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## **Optimization of Electric Power Flow Analysis Using the Gauss-Seidel Method in a Numerical Approach**

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### **ABSTRACT**

The availability of electrical energy is a fundamental requirement in modern society, supporting both daily life and industrial activities. To ensure efficient and reliable energy distribution, power flow analysis is critical. This analysis is grounded in Kirchhoff's laws, which serve as the foundation for understanding electrical circuits. Kirchhoff's Current Law (KCL) states that "the sum of electric currents entering and leaving a branch point is zero," while Kirchhoff's Voltage Law (KVL) asserts that "the sum of electromotive forces and potential drops in a closed circuit must equal zero." These laws guide the formulation and solution of equations describing power flow in electrical networks. To manage the complexity of these systems, the Gauss-Seidel method has emerged as an effective iterative technique for solving large systems of linear equations. In the context of power flow analysis, it calculates busbar voltages, active and reactive power flows, and other parameters, refining the results through successive approximations until convergence is achieved. Python is widely recognized as an ideal platform for implementing the Gauss-Seidel method due to its syntactic simplicity, flexibility, and extensive computational libraries. By leveraging Python, engineers can streamline computations and enhance the accuracy and reliability of power flow analyses. This combination of mathematical rigor and computational power not only ensures precise results but also facilitates the efficient management of complex electrical systems in modern power grids.

**Keywords:** Electrical, Kirchhoff, Gauss-Seidel, Python, Power flow Analysis

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### **INTRODUCTION**

The availability of electrical energy has become a fundamental requirement in modern life, both for domestic and industrial purposes. power flow analysis plays a vital role in ensuring efficient and reliable distribution of electrical energy busbars. Electrical circuits, as one of the applications in the field of physics, require a complex mathematical approach in solving, in practice, solving power flow equations results in a very complex system of equations. (Patel, 2006, Cekdin, 2007)

This drives the need for more effective and accurate computational methods, so the Gauss-Seidel method comes as a promising solution in solving complex linear equation system problems in power flow analysis, Kirchhoff's law is also used as a fundamental basis, then to get more accurate calculation results, Python becomes an ideal choice because of its syntactic simplicity, rich numerical library, and computational efficiency. (Saadat, 2010) Based on this, the purpose of the research on the application of the Gauss-Seidel method in power flow analysis is to analyse the efficiency of the Gauss-Seidel method in solving electrical power flow problems in electrical systems, and optimise the convergence of the Gauss-Seidel method to improve the speed and accuracy of power flow calculations. (Anderson & Fouad, 2002)

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## LITERATURE REVIEW

The theory underlying this research includes Kirchhoff's law and the Gauss-Seidel iteration method. (Sadiku, 2000) Kirchhoff's laws are used to analyse current and voltage in closed electrical circuits. Specifically, Kirchhoff's Law II or Kirchhoff's Voltage Law states that the sum of voltages in a closed path is equal to zero. This principle is applied to form a system of linear equations that represent the relationship between current, voltage, and resistance in a circuit. The Gauss-Seidel iteration method (Purcell & Varberg, 1987) is a numerical approach to solving complex systems of linear equations. The method updates variable values sequentially, using the most recent value in the same iteration. The iteration process continues until the change in value between iterations is below a predefined error tolerance. The advantages of this method include fast convergence, especially in systems where the coefficients are diagonally dominant.

## METHOD

This research method consists of several main steps:

### 1. System of Linear Equations

A linear equation is an equation that contains a variable of degree one. (Kreyszig, 1988) This equation is also called a first-degree equation, There are forms of linear equations that have one variable and more than one variable, for example :

#### - Linear Equation of One Variable

A linear equation is an open sentence whose variables have one degree by using the hyphen 'equal to' (=). A one-variable linear equation is an equation that has only one variable, for example the variable  $x$ . (Erwin, 2007)

#### - Two-Variable Linear Equations

A system of two-variable linear equations is an equation consisting of two linear equations and two variables that has only one solution point. A two-variable linear equation has the following form. General form:

$$\begin{aligned}a_1x + b_1y &= c_1 \\a_2x + b_2y &= c_2\end{aligned}$$

To find the solution set of a system of linear equations of two variables there are several methods.

#### - Three-Variable Linear Equations

A system of three-variable linear equations is a system of equations consisting of three variables (e.g.  $x$ ,  $y$ , and  $z$ ). To solve three-variable linear equations, we use the combined method of elimination and substitution.

