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Small Signal Stability Analysis of Kalimantan 500 KV Electricity System

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***Abstract*— Small signal stability refers to the ability of a system to return to equilibrium after experiencing a small disturbance. In this research, the Kalimantan electricity system will be analyzed for the stability of its small signal. Analysis of the stability of small signals in electrical systems including local disturbances and inter-area disturbances. The Kalimantan system will be analyzed using Power Factory software. System analysis was carried out by evaluating the eigenvalues (real part and imaginary part), oscillation frequency (damped frequency and frequency ratio) produced in the Kalimantan 500 KV electricity analysis. In the analysis results, the Kalimantan system is categorized as stable as indicated by the real part and imaginary part values located on the negative side of the Cartesian coordinate curve. Then, analyzing small signals, there are 117 modes categorized as local mode and 4 modes categorized as inter area mode.**

Keywords—Frequency, Eigenvalue, Small Signal, Oscillation
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I. INTRODUCTION

Small signal stability (small disturbance) is the ability of a power system to maintain synchronism when small scale disturbances occur[1]. Disruptions like this occur continuously in the system due to variations in load and generation. The disturbances are considered small enough to make the linearization of the system equations acceptable for analytical purposes. The possible instability can occur in two forms, namely a steady increase in rotor angle due to a lack of synchronizing torque, and rotor oscillations with increased amplitude due to a lack of damping torque[2]. The nature of the system's response to small disturbances depends on source factors including initial operation, power of the transmission system, and the type of generator excitation control used. For generators connected radially to large power systems, if there is no automatic voltage regulator (i.e. with constant field voltage), torque [3]. Instability is caused by the lack of sufficient synchronizing This results in instability through non-oscillatory modes. The problem of small disturbance stability is one of the efforts to ensure sufficient damping of system oscillations. Instability usually occurs through oscillations with increasing amplitude. In an electric power system, stability can be in the form of frequency stability, voltage stability, and rotor angle stability. Rotor Angle Stability is a way for synchronous electromechanical machines in an electrical power system to remain in sync. Frequency stability is the ability of a power system to maintain a steady state frequency condition due to disturbances[4]. Meanwhile, Voltage Stability is the stability of the electric power system to be able to maintain acceptable voltage values when contingencies or disturbances occur. Small signal stability is related to the ability of a system to maintain machine units connected in a system so that they remain in synchronized condition immediately after a disturbance occurs. The word "small" indicates that there is a disturbance of small magnitude in the system which is related to the rotor angle between the synchronous machines[5]. Small signal stability is a problem due to system disturbances in the form of variations in loading and generation in its electromechanics which causes the mechanical input power of the generator to change slowly while the electrical output power changes quickly, this will affect the rotor speed.

A related small signal stability analysis will be carried out on the Kalimantan electricity network system. Kalimantan's electricity system is divided into three main regions, namely West Kalimantan, East Kalimantan and South Kalimantan. In this research small signal stability will be carried out on the West Kalimantan electricity system. The small signal analysis carried out is related to the electromechanical oscillatory mode. Electromechanical analysis aims to determine the modes in the generator that experience small signals[6].

Electromechanical power plants or generators are an important part of the power generation system. In terms of electrical stability, the generator has two components in the form of a rotor and a stator. The rotor contains a magnetic field and produces voltage in the stator windings. This induced voltage produces electrical output in the generator. Small disturbances in the generator (small signal stability) are caused by a lack of damping torque due to shifts in operating conditions or errors in control equipment settings. Another cause is a lack of synchronization torque that occurs during peak loads [7].

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II. EIGEN VALUE IN POWER STABILITY

Eigenvalue is a scalar number from a matrix A which can be a characteristic of an eigenvalue matrix denoted as λ. Eigenvalue is a value that can show how much influence a variable has on the formation of the characteristics of a matrix. Eigenvalue is obtained based on the equation:

:

$$\boldsymbol{A\phi} = \boldsymbol{\lambda\phi} \quad (1)$$

The characteristic of a time-domain mode in a system based on the eigenvalue λ corresponds to the equation λt. Thus, a system can be determined its stability based on eigenvalue with the following conditions:

a. Real eigenvalue relates to the mode of non-oscillation. A negative real value of the eigenvalue indicates a decaying mode. The greater the magnitude, the faster the decline. Conversely, a positive real value of an eigenvalue indicates an unstable state of a system.

b. Complex eigenvalues appear in the form of conjugate pairs, each value corresponding to an oscillating mode. The real value of the complex eigenvalue gives information about attenuation while the imaginary part gives information about the frequency of oscillations. A negative value of the real part indicates a muffled oscillation while a positive value indicates an oscillation whose amplitude continues to increase.

