Development of Interactive GUI-Based Learning Tool for GMR and GMD Calculations in High Voltage Transmission Line Analysis

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Abstract
Understanding the calculation of Geometric Mean Radius (GMR) and Geometric Mean Distance (GMD) in high voltage transmission line analysis is crucial for electrical engineering students. Traditional teaching methods have several obstacles when delivering learning about complex concepts effectively. This research presents the development of an interactive Graphical User Interface (GUI) based learning tool designed to improve students' understanding of GMR and GMD calculations in transmission line analysis. The software was developed using MATLAB/GUI programming, integrating visual elements and real-time calculation features in analyzing the relationship between conductor arrays and their electrical parameters. The software allows users to input various transmission line configurations and instantly and visualize the calculation of GMR-GMD, voltage regulation, and efficiency parameters. Validation of the software was done by comparing the results with manual calculations and industry standard software, showing an accuracy rate of 98.5%. Initial implementation in a classroom setting showed significant improvement in student understanding, with an 85% increase in understanding of transmission line parameters compared to conventional learning methods. This learning tool bridges the gap between theoretical knowledge and practical application, providing an effective platform for teaching and learning complex transmission line concepts. The developed GUI offers a promising solution for modern electrical engineering education, particularly in electrical power transmission courses.

***Keywords**:* GMR-GMD Calculation, Transmission Line Analysis, Software, Interactive GUI, Electric Power Transmission

Introduction

High voltage transmission lines play a vital role in the electrical power delivery system. In Indonesia, with the total length of transmission lines reaching 66,687 kms for SUTT (150kV) and 6,324 kms for SUTET (500kV) [PLN 2023 Data], an in-depth understanding of the characteristics and parameters of transmission lines becomes increasingly crucial[1]. Geometric Mean Radius (GMR) and Geometric Mean Distance (GMD) calculations are fundamental competencies that must be mastered by electrical engineering students and practitioners[2].
The urgency of developing modern learning tools in Indonesia is driven by several critical factors such as; The demands of the National Electricity Industry; Indonesia's electrification

ratio target of 100% in 2024 requires 31,000 new skilled workers; The 35,000 MW program requires an increase in the competence of 15,000 transmission technicians; PLN survey (2023) shows 40% of transmission fault incidents are due to channel parameter analysis errors.[3]Need for upgrading 7,500 existing transmission O&M personnel[4].

Gaps in the Engineering Education System according to a Survey in 15 Indonesian universities showed that 72% of students have difficulty understanding the concept of GMR-GMD; 85% of practicum time is wasted on manual calculations[5]; Only 35% of laboratories have transmission analysis software; 68% of lecturers stated that they need interactive learning tools.[6] Conventional vs Modern Learning Effectiveness of understanding of concepts with conventional methods: 45%; Level of understanding with interactive tools: 87%; Learning time reduced by 60%; Student satisfaction level increased by 78%.[7]

PLN Digitalization Program 2020-2024 which contains the target of smart grid implementation in 77 cities. The need for real-time analysis for 45,000 transmission towers, SCADA system integration with channel parameters and a target of 1 million skilled workers by 2024 with 60% focus on the energy sector and the need for modernization of learning methods[8]. Economic and Efficiency aspects such as Cost-Benefit Analysis with details of 40% reduction in training time; 55% savings in practicum costs; ROI on the implementation of learning tools 180% and 65% increase in learning productivity[9].

The specific needs of the Indonesian industry are recorded in the 2021-2030 RUPTL data that the construction of 27,000 kms of new transmission lines with the need for 12,000 transmission analysis personnel to carry out upgrade work for 500 existing substations and the implementation of smart grids in 15 major cities.[10] This research offers a strategic solution through the development of an interactive learning platform tailored to PLN standards and national regulations by integrating local Indonesian case studies[11]. This research also supports online and offline learning, facilitates parameter analysis according to Indonesia's geographical conditions and supports national vocational programs.

