and numerical methods by article.

3 Results and Discussion

As research data, selected articles based on criteria set by the researcher. These articles are arranged in a table, as follows:

Table 1: Related articles

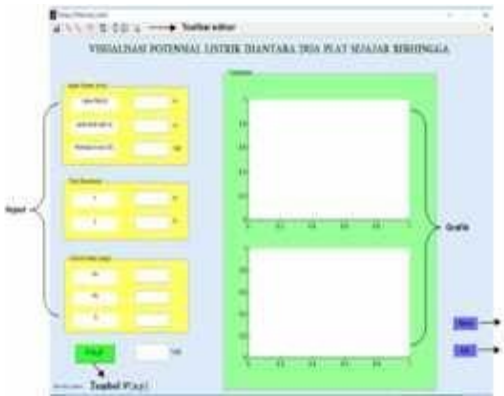
Year	Writer	Title	Journal
2018	Surbakti, Antonius[4]	Visualisasi Potensial Listrik Di Antara Dua Plat Sejajar Berhingga Dengan Program Komputer Berbasis Matlab	Jurnal Fisika FMIPA UNRI
2023	Pratiwi, Nabiilah Jahroo Syafwan, Mahdhivan Lestari, Riri[15]	Penurunan Metode Elemen Batas Dan Aplikasinya Pada Penyelesaian Persamaan Laplace	Jurnal UNAND
2024	Wahid, Nur Samsudin[16]	Simulasi Distribusi Muatan Diskrit Pada Kawat Konduktor Persegi	Jurnal Universitas Blitar
2018	Asih, Tri Sri Noor Waluya, St Budi Supriyono[17]	Perbandingan Finite Difference Method dan Finite Element Method dalam Mencari Solusi Persamaan Diferensial Parsial	Jurnal UNNES
2021	Ashadi Amir, Robby Ikhsan & Waluyo[18]	Model Distribusi Potensial Listrik dan Medan Listrik Pada Isolator porselen Tegangan Menengah 20 kV Berbasis FEM	Edu Elektrika Jurnal
2021	Safarul Azmi[19]	Penggunaan FEM dalam Memetakan Medan Listrik Pada	Jurnal Teknik

		Permukaan Isolator Jenis PIN dan Post 20 kV dan Udara Di Sekitarnya	UNDIP
2020	J, Sijabat. M, Rajagukguk[20]	Simulasi Distribusi Potensial Dan Medan Listrik Pada Kabel Bawah Tanah Menggunakan Femm	Jurnal Teknik Elektro Tanjungpura

In Table 1, it can be seen that the solution of the Laplace Equation is solved using numerical methods, some using FEM, FDM and BEM. And based on the journals in Table 1, the researcher will discuss the research results of previous researchers in the following table 2.

Table 2. Discussion of Research Results Based on Journals

Writer	Research result
Surbakti, Antonius[4]	In this study, researchers solve the Laplace equation in 2-D Kertesian coordinates by visualizing the electric potential between two parallel plates of finite size. But this solution cannot be solved on large plates. This visualization is made using MATLAB software, consisting of a menu program and a main program. And the results of the electric potential are in the form of mesh and contour graphs.



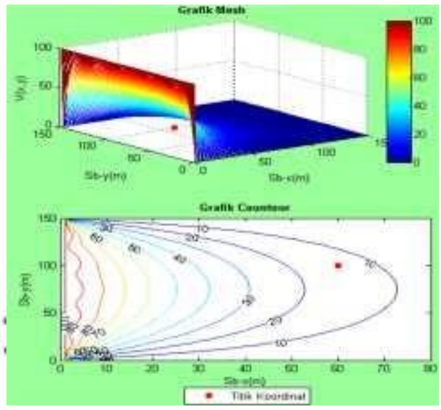


Figure 1. Menu display Figure 2. Main display

Between the menu program and the main program work continuously. WhereThe menu program inputs the parameters required for the calculation, while the main program performs the calculation and visualization of the electric potential. The visualization of the electric potential is displayed through mesh and contour graphs.

Writer	Research result
Pratiwi, Nabiilah Jahroo Syafwan, Mahdhivan Lestari, Riri[15]	In this study, researchers used the Boundary Element Method (BEM) with the Matlab application. Where this journal discusses the Gauss Green equation and the Laplace equation with the value of the Dirichlet boundary condition (when u is known) expressed as 0, while the Neumann boundary condition (when q is known) is expressed as 1.

