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Development of numerical algorithm for power system computation as project-based learning in numerical methods course

Syafii, Baik Budi
Department of Electrical Engineering, Faculty of Engineering, Universitas Andalas, Padang, Indonesia

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ABSTRACT

This article presents the application of a Project-Based Learning (PjBL) approach in the Numerical Methods course, focusing on developing a numerical algorithm for power system computation. The study addresses the challenges of efficiently calculating the bus admittance matrix (Ybus), bus numbering sequences, and handling double-line connections, all crucial for accurate power flow analysis. The objective is to create an efficient algorithm that can be applied to a 7-bus power system, enhancing students' practical skills in numerical methods. The results demonstrate that the algorithm successfully computes the Ybus matrix, resolves bus numbering issues, and handles double-line connections. This approach not only improves computational efficiency but also deepens students' theoretical knowledge and practical problem-solving abilities. The study highlights the effectiveness of PjBL in teaching numerical methods, offering valuable insights for its application in other engineering fields to enhance both learning and real-world problem-solving skills.

Corresponding Author:

Syafii
Department of Electrical Engineering, Faculty of Engineering, Universitas Andalas
Jl. Dr. Mohammad Hatta, Limau Manis, Pauh, Padang, Indonesia
Email: syafii@eng.unand.ac.id

1. INTRODUCTION

Outcome-Based Education (OBE) has become a widely adopted educational paradigm in higher education institutions worldwide. This approach emphasizes the learning outcomes that students are expected to achieve through a structured learning process that focuses on competencies. In OBE, it is crucial for students to master practical skills relevant to industry needs, ensuring they are prepared to tackle professional challenges after graduation. This has driven educational institutions to explore effective teaching methods, including Project-Based Learning (PjBL). PjBL enables students to actively engage in the learning process by working on real-world projects, thereby enhancing both their conceptual understanding and practical technical skills *(Lavado-Anguera et al., 2024)*. Research indicates that implementing OBE can enhance academic leadership and improve students' skill-based learning outcomes, thereby preparing them to meet professional challenges effectively (Radwan et al., 2019; Ibrahim & Amer, 2021). Furthermore, OBE encourages institutions to engage in continuous improvement of their educational offerings, aligning with the broader societal expectations of higher education (Ashwin, 2022; Tam, 2014). As such, OBE not only serves to elevate the quality of education but also fosters a culture of accountability and transparency in assessing student performance and institutional effectiveness (Almuhaideb & Saeed, 2020).

In the Numerical Methods course, applying PjBL is particularly relevant given the importance of computational analysis skills in solving engineering problems, especially in power systems. With the PjBL approach, students can learn and apply numerical algorithms to solve technical problems through various case studies that simulate real-world challenges. This learning approach not only covers foundational numerical methods concepts but also emphasizes mastering computational skills required for analyzing and simulating power systems, such as matrix formation, element sequencing, and handling complex network components. PjBL encourages students to actively participate in their learning by working on real-world projects, which fosters critical thinking and problem-solving skills while aligning with the competencies defined by OBE (Oriza C, et.al, 2021; Meti et al., 2021). Research indicates that integrating PjBL into the curriculum can lead to improved knowledge retention and the development of practical skills essential for students' future careers (Debnath & Pandey, 2011). For instance, a study demonstrated that students who engaged in PjBL within a manufacturing technology laboratory course significantly enhanced their complex problem-solving abilities and communication skills, thereby meeting the desired program outcomes (Meti et al., 2021).

2. METHOD

The application of Project-Based Learning (PjBL) in the Numerical Methods course can begin by assigning a project that students must complete independently. For this course, students work on a power system based on a 7-bus system model, as shown in Figure 1. This model provides a simplified yet realistic representation of power system components and interactions, allowing students to practice computational methods essential for real-world power system analysis.

