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Power Flow Analysis of Electrical Network Systems Using Gauss-Seidel Method and Python

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Abstract

This study aims to analyze the power flow in a 150kV radial power system on the island of Bali, the reason the author uses the Bali island system is because the number of busbars in the system is not too many and the data on the system is known. The problem of this research is limited by determining the voltage, power flow, and power losses in the system. The method used in this study is the Gauss-Seidel method through simulation with the help of Visual Studio Code software and the Python 3.9.2 program. The simulation is carried out by producing a total of 8 iterations. The simulation is carried out to find the parameters of the load voltage, apparent power on the slack bus, current, power flow and power losses on the line.

The simulation results show that, under a load condition of 70% of the load transformer capacity, the voltage at the load bus node experiences a voltage drop, reaching 4.48% at bus 10. So when the system operates for generation conditions, the power that can be generated is 1,275.6 MegaWatt of the total generator installed, and the power delivered to each bus node is 2,090 MVa and the power losses in the system are 3.69% of the total power distributed to the bus nodes.

***Keywords**: Power flow, Electric Power System, Bali Island, Gauss-Seidel Method*

1. Introduction

The need for electrical energy in Indonesia, especially on the island of Bali, is growing very rapidly, all daily activities and activities require electrical energy. These developments will affect the loading and operating conditions in the electric power system [1]. Power flow calculations are carried out to find out information on the power flow and voltage, this information is needed to evaluate the electric power system and analyze loading and generation conditions in the interconnection network, both currently running and conditions that may occur in the future [2].

To determine the electrical condition in an interconnection network, it is necessary to analyze the components of the electric power system which includes generators, transmission lines and loads. With the calculation of the power flow study, it can be used to determine the value of the parameters which include active power, reactive power, voltage, and phase angle found on each busbar in the power network under normal operating conditions. In this description, the idea emerged to analyze the load flow using the Gauss-Seidel method.

Gauss-Seidel is a method for solving power flow studies which is commonly used in the analysis of electric power systems. This method is often used and it is easier to complete mathematical operations and the preparation of computer programs [2]. By using Visual Studio Code software and the Python 3.9.2 programming language to complete power flow calculation computations it will be faster because the Python program is quite light in size and the programming language is easy to understand, more efficient than manual calculations, as well as memory and time usage. much more computationally efficient.

Conducted research with the title"simulation of power flow phenomena in the "IEEE 5-BUS" based power systemnumerical methods and Python 3.9.2" application-assisted flow calculation simulations. The IEEE 5-bus power system provides the basis for calculationsthe existence of a complex system to know the advantages and disadvantages of each power flow calculation method, so that several criteria are obtained compared and the results of the comparison of power flow calculations between the three methods. The Gauss-Seidel, Newton Raphson, and fast power flow calculations decoupled with the same principle in the iteration order technique for each process the solution, namely: (a) determining the bus administration matrix Y from impedance- bus attached line impedance; (b) determination of P and Q values for load buses; (c) determination of the value of P and |V| for generator buses; (d) determination of the voltage value equal to $1 \angle 0o$ for the reference bus or slack bus; (e) the initial assumption that the voltage value is $1 \angle 0o$ for the load bus and generator bus at the beginning of the iteration; (f) calculation of V, P and Q values for the load bus and generator bus with these values; (g) calculation of P and Q values for reference buses; (h) calculation of power flow and power losses on each channel; and (i) repetition of step 5 (e) with new V, P, and Q values for the next iteration, so that the error value is smaller or equal to the specified tolerance limit value. Based on the simulation results, it can be concluded that: (1) The Fast Decoupled method has more profitable (optimum) choices compared to the Newton-Raphson method and the Fast Decoupled method. Gauss-Seidel, so that the application of the Fast Decoupled method is the main choice among the three; (2) For the simulation of power flow calculations, the Fast Decoupled method shows a total accuracy of 57%, Gauss-Seidel 36%, and Newton-Raphson 7%; while for the simulation of calculating channel losses the Fast Decoupled method shows a total accuracy of 50%, Gauss-Seidel 40%, and Newton-Raphson 10% [3].

