MAKALAH SEMINAR HASIL

ANALISIS ALIRAN DAYA DENGAN KOMPUTASI PARALEL

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POWER FLOW ANALYSIS USING PARALLEL COMPUTATION

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***Abstract*- Power flow analysis of a electric power system is performed by solving power flow equations that involving an iterative process. Nowadays, it is simplified by using computer. It is necessary to use computer program to solving the load flow analysis. There are two approaches to execute the power flow analysis program based on the usage of the processor, i.e. sequential algorithm and parallel algorithm.**

In this paper, simulation of power flow analysis with parallel algorithm use three data IEEE power systems, i.e. 30 bus, 118 bus, and 300 bus. It use Newton Raphson methode to solving the power flow analysis. Power flow analysis simulation program is executed by using Matlab. Graphical User Interface (GUI) based application is formed to execute that program.

The result of simulation show that parallel algorithm accelerate computation of power system analysis in IEEE power system 118 bus and 300 bus. Voltage magnitude, voltage phase angle, and power losses of algorithm parallel is equal to sequential algorithm.

***Index Terms*- power systems, parallel algorithm, iteration time, voltage magnitude, voltage phase angle, power losses.**

***Abstrak*- Analisis aliran daya dari suatu sistem tenaga listrik dilakukan dengan cara menyelesaikan persamaan-persamaan aliran daya yang melibatkan suatu proses perulangan (iterasi). Saat ini, perhitungan aliran daya tersebut dipermudah dengan menggunakan komputer. Program komputer membantu perhitungan aliran daya. Berdasarkan penggunaan prosesor komputer, proses perhitungan aliran daya dapat dibedakan menjadi dua, yaitu perhitungan aliran daya komputasi sekuensial dan perhitungan aliran daya komputasi paralel**

Dalam skrispi ini, simulasi perhitungan aliran daya komputasi paralel menggunakan data sistem transmisi IEEE 30 bus, 118 bus, dan 300 bus. Metode aliran daya yang digunakan untuk melakukan simulasi adalah metode Newton Raphson. Simulasi dilakukan dengan menggunakan Matlab. Aplikasi berbasis Garphical User Interface (GUI) dibentuk untuk melakukan simulasi tersebut.

Hasil simulasi menunjukkan bahwa komputasi paralel mempercepat perhitungan aliran daya pada sistem transmisi IEEE 118 bus dan 300 bus. Besar tegangan, sudut fasa tegangan, dan rugi daya dari hasil perhitungan aliran daya komputasi paralel sama dengan komputasi sekuensial.

***Kata Kunci*- sistem transmisi, komputasi paralel, waktu iterasi, besar tegangan, sudut fasa tegangan, rugi daya.**

I. INTRODUCTION

Power flow analysis provides information voltage on each bus, current flows on each transmission line and power losses. Power flow analysis is performed by solving power flow equations that involving an iterative process. Therefore, the completion of the power flow equations requires an iterative method. Iterative method that used in this thesis is Newton Raphson method.

Nowadays, the computer is able to ease the process of power flow analysis computation that requires a iterative process. The computer program is used to compute power flow analysis. It accelerate power flow computation than compute manually. There are two approaches to execute the power flow analysis program based on the usage of the processor, i.e., sequential algorithm and parallel algorithm.

Sequential power flow computation is a power flow computation using conventional solutions such as sequential algorithms. Sequential algorithm is processed by computer using a single processor. These algorithms are often used for power flow computation. Whereas parallel power flow computation is power flow computation which is parallelized on multiple processors. This calculation is the development of sequential power flow computation which is executed togeether using multiple processors. In this paper will be performed comparison between sequential power flow computation and parallel power flow computation.

In this thesis, the power flow computation will be executed using Newton Raphson method that is parallelized on multiple processors. Power flow analysis with parallel computing will be simulated using the Parallel Computing Toolbox (PCT) Matlab R2010a. Simulations performed on IEEE transmission system 30 bus, 118 buses and 300 bus. From these simulations will be compared required iterative time of power flow computation between sequential and parallel computing. Moreover, it also comparing the simulation results from both the power flow computations.