### 2. Kirchhoff's Law I and Kirchhoff's Law II

#### - Kirchhoff's Law I :

Kirchhoff's law 1 says : 'The amount of electric current entering the branch point will be equal to the amount of current leaving the point.' (Aslimeri, 2008)

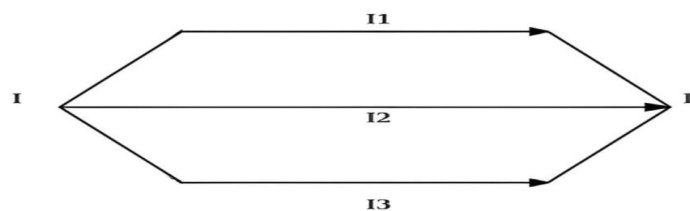


Figure 1 : Kirchhoff's Law I

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In the figure, the incoming current ( $I$ ) is equal to the outgoing current ( $I_1$ ,  $I_2$ ,  $I_3$ , and  $I'$ ). So in short, Kirchoff's law addresses the current on a branch in a closed circuit. The formula for Kirchoff's Law I is

$$\sum I_{masuk} = \sum I_{keluar}$$

Description :

$\sum I_{masuk}$  : total inflow (Ampere)

$\sum I_{keluar}$  : total outflow (Ampere)

- **Kirchoff's Law II :**

Kirchoff's Law II, also called the Closed Circuit Law, contains that the sum of the voltages on each of the constituent components that form a closed circuit is zero. The sum of the voltages or potential differences in a closed circuit is equal to zero. Or it can be written as follows:

$$\sum V = \sum I.R = 0$$

Description :

$\sum V$  : sum of voltages

$\sum I.R$  : the sum of the multiplication of the strength of the electric current and the resistance

### 3. Gauss-Seidel Method

The Gauss-Seidel method is a method of solving simultaneous equations through an iteration process so that the true value is obtained by using the initial value in the next process. The Gauss-Seidel method was introduced by Johann Carl Friedrich Gauss (1777-1855) and Philipp Ludwig von Seidel (1821-1896). The System of Linear Equations with the Gauss Seidel Method uses previously known values. In this method, each calculated variable is immediately updated and used in the calculation of the next variable in the same iteration. (Efrizal, 2010)

In solving a system of linear equations, the iteration process is stopped when the difference between the value of  $x_i$  ( $i = 1$  s/d  $n$ ) and the value of  $x_i$  in the previous iteration is less than the specified error tolerance value, the value of  $x_i$  in the previous iteration is less than the specified error tolerance value. With the same system as above,  $x_1$  and  $x_2$  can be calculated by:

$$x_1^{k+1} = \frac{b_1 - a_{12}x_2^k}{a_{11}}$$

$$x_2^{k+1} = \frac{b_2 - a_{21}x_1^k}{a_{22}}$$

Description :

$x_1^{k+1}$  and  $x_2^{k+1}$  = The new values of variables  $x_1$  and  $x_2$  at iteration  $k+1$ ;

$x_2^k$  = The value of  $x_2$  from the previous iteration ( $k$ ), used when calculating  $x_1^{k+1}$ ;

$x_1^{k+1}$  = The new value of  $x_1$  is directly used to calculate  $x_2^{k+1}$ .

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## RESULT

This research analyzed a nine-loop electrical circuit with a single 20-volt voltage source, simulating a household electrical system. Each loop was designed to represent a specific area within a household, including living rooms, bedrooms, and utility spaces. Resistance values for each loop were assigned based on the circuit's schematic. Kirchhoff's Laws I and II were used to derive a system of nine linear equations representing the current flow in each loop. (Khairina & Harahap, 2018)

The Gauss-Seidel iterative method was employed to solve these equations, starting with initial current values of zero. Python was used to implement the algorithm due to its efficiency, flexibility, and powerful numerical libraries. The iteration process continued until the difference between consecutive iterations met the convergence criteria, set at a tolerance level of  $1 \times 10^{-6}$ . (Education and Science, 2016) The process converged successfully in 46 iterations, yielding the following final current values:

Table 1: Results

| Loop           | Room                           | Current (A) |
|----------------|--------------------------------|-------------|
| I <sub>1</sub> | Living room                    | 0.5852      |
| I <sub>2</sub> | First child's room             | 0.3856      |
| I <sub>3</sub> | Second child's room            | 0.4540      |
| I <sub>4</sub> | Third child's room             | 0.4629      |
| I <sub>5</sub> | Front and back connecting room | 0.4832      |
| I <sub>6</sub> | Family room                    | 0.2899      |
| I <sub>7</sub> | Master bedroom                 | 0.0877      |
| I <sub>8</sub> | Rear connecting room           | 0.1438      |
| I <sub>9</sub> | Kitchen and bathroom           | 0.0554      |