Pada penelitian yang berjudul "Studi Aliran Daya Jaringan Distribusi 20kV di Bali dengan metode yang lebih cepat " dengan melakukan analisis aliran daya dengan membandingkan dua metode yakni metode Fast Decoupled yang diusung oleh Mekhamer dan metode Newton Rapshon, dengan mengidentifikasi pada penyulang Bukit Jati di wilayah Bali Timur dan VIP2 di wilayah Bali Selatan. Hasil analisa dengan metode fast decoupled lebih cepat dibandingkan dengan metode newton rapshon walaupun jumlah iterasi yang dibutuhkan lebih banyak. Untuk hasil tegangan yang diperoleh dari kedua metode ini menunjukan hasil yang mendekati sama. Dalam semua analisa, metode fast decoupled menunjukan hasil yang lebih baik, tidak mengalami masalah konvergensi, sehingga analisa aliran daya pada jaringan distribusi 20kV di Bali dapat diselsaikan dengan baik [4].

Penelitian dengan judul "Analisis Aliran Daya Sistem Kelistrikan 150kV Bali Saat Rekonduktoring SUTT Gilimanuk-Negara-Antosari" melakukan identifikasi kesiapan sistem kelistrikan di Bali dengan menggunakan aplikasi simulator analisis aliran daya. Simulasi dilakukan dengan memadamkan masing-masing penghantar 150kV di sistem kelistrikan Bali secara bergantian dengan memperhatikan empat scenario yaitu sebelum dilakukan rekonduktoring, rekonduktoring sirkit 1, rekonduktoring sirkit 2, dan setelah dilakukan rekonduktoring. Pencatatan tegangan dilakukan disetiap bus dengan toleransi ±5% Vnom. Pencatatan beban dilakukan pada setiap penghantar 150kV yang aktif dengan kapasitas maksimum 80% Inom. Penyelesaian persolaan aliran daya adalah nonlinear dan memerlukan perhitungan persamaan aliran daya dan pemrosesan error secara berulang (iterasi). Hasil dari simulasi yang menunjukan bahwa anomaly hanya didapatkan ketika simulasi pekerjaan rekonduktoring sirkit 1 SUTT 150kV Gilimanuk-Celukan Bawang trip. Menyebabkan beban melebihi 80% Inom pada SUTT 150kV Gilimanuk-Pemaron dan SUTT Gilimanuk-Negara-Antosari 2 [5].

Conducted research on "Design and Build a Smart Home Using the Internet of Things Based on the NodeMCU ESP8266 Microcontroller". The purpose of this research is to help increase security and provide comfort to users because several electronic devices at home have been controlled automatically. The method used in this study is the experimental method (experiment). The results of this study are the tools that have been examined at an average delay value of 3.23 seconds for 3G networks, 1.42 seconds for 4G networks, and 1.38 seconds for WiFi networks. This shows that the communication test between the user and the smart home system using the internet of things affects the quality of the network signal and the device functions optimally at long distances. [6].

Conducted research on "Design of a Power Factor Monitoring and Improvement System for Atmega32 Microcontroller-Based Household Electricity Consumption". The purpose of this research is to design this tool in order to be able to reduce the cost of using household electrical loads efficiently. The method used in this study is an experimental method (experiment). the results of this study are on the results of testing tools 4the percentage increase in the value of the power factor is homogeneous as much as 27.12% and after improving the power factor using a capacitor bank can save costs as much as Rp. 17,197.44, - or around 22% and can monitor by SMS so this provides that the tool can monitor and improve power factor efficiently [7].

2. Methods

2.1. Research Flow

The method used in this study is a qualitative type by doing design, creation and simulation. The stages carried out in this research can be seen in Figure 1 below.

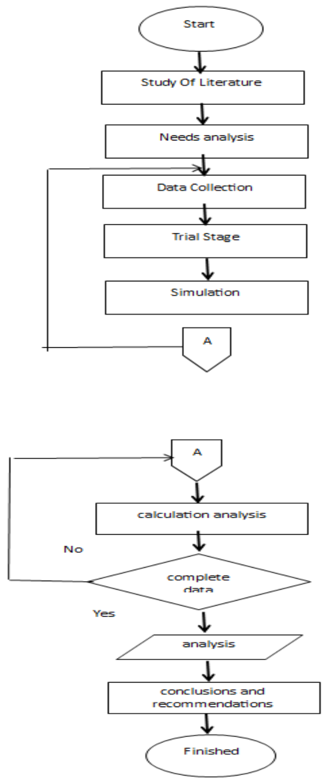

Figure 1 Research Flowchart

2.2. Gauss-Seidel Method Simulation

To carry out a power flow study simulation in this research is used 16 Bus structure as a comparison calculation. After determining the research method at this writing, it is necessary to have a simulation method so that it can be understood and facilitates programming for the author himself. After getting the parameters that have been arranged and the linear equation method, the flow chart of the simulation method can be seen in Figure 2