II. LITERATURE

A. Power Flow Equations

The equation of power system can be expressed in the form of admittance as follows [5] :

$$I_{bus} = Y_{bus}V_{bus} \quad (1)$$

where

Ibus : current matrix on each bus

Ybus : admittance matrix

Vbus : voltage matrix on each bus

Equation (2) is a equation for compute power on each bus [3].

$$P_p - jQ_p = V_p^* \, i_{pq} \quad (2)$$

where

P_p : Active power on bus *p*

Q_p : Reactive power on bus *p*

V_p : Voltage on bus *p*

i_{pq} : Current on line *p* to *q*

Besides determining power on each bus, power flow analysis is also used to determine power loss on transmission line during power distribution from power plant to the load center.

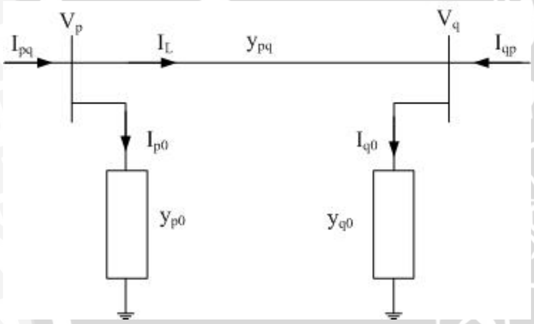

Figure 1 Transmission line model for power flow computation
(Source: Nugroho, 2008)

Notice the line connected between bus *p* and *q* at Figure 1. Line current I_{pq} which is measured from bus *p* and considered positive for direction *p* to *q*, can be expressed in Equation (3) [6].

$$I_{pq} = I_L + I_{p0} = y_{pq}(V_p - V_q) + y_{p0}V_p \quad (3)$$

where

I_{pq} : Current on bus *p*

I_L : Line current between bus *p* and bus *q*

I_{p0} : Half line charging current

y_{pq} : Admittance between bus *p* and bus *q*

y_{p0} : Half line charghing

V_p : Voltage on bus *p*

V_q : Voltage on bus *q*

Similarly, Line current I_{qp} which is measured from bus *p* and considered positive for direction *q* to *p*, can be expressed on Equation (4)

$$I_{qp} = -I_L + I_{q0} = y_{pq}(V_q - V_p) + y_{q0}V_q \quad (4)$$

Complex power S_{pq} from bus *p* to *q* and S_{qp} from bus *q* to *p* is expressed on Equations (5) and (6) [6].

$$S_{pq} = V_p I_{pq}^* \quad (5)$$

$$S_{qp} = V_q I_{qp}^* \quad (6)$$

Power loss in line *pq* is sum of rated power which is determined from Equations (5) and (6), so that can be expressed in Equation (7).

$$S_{L\ pq} = S_{pq} + S_{qp} \quad (7)$$

Total power loss equation for system with *n* number of bus is expressed in Equation (8) [6].

$$S_{LT} = \sum_{p=1}^{n}\sum_{q=1}^{n} S_{L\ pq} \quad (8)$$

where

$S_{L\,pq}$: Power loss on line between bus *p* and *q*

S_{LT} : Total power loss

B. Newton Raphson Method

Power flow problem can be solved by using Newton Raphson method that use nonlinier equations. It express active and reactive power as voltage magnitude and voltage phase angle function. Consider $V_p = V_p\angle\theta_p$, $Y_{pq} = G_{pq} + jB_{pq}$, and $\theta_{pq} = \theta_p - \theta_q$, power equation on bus *p* can be expressed in Equation (9) [5] :

$$P_p - jQ_p = V_p\,I_p^* = V_p\sum_{q=1}^{n}(G_{pq} + jB_{pq})V_q\angle(\theta_q - \theta_p) \quad (9)$$

By splitting the real and imaginary parts of Equation (9), it is obtained active and reactive power equation as follows [5]:

$$P_p = V_p\sum_{q=1}^{n}V_q\left(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq}\right) \quad (10)$$

$$Q_p = V_p\sum_{q=1}^{n}V_q\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right) \quad (11)$$

With linearization, will obtain a linier system in $\Delta\delta$ and $\Delta V/_V$ that can be writtem in Equation (12) [3]:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}H & N\\ J & L\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V/_V\end{bmatrix} \quad (12)$$

where

$$\Delta P_p = P_p^{diket} - V_p\sum_{q=1}^{n}V_q\left(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq}\right) \quad (13)$$

$$\Delta Q_p = Q_p^{diket} - V_p\sum_{q=1}^{n}V_q\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right) \quad (14)$$

$$p = 1,2,3,\dots(p \neq slack\ bus)$$

The equations to determine jacobian matrix elements can be derived from power equations. Jacobiam matrix element is given in following equations:

- For p ≠ q

$$H_{pq} = \frac{\partial P_p}{\partial\delta_q} = V_pV_q\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right) \quad (15)$$

$$N_{pq} = V_q\frac{\partial P_p}{\partial V_q} = V_pV_q\left(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq}\right) \quad (16)$$

$$J_{pq} = \frac{\partial Q_p}{\partial\delta_q} = V_pV_q\left(-G_{pq}\cos\theta_{pq} - B_{pq}\sin\theta_{pq}\right) \quad (17)$$

$$L_{pq} = V_q\frac{\partial Q_p}{\partial V_q} = V_pV_q\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right) \quad (18)$$

- For p = q

$$H_{pp}=\frac{\partial P_p}{\partial \delta_p}=-Q_p-B_{pp}{V_p}^2 \quad (19)$$

$$N_{pp}=V_p\frac{\partial P_p}{\partial V_p}=P_p+G_{pp}{V_p}^2 \quad (20)$$

$$J_{pp}=\frac{\partial Q_p}{\partial \delta_p}=P_p-G_{pp}{V_p}^2 \quad (21)$$

$$L_{pp}=V_p\frac{\partial Q_p}{\partial V_p}=Q_p-B_{pp}{V_p}^2 \quad (22)$$

If bus p is bus PV where value of Q_p is not initialized, so it isn't obtained value of ΔQ_p. Otherwise, due to voltage magnitude is constant so that value of $\Delta V_p = 0$ [5].

The result from Equation (12) are the difference of voltage magnitude ($^{\Delta V}/_{V}$) and the difference of voltage phase angle (Δθ). To obtain new voltage magnitude and voltage phase angle use Equations (23) dan (24) [3].

$$\theta^{baru}=\theta^{lama}+\Delta\theta \quad (23)$$

$$V^{baru}=V^{lama}+\frac{\Delta V}{V}V^{lama} \quad (24)$$

where

θ^{baru}	: New voltage phase angle
θ^{lama}	: Old voltage phase angle
$\Delta\theta$	: Difference of voltage phase angle
V^{baru}	: New voltage magnitude
V^{lama}	: Old voltage magnitude
$^{\Delta V}/_{V}$	: Difference of voltage magnitude

C. LU Decomposition

LU decomposition is a modification of the elimination method. Here, we decompose the coficient matrix A into the product of two triangular matrices in the form [2] :

$$A = LU \quad (25)$$

where L is a lower triangular matrix and U is the upper triangular matrix. Both are the same size as coficients matrix A. There are two method for solving LU Decomposition method, i.e. Doolittle method (Gauss Elimination) and Crout method. In this paper use Doolittle method [2].

The general forms of L and U are written as :

$$L=\begin{bmatrix}1 & 0 & \dots & 0\\ l_{21} & 1 & \dots & 0\\ \vdots & \vdots & & \vdots\\ l_{n1} & l_{n2} & \dots & 1\end{bmatrix},\quad U=\begin{bmatrix}u_{11} & u_{12} & \dots & u_{1n}\\ 0 & u_{22} & \dots & u_{2n}\\ \vdots & \vdots & & \vdots\\ 0 & 0 & \dots & u_{nn}\end{bmatrix} \quad (26)$$

Such that $l_{ij}=0$ for $i<j$ and $u_{ij}=0$ for $i>j$. Consider a linier system

$$Ax = b \quad (27)$$

And let A be factored into the product of L and U, as shown by Equation (26). The linier system Equation (27) become:

$$LUx = b \quad (28)$$

Equation (28) can be derived to Equations (29) and (30)

$$Ux = y \quad (29)$$

$$Ly = b \quad (30)$$

The unknown elements of matrix L and matrix U are computed by equating corresponding elements in matrices A and LU in a systematic way. Once matrices L and U have been constructed, Equation (28) can be solved in the following two steps [2]:

1. Solving the system $Ly = b$

   Using forward elimination, we will find the components of the unknown matrix y using following steps:

$$y_1 = b_1 \quad (29)$$

$$y_i = b_i - \sum_{j=1}^{i-1} l_{ij}\, y_j \quad (30)$$

2. Solving the system $Ux = y$

   Using backward subtitution, we will find the components of unknown matrix x using following steps:

$$x_n = \frac{y_n}{u_{nn}} \quad (31)$$

$$x_i = \frac{1}{u_{ii}} y_i - \sum_{j=i+1}^{n} u_{ij}\, x_j \quad (32)$$

$$i = n-1, n-2, \dots, 1$$

D. Parallel Computing Toolbox (PCT)

Matlab has developed Parallel Computing Toolbox (PCT) which is required in all parallel aplications. PCT has developed from Matlab version 2008a until now [1]. Parallel Computing Toolbox solve computationally and data-intensive problems using multicore processors, GPUs, and computer clusters. The PCT allows users to run up to 12 MATLAB Labs or Workers on a single machine [4]. Figure 2 show architecture of Parallel Computing Toolbox.