Table 3: Comparison of numerical and exact values

x	y	numeric value	exact value	error
0.25	0.25	0.0540629061902463	0.0531870283400740	0.00087588
0.5	0.25	0.142713936563912	0.140904042339132	0.0018
0.75	0.25	0.320264345551885	0.320098522049454	0.00016582
0.25	0.5	0.000520417	0.000460576	0.000059841
0.5	0.5	0.00294903	0.001220167	0.0017
0.75	0.5	0.001452831	0.002771913	0.0013
0.25	0.75	-0.0540629061902463	-0.0531870283400740	0.00087588
0.5	0.75	-0.142713936563912	-0.140904042339132	0.0018

0.75	0.75	-0.309852450316272	-0.320098522049454	0.0102

	From the data in table 3. We can see that the difference between the numerical value and the exact value. The more line segments are formed, the closer the numerical solution will be to the exact solution.
Wahid, Nur Samsudin[16]	This study was conducted to optimize the design of electrical potential in electronic devices using square wire, with python-language computer simulation using google colab and FEM method. The results obtained from this study are The charge distribution pattern found shows that the corners of the square wire are areas with high charge concentration, which can affect the electrical and magnetic properties around the wire. So it is concluded that the square wire is significantly influenced by the geometry of the wire.
Thank you, Tri Sri Noor Waluya, St. Budi Supriyono[17]	From the researcher's research, FDM and FEM are numerical methods that can both be used to find solutions to partial differential equations, which are difficult to determine analytical solutions. However, the basis of the difference between FDM and FEM is that in the discretization process, FDM divides the variable domain into finite squares, while FEM divides the domain not necessarily into square shapes..
Ashadi Amir, Robby Ikhsan & Waluyo[18]	The method used in this study is the FEM method with a discretization process. And the analysis of its solution is divided into 2 parts, namely structural analysis and non-structural analysis. The basic equations used to calculate the potential and electric field are Maxwell's equations and Laplace's equations. So the results of this study are that the pattern of electric potential distribution always follows the contour of the insulator surface itself, so that the size of an insulator's fins will affect the distribution of voltage and electric fields on the surface and ends of the insulator.
Safarul Azmi[19]	From this study, the analysis used is a non-structural FEM study analysis, namely the distribution of electric potential and electric fields. This study was conducted to map the electric field. From the results obtained, the electric pole from the post type insulator has a stronger electric field than the Pin type electric pole. And from this study, the results of the electric potential from the Matlab simulation with Ansys produce an identical electric field.
J, Sijabat. M, Rajagukguk[20]	This study uses the finite element method with a discretization process approach, which is computed using the Finite Element Method Magnetics (FEMM) program. The results of this study explain the value of the potential distribution and electric field in the cable insulation material layer from the conductor core to the cable sheath layer.

In table 2, researchers can see that the use of numerical methods is widely used in solving the Laplace equation. The results obtained using numerical methods are not only more accurate but can also solve the Laplace equation easily. The Laplace equation is generally very useful in determining the electric potential in a conductor, but sometimes its mathematical differential form is difficult to approach, so that each value sometimes gives a large error. To avoid these problems, the type of Laplace differential equation can be approached by numerical calculations, so that it is easier to calculate[21].

4 Conclusion

This meta-analysis shows that numerical methods for solving Laplace equation such as FEM, FDM, and BEM are more effective than analytical methods in solving Laplace equation for complex geometries. FEM excels in flexibility and accuracy, while FDM is simpler but has limitations in certain geometries. BEM offers effective solutions for open domains. All numerical methods provide accurate and consistent results, making them suitable for a wide range of applications, including electronic device simulation, geophysical exploration, and high-voltage insulation system design. This study emphasizes the importance of numerical approaches in facilitating the analysis of electric potential distribution and encourages further research to develop more efficient methods that are integrated with modern technologies.

Reference

[1] et al. T. validity of S. basic physics teaching material for biology student. T. 8TH A. I. S. O. T. I. S. A. S. E. (AISTSSE) 2021. 2022 N. 29;2659. Wulandari D, Roza D, Pulungan ASS, Rangkuti MA, Barta WW, Tanjung YI, "No Title".

[2] A. Soraya, "Kelistrikmagnetan," *Sekol. Tinggi Agama Islam Negeri Mandailing*, pp. 1–23, 2021.