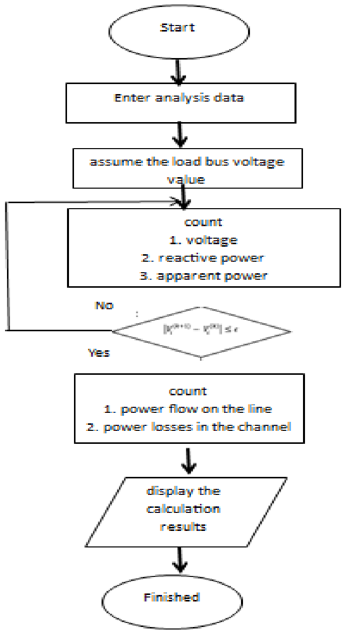

Figure 2 Flow Chart of the Gauss Seidel Method

Enter Analysis Data, Before calculating voltage, active power, reactive power, and so on. So, it is necessary to enter data or variables such as channel data, Load Bus loading data, and PV bus active power data that will be used in the calculation, before entering this stage it is necessary to find admittance values Y . Assumption of Voltage Value on Load Bus In the parameters that have been obtained, there are values that known and unknown values. In a power flow study, assumed values for unknown parameters are needed to perform calculations so that the iteration can run well.

Calculating Voltage, Active Power, and Apparent Power Parameters In this step, the process of calculating voltage, reactive power, phase angle, and apparent power is carried out. Calculations using the Gauss-Seidel method get the latest value from the previous iteration, the process is carried out repeatedly by entering the latest value until the iteration process produces a convergent value.

Calculating Power Flow Value and Power Losses After getting the value from the calculation of voltage, reactive power, phase angle,and apparent power, then the next step is to calculate the value of the power flow and look for power losses on the channel using the parameters that already obtained from the previous calculations. Before counting the amount of power flow and power losses in the channel is based on the formula for finding the power flow on a line requires the sum of the current values flowing in each channel.

Displays Calculation Results. At this stage, namely displaying the results of calculations by running program to get the calculation results from the steps that have been done. This stage serves to retrieve the results data to be analyzed.

3. Result

Testing was carried out using a program that had been designed using Visual Studio Code software with the Python program version 3.9.2. The tests carried out accompany the iteration results and calculation of the voltage, phase angle, active power and reactive power as well as the power flow of each busbar from existing data. After the calculation results have been obtained, the power flow in the power system channel of the island of Bali can be determined.

The 150kV power plant in Bali has a capacity of 998 MW which is dominated by 618 MW of fuel oil generators and 380 MW of coal fired power plants. The 2016 Bali Island Power System topology is shown in Figure 3.

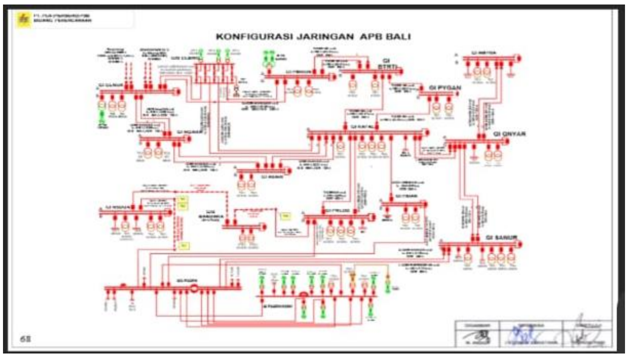

Figure 3 The 2016 Bali Island Power System Topology

3.1. Computational Testing

Computational testing to find the value of voltage and reactive power on the Load Bus and PV bus involves the apparent power variable on each busbar, then the admittance value on the line connected to each busbar, and the initial assumed voltage value of 1+0j on the Load Bus as well as PV buses.

3.2. Testing the Bus Load Voltage Value

In the Gauss-Seidel iteration program to find the initial iteration, the assumed value is used as a variable to find the first iteration. In the Gauss-Seidel method the variables that have been obtained are then used as the latest values to find other voltage values. In the Bali Island system the number of Load Buses is 12 buses, namely Buses 4,5,6,7,8,9,10,11,12,13,14, and bus 15. Then based on the power flow formula the Gauss-Seidel method to find the voltage value on the Load Bus can be seen in Figure 4.