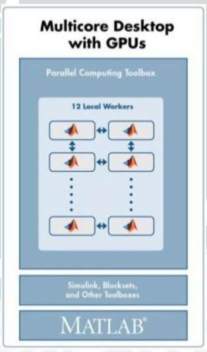

Figure 2 Parallel Computing Toolbox
(Source: Samsi, 2008)

PCT has functions which is used to compute in parallel processing. Several function which is used in this paper as follows:

1) *matlabpool*

   This function is used to reserves a collection of MATLAB worker to run loop iterations.

2) *spmd*
   This function is used to run parallel computing in single program multiple data (SPMD).
3) *codistributed*
   This function can distribute array or matrix to parallel workers, so the array can be processed in parallel processing.
4) *gop* dan *gcat*
   Function *gop* is used to compute with general operation in each worker. Function *gcat* is used to arrange matrix vertically from each prosesor.

III. RESEARCH METHODOLOGY

Data used are secondary data that sourced from reference book, jurnal, and essay that relevant to this paper. These are IEEE transmission system data 30 bus, 118 bus, and 300 bus. This research steps of paralel computing power flow analysis is figured in Figure 3.

In this paper, it is made a interface that use GUIDE toolbox in Matlab. This interface use to simulate the parallel computing power flow analysis. Power flow analysis simulation use Newton Raphson method. From simulation result, it is analyzed as follow:

1. Comparing the result of sequential computing and parallel computing.
2. Analyse voltage and power loss of power flow computing result on IEEE transmission systems 30 bus, 118 bus, and 300 bus.
3. Comparing time required to iteration between sequential computing and parallel computing.

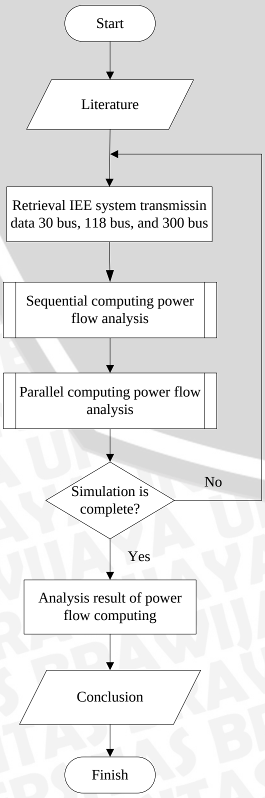

Figure 3 Flowchart of research

IV. RESULT AND DISCUSSION

In this section will be discussed parallel computing on power flow analysis. Problems will be discussed are power sysem stability and power flow computation speed using parallel computing. Data used is IEEE transmission system data 30 bus, 118 bus, and 300 bus.

A. Data Processing

Data processing is performed to establish data transmission system become data matrix. It is used for computation of power flow analysis.

1. Sequential Matrix Data Processing

From the transmission system data, it is formed data matrix as input data of power flow computation. This matrices is used on sequential computation of power flow analysis. It has matrix dimension correspond to number of transmission system bus is used. For IEEE transmission system 30 bus, voltage magnitude matrix (V), voltage phase angle matrix (θ), and power (Sbus) have matrix dimension 30x1. While for the admitance matrix (Ybus) has matrix dimension 30x30.

2. Parallel Matrix Data Processing

Data matrix of parallel computing is used to parallel computing on power flow analysis. It is distributed corresponding to number of processor. Matrix V, θ, Ybus, and Sbus is distributed by distribute matrix dimension become 2 matrix. Matrix V, θ, and Sbus have matrix dimension 15x1 on each prosessor. While matrix Ybus has matrix dimension 15x30 on each prosessor.

B. Power Flow Simulation

Power flow simulation is done in two ways, i.e. computing power flow simulation of sequential and parallel computing.

1. Sequential Computing Power Flow Simulation

Simulation results using sequential computational power flow analysis applications in IEEE data transmission systems 30 bus is found in Figure 4. Simulation is also computed with IEEE transmission system 118 bus and 300 bus. The simulation is computed with the variation of different error. The generally simulation results is contained in Table 1.