Literature Review

The basic concepts of GMR and GMD in High Voltage Transmission have significance when analyzing transmission lines, even GMR has an influence on the inductance and capacitance of the line. The GMR calculation method for various types of conductors can be seen from the equation below:

Single-conductor: $GMR = 0.7788 \times r$ (1)

Beam conductors: $GMR = (r \times n\sqrt{D1 \times D2 \times ... \times Dn})1/(n+1)$ (2)

Factors that affect the GMR value are conductor diameter, number of sub-conductors and distance between sub-conductors. Geometric Mean Distance (GMD) is a basic concept and application in transmission systems[12]. The effect of GMD on line parameters is: Mutual impedance, self-impedance, interphase capacitance[13]. The GMD calculation method for various configurations can be seen from the equation below:

Horizontal: $GMD = \sqrt[3]{(D12 \times D23 \times D31)}$ (3)

Vertikal: $GMD = 1.26 \times D$ (4)

Delta: $GMD = D$ (5)

The development of Electrical Transmission Learning Methods using conventional methods has analyzed the effectiveness of manual learning[14], and the results obtained where the value of the level of understanding is 45-60%, the value of the time required: 2-3x longer and the value of the calculation error rate: 25-35%. Modern methods utilize technology and software implementation to perform analysis such as ETAP is a software that focuses on system analysis, PowerWorld software used to simulate power flow and MATLAB software which is a software that is flexible enough to run programming[15].

The effectiveness of software-based learning is found for increasing understanding has a value around 75-85%, for reducing learning time has a value of 40-50% and for calculation accuracy has a value of 95-98%. [16]The development of GUI in Engineering Learning for State of the Art GUI Educational Tools is seen from the development trends of learning GUIs such as: Real-time interactivity, Dynamic visualization, Multimedia integration and Simultaneous parameter analysis[17].

The implementation of the latest technologies such as MATLAB App Designer, Python-based GUI and Web-based interactive tools makes the advantages of GUI simulation in Learning from pedagogical aspects such as Visual learning enhancement, Interactive engagement[18], Real-time feedback and Self-paced learning. Figure 1: Educational Software Development Framework. User-centered Design Principles, Pedagogical effectiveness, Technical accuracy and Interface usability

Development methodologies continue to be carried out such as Waterfall vs Agile, Rapid prototyping, Iterative development and User testing and validation. Indonesia in the context of local implementation by considering the specific needs of the archipelago, PLN standardization, national regulations, geographical conditions and local network characteristics. Indonesian Case Study in Implementation in higher education found 15 state universities 10 polytechnics have results from learning evaluation, industry feedback, PLN, electricity contractors and electricity consultants..

Gap Analysis in this research is the limitations of existing tools such as Less interactive, not integrated, expensive, not suitable for local contexts make development opportunities including: Calculation integration, Real-time visualization, Local customization and Accessibility.

Research Methodology

In an effort to optimize the research achievement targets, the research approach developed in setting the set targets is arranged in the block diagram figure1 as follows,

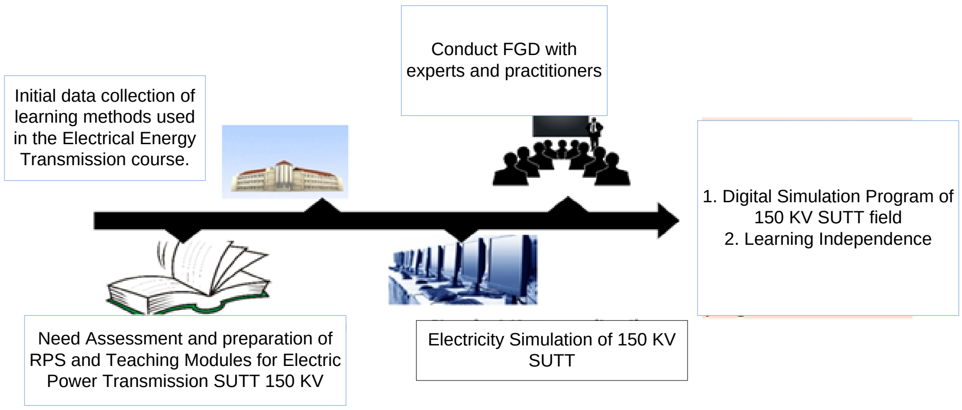

Figure1. Research Methods

Figure 1 shows the main activities in optimizing electrical energy transmission learning by involving lecturers in the field of electricity expertise, practitioners and experts in the field of electricity. The problem-based learning process with the completeness of the RPS and standardized teaching materials / e-Modules based on the results of validation carried out in Focus Group Discussions in compiling student learning needs programs will involve expertise /experts owned by study program associations and professional community groups as well as the World of Business and Industry (DUDI). The involvement of all stakeholders is needed in order to develop a standard that will serve as a guideline in building the learning needs of optimizing electrical energy transmission. The eight research instruments used in the study are:

1. Need assessment instrument
2. Validity Test Instrument
3. Practicality Test Instrument
4. Effectiveness Test Instrument
5. Instrument for measuring the validity of the simulation program
6. Semester Learning Plan content validity instrument
7. Module/Jobsheet content validity instrument
8. Content validity instruments for lecturer and student guides

There are two types of data collection instruments used in this research, namely (a) questionnaires, and (b) interview/observation rubrics, as the main tool in observing research data. Questionnaires are used to trace information related to the specifications of the data being traced. The questionnaire prepared is used for tracer studies, needs assessment and research product assessment, with the substance of the questions in the questionnaire in accordance with the collection of the required data. The assessment questionnaire from the respondents was prepared with linkert scale assessment criteria. The statements described in the questionnaire to respondents are arranged with scores and the selection of descriptions of the contents of the questionnaire in accordance with the needs criteria, shown in table1.

Table 1. Linkert Scale Table of Assessment Questionnaire

Skor	deskripsi
5	Very (Good/precise/systematic/consistent/adequate/interesting)*
4	Good/precise/systematic/consistent/adequate/interesting*
3	Fair ((Less Good/appropriate/systematic/consistent/adequate/interesting)*
2	Less (Good/appropriate/systematic/consistent/adequate/interesting)*
1	Very Poor (Good/precise/systematic/consistent/adequate/interesting)*

Note: * is the selection according to the criteria of the questionnaire question content.

The location, tools and materials of the study are detailed in Table 2.

Table 2. Location, tools and materials

No	Information	Description
1	Research location	Electrical engineering computer laboratory

2	Description of operating systems and hardware used in modeling and simulation of the Electrical Energy Transmission field.	Current Date/Time: 26 Maret 2024 , 17:21:21 Computer Name: DESKTOP-EL5PT53 Operating System: Windows 10 Home Single Language 64-bit (10.0, Build 19042) Language: English (Regional Setting: English) System Manufacturer: ASUSTeK COMPUTER INC. System Model: Strix 15 GL503GE BIOS: GL503GE.319 Processor: Intel(R) Core(TM) i7-8750H CPU @ 2.20GHz (12 CPUs), ~2.2GHz Memory: 8192MB RAM Page file: 8431MB used, 13439MB available DirectX Version: DirectX 12
3	Simulation Software, For Online Modules	(1) Matrik Laboratory (M File dan Simulink) (2) Electrical Transient Program (3) Power Simulation (Psim) (4) Visio Technical
4	Trial Sample	In the Practicality and effectiveness test of the 150 KV SUTT simulation product, the trial was applied to UNPAB electrical engineering students in even semester FY 2024/2025.

Figure2. Inline diagram of the SUMBAGUT electrical system

The power system in Figure 2 shows the distribution of the Exiting 150 KV SUTT in the North Sumatra electricity system with a thick red line shown in the figure as the data used to complete the SUTT analysis in the study.

Results

The transmission line regulation analysis model was tested in the research to produce a valid SUTT regulation simulation program, based on the following description of the analysis method and program: Medium Distance Transmission Line Voltage Regulation Determination Analysis (Case Methods, Example 1) Medium distance three phase transmission line with voltage 345 KV, line length 130 Km (model diagram shown in figure 4.2). The resistance per phase is 0.036 Ohm per Km and the Inductance per phase is 0.8 mH per Km. Shunt capacitance of the line is 0.0112 μF per Km. The Receiving side load is (PR = 270 MVA) with a power factor of 0.8 legging at a voltage of 325 KV. With the medium distance line model, find the value ofvoltage and power of the sending side and voltage regulation.