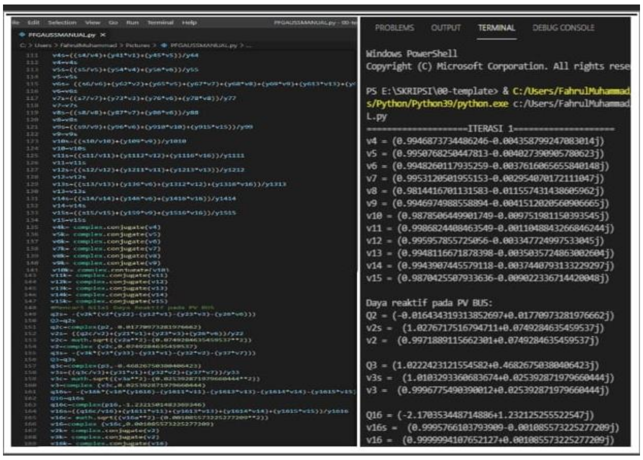

Figure 4 Python Ptogram Simulation with the Gauss-Seidel Mtehod

Table 1. Results of the Load Bus Voltage Test in Iteration 1.

Iterasi 1				
No. Bus	Tegangan	Sudut Fasa	Daya Aktif	Daya Reaktif
4	0.9946	-0.0043	0.238	0.146
5	0.9950	-0.0040	0.198	0.1226
6	0.9948	-0.0037	0.833	0.516
7	0.9953	-0.0029	0.1229	0.0762
8	0.9814	-0.0115	0.357	0.2212
9	0.9946	-0.0041	0.476	0.295
10	0.9878	-0.0097	0.198	0.1226
11	0.9986	-0.0011	0.714	0.4424
12	0.9959	-0.0033	0.476	0.295
13	0.9948	-0.0035	0.714	0.4424
14	0.9943	-0.0037	0.476	0.295
15	0.9870	-0.0090	0.833	0.516

Based on table 1, it is shown that iteration 1 is the first step in solving the stress parameters on the Load Bus, therefore the results in the first iteration can be continued until a convergent value is obtained.

3.3. PV Bus Reactive Power Testing

Based on the Gauss-Seidel power flow theory, to find the reactive power value on the PV bus it is necessary to complete the calculation of the Load Bus voltage. Based on the value of the Load Bus voltage, the test results at iteration 1 on the PV bus are shown in table 2.

Table 2 the test results at iteration 1 on the PV bus

Iterasi 1				
No. Bus	Daya Aktif	Daya Reaktif	Tegangan	Sudut Fasa(derajat)
2	2.53	0.0177	0.9971	0.0749
3	0.164	0.4682	0.9996	0.0253
16	1.446	1.2321	0.9999	0.0010

Calculation of power flow on the 16 Bali Island Bus system with the Gauss-Seidel method using the Python 3.9.2 program and Visual Studio Code software. The results obtained using the Gauss-Seidel method by doing 8 iterations and a tolerance value of 0.001, computation time of ± 4 seconds. The results obtained are as in table 3.