Table 1 The computation result of sequential computing

Number of Bus	Error	Iteration	Iteration Time (second)
30 bus	$1x10^{-3}$	3	0,0128
	$1x10^{-6}$	5	0,0258
	$1x10^{-8}$	6	0,0281
118 bus	$1x10^{-3}$	2	0,1878
	$1x10^{-6}$	4	0,3668
	$1x10^{-8}$	6	0,5243
300 bus	$1x10^{-3}$	4	5,0549
	$1x10^{-6}$	6	7,0296
	$1x10^{-8}$	8	9,8259

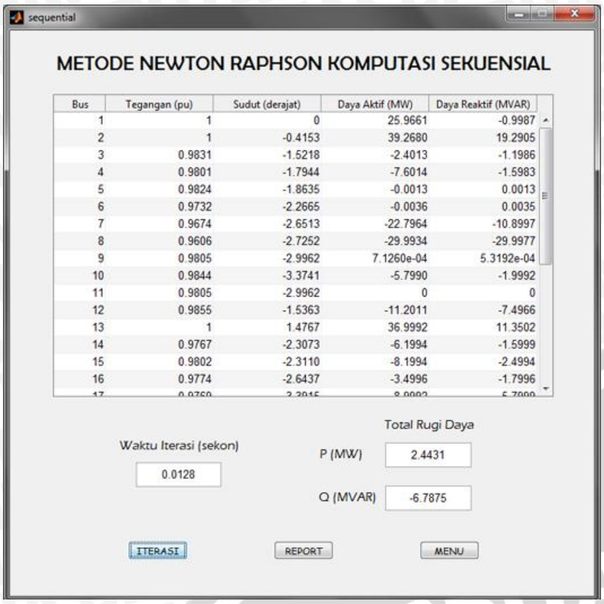

Figure 4 Sequential computational simulation results of IEEE transmission system 30 bus
(Source: Simulation result)

2. Parallel Computing Power Flow Analysis

The simulation results using the parallel computing power flow analysis applications in data transmission systems IEEE 30 buses are in Figure 4.

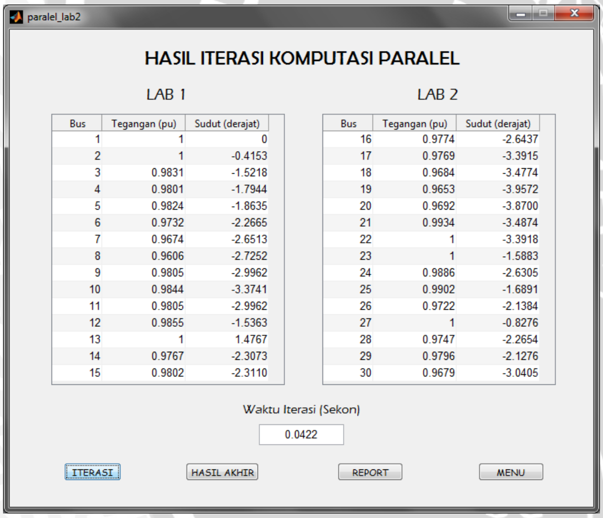

Figure 5 Parallel computational simulation results of IEEE transmission system 30 bus
(Source: Simulation Result)

Simulation is also computed with IEEE transmission system 118 bus and 300 bus. The simulation is computed with the variation of different error. The generally simulation results is contained in Table 2.

Table 2 The computation result of parallel computing

Number of Bus	Error	Iteration	Iteration Time (second)
30 bus	$1x10^{-3}$	3	0,0422
	$1x10^{-6}$	5	0,0692
	$1x10^{-8}$	6	0,0821
118 bus	$1x10^{-3}$	2	0,1106
	$1x10^{-6}$	4	0,2209
	$1x10^{-8}$	6	0,3229
300 bus	$1x10^{-3}$	4	2,0082
	$1x10^{-6}$	6	2,8727
	$1x10^{-8}$	8	3,7113

C. Power Loss Computation

Power losss of transmission system is computed using Equation (7). The voltage used is the voltage iteration results of power flow computation. Total power losses of the system can be computed by summing the power loss of each line transmission as shown in Equation (8). Total power losses for each data transmission system can be seen in Table 3. In Table 3 shows that the power which is required by the load is met with a total power loss of each system.