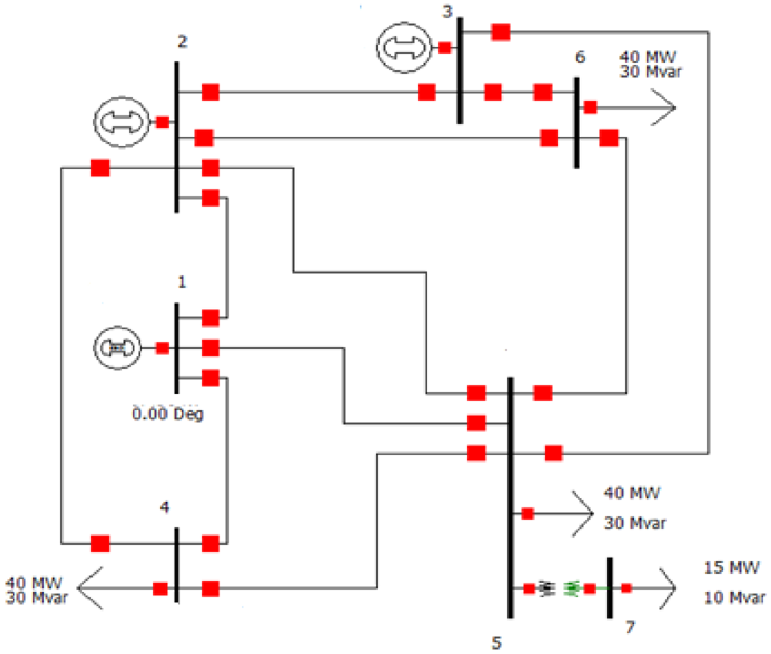

Figure 1: Diagram of a 7-Bus Power System

To support the project, students are provided with the necessary line data, including the resistance, reactance, and shunt admittance values for each line segment in the 7-bus system. This data is essential for calculating power flows and system admittance. Additionally, relevant formulas, such as those for calculating the bus admittance matrix (Y-bus matrix), bus sequence, and handling of double lines, are outlined for students as part of the instructional materials.

Table 1. Line Data

Send line	Receive line	R	X	Bc
1	2	0.1	0.2	0.02
1	4	0.05	0.2	0.02
1	5	0.08	0.3	0.03
2	3	0.05	0.25	0.03
2	4	0.05	0.1	0.01
2	5	0.1	0.3	0.02

2	6	0.07	0.2	0.025
3	5	0.12	0.26	0.025
3	6	0.02	0.1	0.01
4	5	0.2	0.4	0.04
5	6	0.1	0.3	0.03
7	5	0	0.01	0

The bus admittance matrix, Ybus, can also be calculated using transformer and line input data with the following equation:

$$Y_{ii} = \sum_{j=0}^{n} y_{ij} + y_{i0} \qquad j \neq i \tag{1}$$

$$Y_{ij} = Y_{ji} = -\, y_{ij} \tag{2}$$

Student Tasks and Algorithm Development

The first task requires students to derive an efficient algorithm for constructing the bus admittance matrix, Y-bus, from the provided line data. This matrix is a fundamental element in power system analysis, as it represents the network's connectivity and impedance relationships between buses. Students are instructed to develop an algorithm that minimizes computational complexity, ensuring it can be scaled up to handle larger systems if needed.

Following this foundational task, students are guided to modify their algorithm to address additional cases commonly encountered in power system computation. These include: Bus Number Sequencing: Students will adjust their algorithm to handle the correct sequencing of bus numbers, which is critical for ensuring accurate data representation and flow within the matrix. Handling Double Lines: In cases where two or more lines connect the same pair of buses, students must modify their algorithm to incorporate these double lines, summing the admittance of the parallel lines accordingly.

By tackling these tasks, students progressively develop a comprehensive understanding of numerical methods in power system computations. Through the PjBL approach, they gain practical skills in algorithmic design and computational efficiency, which are directly applicable to real-world power system analysis and simulation.

3. RESULTS AND DISCUSSION

3.1. Construct Admitance Matrik

The numerical algorithm developed for this project was applied to calculate the bus admittance matrix (Ybus) for the 7-bus power system, as shown in Figure 1. Recent studies recommend higher-order numerical schemes and robust numerical handling to improve power-flow solution stability, particularly for ill-conditioned networks (Zafar et al., 2024; Tostado-Véliz et al., 2021). The numerical algorithm in forming the Ybus matrix as below:

```
for (l=1;l<=Nl;l++){
       i= sl [l];
       j= el [l];
       aa = rl[l]*rl[l]+xl[l]*xl[l];
       g[i][j] = -rl[l]/aa;
       g[j][i] = g[i][j];
       b[i][j] = xl[l]/aa;
       b[j][i] = b[i][j];
       g[i][i] += rl[l]/aa;
       g[j][j] += rl[l]/aa;
       b[i][i] += -xl[l]/aa + bl[l]/2;
       b[j][j] += -xl[l]/aa + bl[l]/2;
}
```

The Admittance matrix result as show in Figure 2.