Table 3 The results obtained using the Gauss-Seidel method

Bus	Iterasi 1	Iterasi 2	Iterasi 3	Iterasi 4	Iterasi 5	Iterasi 6	Iterasi 7	Iterasi 8
2	0.9971+0.0749j	0.9928+0.0930j	0.9877+0.1003j	0.9821+0.1046j	0.9762+0.1080j	0.9698+0.1113j	0.9630+0.1147j	0.9556+0.1192j
3	0.9996+0.0253j	0.9990+0.0352j	0.9982+0.0391j	0.9974+0.0407j	0.9965+0.0414j	0.9957+0.0418j	0.9947+0.0441j	0.9937+0.0437j
4	0.9946-0.0043j	0.9921-0.0063j	0.9900-0.0079j	0.9878-0.0091j	0.9856-0.0098j)	0.9839-0.0102j	0.9826-0.0103j	0.9816-0.0104j
5	0.9950-0.0040j	0.9908-0.0071j	0.9863-0.0096j	0.9820-0.0110j	0.9786-0.0117j)	0.9759-0.0121j	0.9740-0.0123j	0.9725-0.0123j
6	0.9948-0.0037j	0.9891-0.0066j	0.9838-0.0081j	0.9797-0.0089j	0.9766-0.0092j)	0.9743-0.0094j	0.9725-0.0094j	0.9712-0.0093j
7	0.9953-0.0029j	0.9878+0.0039j	0.9840+0.0083j	0.9812+0.0102j	0.9790+0.0109j)	0.9772+0.0111j	0.9757+0.0114j	0.9744+0.0124j
8	0.9814-0.0115j	0.9746-0.0102j	0.9699-0.0092j	0.9663-0.0088j	0.9635-0.0088j)	0.9614-0.0088j	0.9597-0.0087j	0.9583-0.0082j
9	0.9946-0.0041j	0.9845-0.0110j	0.9773-0.0146j	0.9723-0.0163j	0.9686-0.0172j)	0.9659-0.0176j	0.9640-0.0177j	0.9625-0.0177j
10	0.9878-0.0097j	0.9775-0.0166j	0.9702-0.0202j	0.9651-0.0219j	0.9614-0.0228j)	0.9587-0.0232j	0.9567-0.0234j	0.9552-0.0234j
11	0.9986-0.0011j	0.9978-0.0009j	0.9973-0.0007j	0.9972-0.0005j	0.9972-0.0004j)	0.9971-0.0002j	0.9971-0.0002j	0.9971-0.0001j
12	0.9959-0.0033j	0.9939-0.0041j	0.9933-0.0038j	0.9930-0.0036j	0.9929-0.0034j)	0.9928-0.0033j	0.9927-0.0033j	0.9926-0.0032j
13	0.9948-0.0035j	0.9937-0.0031j	0.9930-0.0028j	0.9925-0.0026j	0.9922-0.0025j)	0.9919-0.0025j	0.9917-0.0024j	0.9916-0.0024j
14	0.9943-0.0037j	0.9918-0.0043j	0.9895-0.0047j	0.9878-0.0049j	0.9864-0.0050j)	0.9854-0.0050j	0.9847-0.0050j	0.9841-0.0049j
15	0.9870-0.0090j	0.9800-0.0125j	0.9752-0.0143j	0.9718-0.0151j	0.9694-0.015j)	0.9676-0.0156j	0.9663-0.0156j	0.9654-0.0156j
16	0.9999+0.0010j	0.9999+0.0015j	0.9999+0.0018j	0.9999+0.0019j	0.9999+0.0020j	0.9999+0.0020j	0.9999+0.0021j	0.9999+0.0021j

The electric power system on the island of Bali is a radial transmission system with a weakly continuous loop. It can be seen in table 3 where the voltage on each bus has a voltage drop and the phase angle on each generator is different, but the comparison is not too great. As for the voltage from the bus nodes, good results are obtained, because in the system there is no voltage drop above 5% set by PLN

3.4. Result of Current Testing

Based on the power flow formula in the system electric power, then for the current test results on each busbar the results are as shown in table 4

Table 4 current test results

Bus	Arus	sudut
1	1.9705	0.1721
2	1.9705	0.1722
3	0.7635	-0.2114
4	0.3012	0.4709
5	0.0277	0.1708
6	0.2471	-1.2063
7	0.4070	0.1046
8	0.3698	0.2338
9	0.5184	0.2966
10	0.2036	0.1331
11	0.3528	-0.7704
12	0.4188	0.3641
13	0.3298	-1.4964
14	0.5375	-1.9734
15	0.1040	-1.3177
16	4.2714	-3.0283

while the comparison of the results of the voltage and current tests on each busbar is shown in Figure 5.

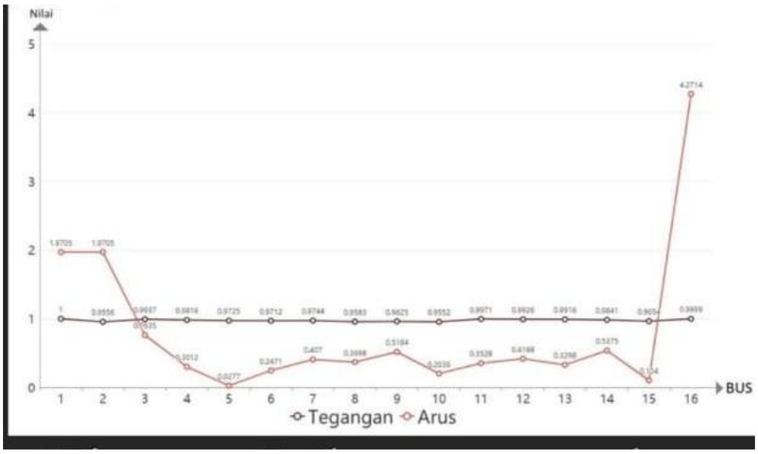

Figure 5 the comparison of the results of the voltage and current

3.5. Test results of Power Flow and Channel Power Losses

In the Bali Island electric power system, the power flow is determined based on the voltage and current values that have been obtained. As is known, the voltage has a voltage drop on each bus, so after doing the calculations, the power flow in the Bali Island system is shown in table 5.