Table 3 Total power loss of transmission system

Number of Bus	Total Power Loss	
	P_{total} (MW)	Q_{total} (MVAR)
30 bus	2,4431	-6,7875
118 bus	132,8628	-642,3161
300 bus	409,5265	195,7385

D. Analysis of Power Flow Simulation Result

In this paper, the analysis of the power flow simulation results with sequential and parallel computing includes the analysis of the results of the iteration time, comparing the results of sequential and parallel computing, and voltage analysis of power flow computation in each system tranmsisi IEEE.

1. Iteration Time

According to the results in Table 4, the time iteration generated by parallel computing are not all much faster than sequential computing. Transmission systems IEEE 118 bus and 300 bus iteration produces a more rapid parallel computation, while the transmission of IEEE 30 bus system produces a slower time. This is because the processors are capable of processing data matrix with 30x1 and 30x30 order quickly.

Table 4 Comparison of sequential and parallel computing iteration time

Bus	Error	Iteration	Iteration Time (second)		Difference Time
			Sequential Computing	Parallel Computing	
30 bus	$1x10^{-3}$	3	0,0128	0,0422	-0,0294
	$1x10^{-6}$	5	0,0258	0,0692	-0,0434
	$1x10^{-8}$	6	0,0281	0,0821	-0,0540
118 bus	$1x10^{-3}$	2	0,1878	0,1106	0,0772
	$1x10^{-6}$	4	0,3668	0,2209	0,1459
	$1x10^{-8}$	6	0,5243	0,3229	0,2014
300 bus	$1x10^{-3}$	4	5,0549	2,0082	3,0467
	$1x10^{-6}$	6	7,0296	2,8727	4,1569
	$1x10^{-8}$	8	9,8259	3,7113	6,1146

Based on the calculation of time difference generated by each data transmission systems IEEE 118 bus and 300 bus, it can be proved that parallel computing can do iterations faster than sequential computing. Computation using parallel computing produce iterations same amount of sequential computation, but the time needed to iterate faster. Moreover, with the increasing number of iterations, the power flow analysis using parallel computing can compute faster than sequential computing. This can be evidenced by greater number of iterations, more iteration time difference between sequential and parallel computing.

2. Comparison of Sequential and Parallel Computing Results

From the calculation in Figure 4, we can see results of the IEEE 30 bus transmission system power flow computation using parallel computing. It generate voltage magnitude and voltage phase angle equal to the sequential computational results in Figure 5. The number of iterations from any data transmission system also has the same amount. Computation with IEEE transmission systems data 118 bus and 300 bus are also generating voltage magnitude and phase angle of the same voltage with the results of sequential computing.

The same results from both computational due to parallel computing only distribute data matrix on each processor in its computing process. While each processor using the same program to process the data. Purpose of distribution data matrix is that each processor get matrix with its dimensions smaller than initial matrix so that the processor can process data faster.

3. Results Analysis

From the simulation results, the power flow computation using parallel computation is performed in distributed matrix on 2 processor. This results are merged into a matrix of non-distribution. It can be analyzed or used for other calculations.

From the calculation of the transmission system IEEE 30 buses and 118 bus, the voltage generated is between the minimum and maximum voltage of the system tramisi. It is proved that transmission system IEEE 30 buses and 118 buses have a great system. While the 300 bus transmission system, some of the voltage of the bus system is in excess of the maximum voltage and the voltage is less than the minimum. With the large voltages that exceed or are less than the required voltage transmission system is not so good..

V. CONCLUSIONS AND ADVICES

A. Conclusions

In this paper, it is obtained several conclusions as follows:

1. Voltage magnitude and voltage phase angle of parallel computing have same value as voltage magnitude and voltage phase angle of sequential computing. So, parallel computing can be implemented for power flow analysis.
2. In IEEE transmission system 118 bus and 300 bus, iteration time of parallel computing is faster than iteration time of sequential computing.
3. Parallel computation accelerate power flow computation in large transmission system. This can be evidance by greater number of transmission system bus, more iteration time difference between sequential and parallel computing.
4. Power flow computation which generate large amount of iterations is computed faster using parallel computing. This can be evidance by larger amount of iterations, more iteration time difference between sequential and parallel computing.

B. Advices

Advices that can be given for this paper are:

1. Parallel computation can be simulated on power flow analysis with more than 300 bus transmission systems.
2. Power flow analysis using parallel computation can be developed by using other power flow analysis method.
3. This parallel computation program can be developed with more than to processor tha is used.

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