[3] H. Abdullah, P. Palloan, and A. A. Arsyad, *Elektrostatis dan Rangkaian Listrik (Hasil Pengembangan Bahan Ajar Fisika Berbasis Metakognisi).* 2023. [Online]. Available: http://eprints.unm.ac.id/32234/%0Ahttp://eprints.unm.ac.id/32234/1/File_Buku_Helmi_ISBN.pdf

[4] A. Surbakti and D. Jurusan Fisika Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Riau Pekanbaru Kampus Bina Widya Jl Muchtar Luthfi Panam Pekanbaru, "Visualisasi Potensial Listrik Di Antara Dua Plat Sejajar Berhingga Dengan Program Komputer Berbasis Matlab Mahasiswa Program Studi-S1 Fisika," vol. 15, no. 01, pp. 13–16, 2018, [Online]. Available: http://ejournal.unri.ac.id./index.php/JKFI

[5] Mahdhivan Syafwan, "Turunan Numerik," *J. Politek. Elektron.*, p. 9, 2018.

[6] S. A. (2015). C. des isolateurspollués. A. Bessedik, "No Title".

[7] A. J. (2010). A. M. E. H. (MEH) pada S. R. B. A. P. S. U. S. M. Prasetyo, "No Title".

[8] O. Katsikadelis, J.T. 2002. Boundary Element : Theory and Applications. Elsevier Science, "No Title".

[9] V. 2001. F. F. D. to F. E. Thomée and 1-54. a short History of Numerical Analysis of Partial Differential Equations. Journal of Computational and Applied Mathematics 128, "No Title".

[10] P. 5900 [Internet]. 2020 J. 22 [cited 2024 N. 1];12(15):5900. A. from: https://www. mdpi. com/207.-1050/12/15/5900/htm Abelha M, Fernandes S, Mesquita D, Seabra F, Ferreira-Oliveira AT. Graduate Employability and Competence Development in Higher Education—A Systematic Literature Review Using PRISMA. Sustainability 2020, Vol 12, "No Title".

[11] S. P. I. P.-P. recommendations for prospective authors. S. R. [Internet]. 2016 J. 28 [cited 2024 N. 1];5(1). A. from: https://pubmed. ncbi. nlm. nih. gov/26822481. Moher D, Stewart L, "No Title".

[12] R. M. A. systematic literature review on serious games evaluation: A. application to software project management. C. E. 2015 S. 1;87:396–422. Calderón A, "No Title".

[13] et al. T. P. statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. B. [Internet]. 2009 [cited 2024 N. 1];339. A. from: https://pubmed. ncbi. nlm. nih. gov/19. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, "No Title".

[14] Snyder H. Literature review as a research methodology: An overview and guidelines. J Bus Res. 2019 Nov 1;104:333–9., "No Title".

[15] N. J. PRATIWI, M. Syafwan, and R. Lestari, "Penurunan Metode Elemen Batas Dan Aplikasinya Pada Penyelesaian Persamaan Laplace," *J. Mat. UNAND*, vol. 12, no. 1, p. 1, 2023, doi: 10.25077/jmua.12.1.1-14.2022.

[16] R. Adolph, "済無No Title No Title No Title," vol. 14, no. 1, pp. 1–23, 2016.

[17] T. S. N. Asih, S. B. Waluya, and Supriyono, "Perbandingan Finite Difference Method dan Finite Element Method dalam Mencari Solusi Persamaan Diferensial Parsial," *Prism. 1*, vol. 1, pp. 885–888, 2018, [Online]. Available: https://journal.unnes.ac.id/sju/index.php/prisma/

[18] A. A. Nurhakim, R. Ikhsan, and A. Rasyid, "Model Distribusi Potensial Listrik dan Medan Listrik pada Isolator Porselen Tegangan Menengah 20 kV Berbasis FEM," *Edu Elektr. J.*, vol. 10, no. 2, pp. 42–46, 2021, [Online]. Available: https://journal.unnes.ac.id

[19] S. Azmi, "Enggunaan Fem (Finite Element Method) Dalam Memetakan Medan Listrik Pada Permukaan Isolator Jenis Pin Dan Post 20 Kv Dan Udara Disekitarnya," *Handb. Fluid Dyn. Second Ed.*, vol. 609, pp. 36.1-36.63, 2016.

[20] J. P. Sijabat and M. Rajagukguk, "Simulasi Distribusi Potensial Dan Medan Listrik Pada Kabel Bawah Tanah Menggunakan Femm," *J. Tek. Elektro Univ. Tanjungpura*, vol. 1, no. 1, 2020, [Online]. Available: https://jurnal.untan.ac.id

[21] R. Affandi and I. Pendahuluan, "Solusi Persamaan Laplace Dua Dimensi Untuk Metode Numerik," no. 1, pp. 1–4, 2017.