Table 5 Power Flow in the Bali Electric Power System

Bus	Daya Terkirim	Bus	Daya diterima
S159	-0.0565+0.1813j	S915	0.0559-0.1809j
S1112	-0.1528+0.5486j	S1211	0.1504-0.5466j
S1312	-0.0413+0.0256j	S1213	0.0412-0.0256j
S1611	1.1877-0.7679j	S1116	-1.1825+0.7685j
S1613	-1.0020+0.7123j	S1316	0.9903-0.7108j
S1614	1.0690-0.8851j	S1416	-1.0457+0.8786j
S1615	1.0190-0.6537j	S1516	-0.9722+0.6491j

Based on table 5, the results of the power flow in the Bali system are obtained where the total capable power supplied by the generator is 1,275.6 MW with a reactive power of 429.93 MVar.

After obtaining the value of the power flow in the system, the next step is to obtain the apparent power value, namely converting the complex numbers of the power variables into phasor numbers, then finding the power loss values of each channel in the Bali Island power system shown in Table 6.

Table 6 Power Losses in Line

Pengirim		Penerima		Rugi-rugi Daya	
No.Bus	Daya MVA	No.Bus	Daya MVA	Saluran	Daya MVA
1	1.532 ∠-5,7	2	1,49∠-1,41	1 - 2	0,12∠73
3	0,581∠-8,47	1	0,52∠-10,98	3 - 1	0,065∠-11,84
1	0,4325∠-79,34	4	0,4246∠-79,94	1 - 4	0,009∠50
2	1,322∠10,34	3	1,2801∠-14,94	2 - 3	0,112∠-55,5
2	0,475∠-0,47	6	0,471∠7,19	2 - 6	0,055∠-82
3	0,581∠-56,79	7	0,569∠-58,58	3 - 7	0,021∠1,42
5	0,184∠81,86	4	0,183∠81,75	5 - 4	0,001∠-78,78
6	0,1206∠3,5	5	0,1205∠3,6	6 - 5	0,0002∠-61
7	0,1816∠35	6	0,181∠36	7 - 6	0.003∠-43,76
6	0,188∠57,27	8	0,185∠57,65	6 - 8	0.0032∠35
6	0,545∠-65,4	9	0,54∠-65,91	6 - 9	0.007∠21,65
13	0,404∠87,9	6	0,396∠-87,49	13 - 6	0,0085∠107,38
14	0,814∠-82,5	6	0,8036∠82,2	14 - 6	0,011∠104,5
7	0,293∠-71,35	8	0,288∠-72,72	7 - 8	0,0052∠17,78
9	0,2341∠-80,16	10	0,2324∠-80,52	9 - 10	0,0022∠39,57
15	0,1899∠-80,76	9	0,1893∠-80,92	15 - 9	0,0008∠39,4
11	0,5694∠-82,7	12	0,5669∠-82,9	11 - 12	0,0032∠44,37
13	0,0486∠-35,32	12	0,0485∠-35,39	13 - 12	0,0001∠4,68
16	1,414∠-36,53	11	1,410∠-36,68	16 - 11	0,0054∠-6,13
16	1,229∠-39,34	13	1,219∠-39,63	16 - 13	0,0117∠7,7
16	1,3878∠-44	14	1,3658∠-44,48	16 - 14	0,0248∠16,57
16	1,2106∠-36,31	15	1,1689∠-37,47	16 - 15	0,048∠6,87

Based on the data in table 6, there is some power flowing with a poor power factor value, there is a flow from bus 13 to bus 6 where the power factor is 0.025 then bus 14 to bus 6 of 0.13 and bus 6 to bus 5 of 0, 14, this value is very far from that set by PLN with a power factor value of 0.8 or 0.9. So it is necessary to improve the system to reduce the value of reactive power in the electric power system network, one of the efforts to improve the power factor is by using a capacitor bank.

4. Conclusion

This study suggests that it is required to improve the system in order to lower the value of reactive power in the electric power system network. Utilizing a capacitor bank is one of the strategies that may be utilized in an effort to improve the power factor.

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