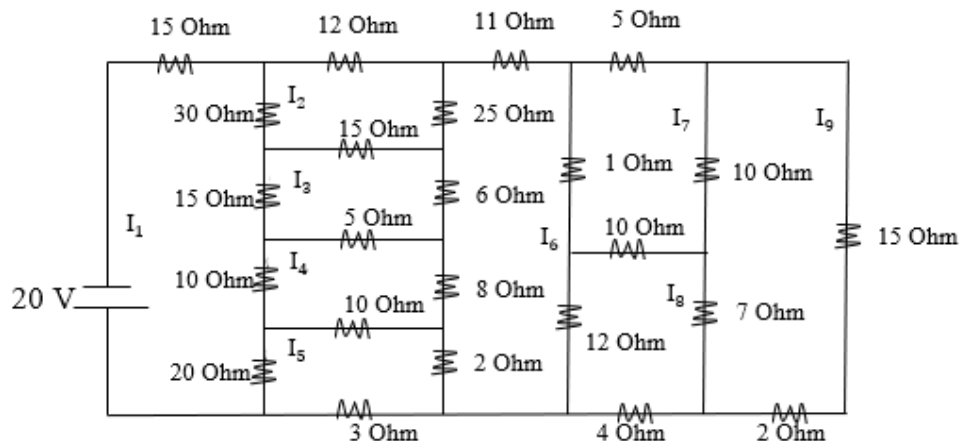


Figure 2 : Electrical circuit problems

## DISCUSSIONS

The analysis underscores the effectiveness of the Gauss-Seidel method in solving complex systems of linear equations in power flow analysis. The method's iterative approach ensured precise convergence, with the process halting at 46 iterations when the tolerance threshold of  $1 \times 10^{-6}$  was achieved. Python's role as a computational tool was pivotal, offering streamlined implementation, high accuracy, and rapid execution.

### Practical Implications

Table 2.3 reveals the distribution of current strengths across different loops. For example, the living room (I<sub>1</sub>: 0.5852 A) and front-back connecting rooms (I<sub>5</sub>: 0.4832 A) exhibited higher current demands, signaling zones of significant power consumption. In contrast, the kitchen and bathroom (I<sub>9</sub>: 0.0554 A) had

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lower current strengths, potentially requiring voltage adjustments to ensure adequate power supply. Such findings enable electrical designers to optimize circuit configurations, reduce energy waste, and minimize risks like dim lighting or overloaded circuits. (Fast-Decoupled, 2015)

### **Methodological Insights**

The Gauss-Seidel method's success is rooted in its sequential updating mechanism, which uses newly calculated values immediately within the same iteration. This feature accelerates convergence, particularly for systems with diagonally dominant matrices. The incorporation of Kirchhoff's Laws further enhanced the model's accuracy, ensuring the equations adhered to real-world electrical principles. (Gama et.al, 2012)

The adaptability of the method and Python's computational capabilities make this approach suitable for a wide array of applications. From residential power systems to larger industrial grids, the Gauss-Seidel method offers a robust framework for analyzing and optimizing electrical systems. (Golub & Van Loan, 1996)

### **Broader Implications**

Beyond household circuits, the findings highlight the potential of iterative numerical methods in promoting energy efficiency and sustainability. Identifying areas of inefficient power distribution helps reduce energy wastage, aligning with the global push toward greener energy practices. The results also support advancements in smart grid systems, where real-time adjustments are critical for maintaining balance between supply and demand.

### **Limitations and Future Work**

While the study achieved accurate results, certain simplifications, such as constant resistance values and the absence of external factors like temperature fluctuations, limit the model's scope. Future research could incorporate dynamic elements, explore alternative methods like Newton-Raphson, and apply the Gauss-Seidel approach to three-phase or non-linear electrical systems.

## **CONCLUSION**

This research demonstrated the effectiveness of the Gauss-Seidel method for analyzing and optimizing power flow in a nine-loop electrical circuit. By leveraging Python's computational efficiency and employing Kirchhoff's Laws, the study achieved precise current calculations across all loops, converging within 46 iterations at a tolerance level of  $1 \times 10^{-6}$ .

The results provide actionable insights for electrical system design, highlighting areas for voltage adjustment and identifying high-consumption zones. These findings contribute to the broader goals of energy efficiency, reliability, and sustainability in electrical system design.

Future studies could expand on this work by integrating dynamic factors, exploring hybrid numerical methods, and applying the analysis to larger and more complex systems, further broadening its applicability in real-world scenarios.

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