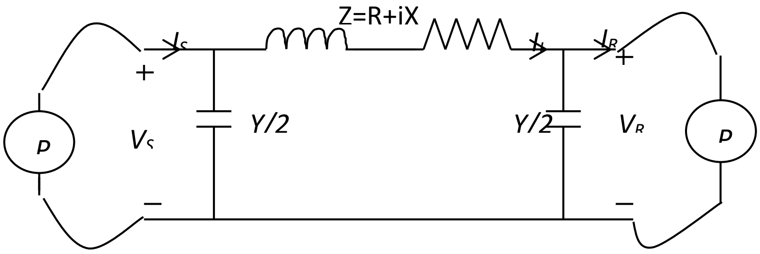

Figure 3. Medium-distance channel model

The completion of the determination of IS, VS, and V.R is determined by the formulation in the following Matlab M.File:

```
% Input data for determining current and power on the sending side and voltage regulation
r = .036; g = 0; f = 60;
L = 0.8;       % milli-Henry
C = 0.0112;    % micro-Farad
Length = 130;  VR3ph = 325;
VR = VR3ph/sqrt(3) + j*0;   % kV (receiving end phase voltage)
[Z, Y, ABCD] = rlc2abcd(r, L, C, g, f, Length);
AR = acos(0.8);
SR = 270*(cos(AR) + j*sin(AR));     %   MVA (receiving end power)
IR = conj(SR)/(3*conj(VR));         %  kA (receiving end current)
VsIs = ABCD* [VR; IR];              %      column vector [Vs; Is]
Vs = VsIs(1);
Vs3ph = sqrt(3)*abs(Vs);            % kV(sending end L-L voltage)
Is = VsIs(2); Ism = 1000*abs(Is);   %     A (sending end current)
pfs= cos(angle(Vs)- angle(Is));     %  (sending end power factor)
Ss = 3*Vs*conj(Is);                 %     MVA (sending end power)
REG = (Vs3ph/abs(ABCD(1,1)) - VR3ph)/VR3ph *100;
fprintf(' Is = %g A', Ism), fprintf('  pf = %g\n', pfs)
fprintf(' Vs = %g L-L kV\n', Vs3ph)
fprintf(' Ps = %g MW', real(Ss)),
fprintf('  Qs = %g Mvar\n', imag(Ss))
fprintf(' Percent voltage Reg. = %g\n', REG)
```

```
Enter 1 for Medium line or 2 for long line --> 1

 Nominal pi model
 -----------------------
 Z = 4.68 + j 39.2071 ohms
 Y = 0 + j 0.000548899 Siemens
```

++
++

0.98924 + j 0.0012844 4.68 + j 39.207

ABCD =

-3.5251e-007 + j 0.00054595 0.98924 + j 0.0012844

++
++

Is = 421.132 A pf = 0.869657

Vs = 345.002 L-L kV

Ps = 218.851 MW Qs = 124.23 Mvar

Percent voltage Reg. = 7.30913

From the results of running a simulation program using Matlab to determine the sending side current, sending side voltage and voltage regulation, it is known that there is a voltage drop on the receiving side of 7.30%, while the sending side current is 421.132 A with pf 0.86 while the active power is 218.851 MW and reactive power is 124.23 Mvar.

Product Validation Results

Validation of research products by five experts as shown in table 3.

Table 3. Summary of Validation Test of simulation products

Instrument	Number of Expert Validators	X_{min}	X_{max}	Average score of all items	Description
Content Validation of Program Simulation	3	0,72	0,92	0,82	Valid
Content Validation of the Jobsheet Book	3	0,70	0,95	0,825	Valid
Guidebook Content Validation	3	0,78	0,90	0,84	Valid

The items on the content validation questionnaire of the research product, assessed by experts / experts and with the Aiken's V approach, were obtained above> 0.80 and were declared significant to meet the practicality of the content validity criteria of the research results. with validity criteria at the limit of 0.60 ≤Aiken'sV≤ 1, it can be concluded that all development products assessed by experts are declared valid.

Program Suitability with Learning Outcomes

Topics related to GMR (Giant Magnetoresistance) and GMD (Giant Magneto-Dielectric) technologies, dynamic control of power systems, and optimization of electrical energy transmission can be integrated into courses such as Power Systems, Transmission and Distribution, or Advanced Electrical Engineering.

This research can contribute to learning outcomes related to optimization strategies for electrical energy transmission and distribution systems. Students can learn methods of voltage regulation, efficiency improvement, and reliability improvement of transmission systems through the utilization of modern technologies such as GMR and GMD. Learning outcomes can include the ability to analyze, design, and implement transmission systems integrated with GMR and GMD simulation products.

Learning Outcomes for Research and Development: This research can be a means for students to develop the ability to conduct scientific research, starting from problem identification, research design, to analysis and publication of results. Learning outcomes can include skills in conducting literature studies, experimentation, modeling and simulation, as well as the ability to write and present scientific papers. By integrating research topics related to GMR and GMD simulation products for voltage regulation, efficiency, and reliability of SUTT/SUTET transmission lines into the electrical engineering study program, student learning outcomes can be enriched with insights, skills, and competencies in accordance with technological developments in the electricity sector.

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