Name	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7
1	4.01 - j11.78	-2.00 + j4.00		-1.18 + j4.71	-0.83 + j3.11		
2	-2.00 + j4.00	9.33 - j23.25	-0.77 + j3.85	-4.00 + j8.00	-1.00 + j3.00	-1.56 + j4.45	
3		-0.77 + j3.85	4.16 - j16.60		-1.46 + j3.17	-1.92 + j9.62	
4	-1.18 + j4.71	-4.00 + j8.00		6.18 - j14.67	-1.00 + j2.00		
5	-0.83 + j3.11	-1.00 + j3.00	-1.46 + j3.17	-1.00 + j2.00	5.29 - j114.21	-1.00 + j3.00	-0.00 + j100
6		-1.56 + j4.45	-1.92 + j9.62		-1.00 + j3.00	4.48 - j17.04	
7					-0.00 + j100.00		0.00 - j100

Figure 2. Computed Bus Admittance Matrix (Ybus)

The algorithm demonstrated efficient and accurate results in forming the Ybus matrix, validating its suitability for complex power system computations. The accuracy and speed of this computation highlight the algorithm's effectiveness in handling large data sets and complex system parameters commonly found in power systems.

3.2. Bus Numbering Sequence

The 7-bus system with unordered bus numbers is shoen in Figure 3. The algorithm to reorder the bus numbering in the power system model was applied. Using this algorithm, the sequencing issues typically encountered in unsorted power systems were successfully resolved. By aligning the bus numbers in a logical order, the algorithm enables more streamlined power flow computations and improves the clarity of data representation in the Ybus matrix. Matrix reordering and bandwidth-reducing strategies have been proven effective in optimizing sparse admittance matrices and accelerating power flow computations (Zhu et al., 2022; Chen & Bian, 2021).

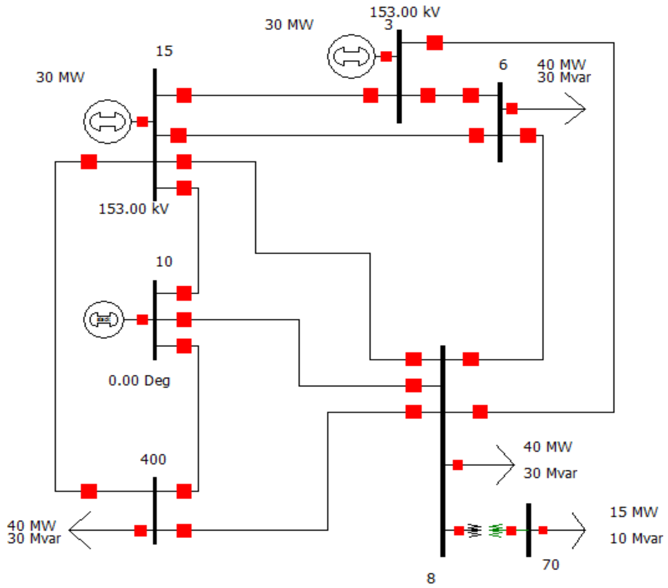

Figure 3. 7-bus system with unordered bus numbers.

Rearrangement of bus numbers translated to computer coding as below:

```
/ Rearrangement of bus numbers
for (i = 1; i <= nb; i++) {
   new_bus[i] = 0;
}

for (i = 1; i <= nb; i++) {
   old_bus[i] = no[i];
   new_bus[old_bus[i]] = i;
}

for (i = 1; i <= nb; i++) {
   no[i] = new_bus[no[i]];
}

for (i = 1; i <= nl; i++) {
```

```
      sl[i] = new_bus[sl[i]];
      el[i] = new_bus[el[i]];
   }
```

At the end of the program, add the following code to return to the original bus numbers:

```
   for (i = 1; i <= nb; i++) {
      no[i] = old_bus[no[i]];
   }
```

For the line data, add:

```
   for (l = 1; l <= nl; l++) {
      // Additional code here
      sl[l] = old_bus[sl[l]];
      el[l] = old_bus[el[l]];
      // Additional code here
   }
```

3.3. Handling Double Lines

The algorithm was also tested for its ability to handle double lines within the 7-bus system, as shown in Figure 4. Through a modified approach, the numerical algorithm accurately processed double lines by correctly summing their admittances (Tostado-Véliz et al., 2021). This capability is crucial for accurately representing power systems with parallel transmission lines, which are often used to increase capacity or redundancy. The successful implementation of this feature demonstrates the algorithm's adaptability to real-world power system configurations, where such complexities are common.

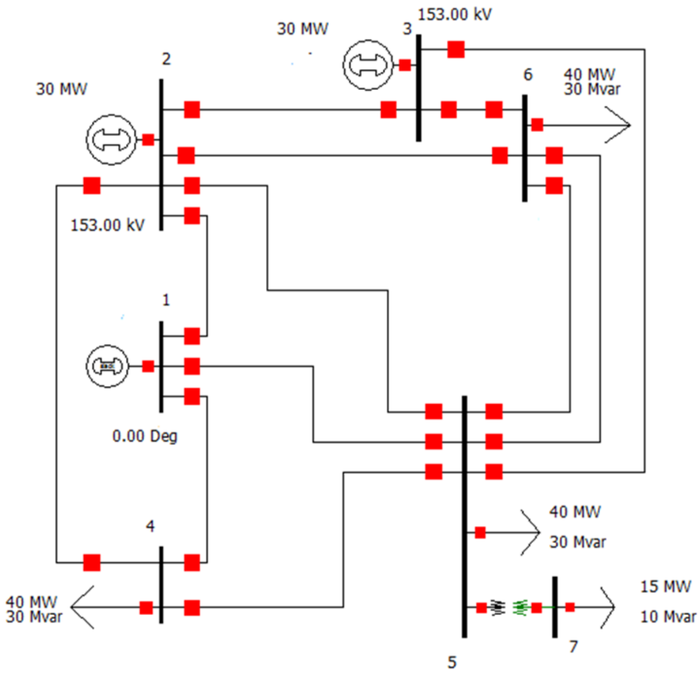

Figure 4. 7-bus system with a double line from bus 5 to bus 6.

Because there is an additional line with the same bus numbers, namely from bus 5 to bus 6, the previous power flow program cannot be executed. To address this issue, code must be added at the beginning of the program to support the double line, as follows:

```
   // Support double line
    for (k=1; k<=nl; ++k)
      dl[k]=1;

    for (k=1;k<=nl;++k)
      for (l=k+1;l<=nl;++l)
```

```
{
if(sl[k]==sl[l] && el[k]==el[l])
  {
  dl[l]=2;
  xl[k]=xl[k]/2;
  rl[k]=rl[k]/2;
  }
else if  (sl[k]==el[l] && el[k]==sl[l])
  {
  dl[l]=2;
  xl[k]=xl[k]/2;
  rl[k]=rl[k]/2;
  }
}
```

The results affirm that this numerical algorithm efficiently addresses key computational tasks within power system analysis: forming the Ybus matrix, handling bus number sequencing, and managing double-line configurations. The ability of the algorithm to address these challenges enhances its potential application in practical power system studies, offering a reliable tool for both educational and professional purposes in the field of numerical methods for power systems.

4. CONCLUSION

In this study, a numerical algorithm was developed and successfully applied to address key computational tasks in power system analysis as part of a Project-Based Learning (PjBL) approach in the Numerical Methods course. The algorithm demonstrated its ability to efficiently calculate the bus admittance matrix (Ybus), handle bus numbering sequences, and resolve issues related to double-line connections within a 7-bus power system. The results confirmed that the algorithm provided an efficient and accurate method for constructing the Ybus matrix, which is essential for power flow analysis. By optimizing computational processes, the algorithm ensures that larger and more complex systems can be handled effectively. Additionally, the implementation of a bus numbering sequence resolved the problem of disordered bus indices, improving data organization and the reliability of subsequent analysis. Furthermore, the algorithm successfully addressed the challenge of double-line connections, maintaining the integrity of the power system's admittance representation. Through this project, students not only gained practical experience in numerical methods but also developed problem-solving skills that are directly applicable to real-world power system computation. The successful application of PjBL in this context highlights its potential as an effective teaching strategy for developing both theoretical and practical expertise in engineering students. Future research can expand this work by applying the algorithm to larger power systems or integrating additional system components, such as generators or transformers, to further enhance the robustness of the computational methods. Moreover, adapting high-performance computing methods and integrating AI for solver optimization should be explored (Alawneh et al., 2023; Kang & Li, 2024), along with large-scale PBL evaluations for instructional validation (Ramírez de Dampierre et al., 2024). The approach also has the potential for broader application in other areas of numerical analysis, offering valuable insights for improving computational efficiency in various engineering fields.

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