The complex eigenvalue is given as follows:

$$\lambda = \sigma \pm j\,\omega \quad (2)$$

Where the oscillation frequency in Hz is :

$$f = \omega\ 2\pi \quad (3)$$

And the damping ratio is obtained based on:

$$\zeta = -\sigma\ \sqrt{\sigma}\ 2 + \omega 2\ (2.17) \quad (4)$$

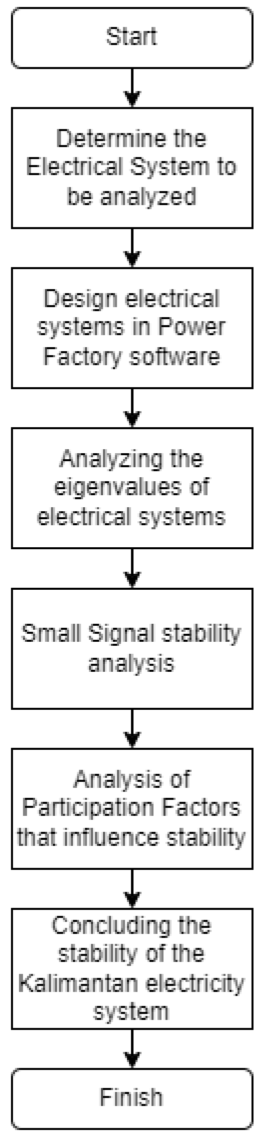
When the system has been revealed into a state space analysis or block diagram, the system analysis can be known through its eigenvalue. The stability of a nonlinear system from small disturbances is given from the roots (eigen) equations characteristic of the system :

a. If the eigenvalue is negative, then a system can be said to be stable
b. If one of the roots is positive, then a system is said to be unstable
c. If the real value of the eigenvalue is close to zero, then it cannot be said that the system is stable or not (critical).

III. METHOD

A. Flowchart

The following flowchart shows the mechanism for analyzing small signal stability in the Kalimantan 500 kV electricity system. In this small signal analysis, we first map the location of the generator in the Kalimantan area which consists of West, South and East Southeast Kalimantan. Then proceed with eigenvalue analysis (real part and imaginary part). Eigenvalue analysis is used to determine whether the system is in a stable state or not. Next, small signal analysis is carried out in the Power Factory software. A small disturbance in the Kalimantan electrical system can be analyzed by what modes participate in the small signal. So, based on the small signal analysis, the electrical system can be analyzed in terms of its stability and it can be seen what modes have an effect on this stability.



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B. Distribution of Generator Locations

Kalimantan Island is the 2nd largest island owned by Indonesia. Kalimantan Island consists of various provincial regions which are governmentally divided into South Kalimantan, North Kalimantan, Central Kalimantan, East Kalimantan, and West Kalimantan. With an area reaching 4 times the size of Java island which is 539,238 km^2, Kalimantan needs a qualified power plant and system. Therefore, it can be found steam power plants, gas power plants, hydroelectric power plants, and other plants located in Kalimantan. This is to meet the electricity needs of the island of Kalimantan. To facilitate the division of power areas in Kalimantan, make a grouping based on the geographical area of the island of Kalimantan. These areas include Kaltimra (East Kalimantan and North Kalimantan), Central Kalimantan (South Kalimantan and Central Kalimantan), and West Kalimantan (West Kalimantan).

Figure 1 Kalimantan Power Plant Distribution

The transmission network between Kalimantan provinces is connected to a 500 kV backbone transmission network. The 500 kV transmission network connects the regions of Kaltimra, Central Kalimantan and West Kalimantan. The single line diagram for the East Kalimantan region is located in the bottom box, Central Kalimantan on the right and West Kalimantan in the left box. In a single line diagram, there are generally several components such as a transformer, circuit breaker, busbar, and shunt filter. The transformer functions to reduce the voltage from 500 kV to 500 kV for consumer needs. For every busbar and transformer division, there is a circuit breaker that protects electronic equipment. This aims to ensure that if disturbances such as over current occur, electronic equipment is not damaged. Apart from that, to improve power quality, a shunt filter is also installed on the 500 kV single line transmission diagram. This device functions as a filter to reduce current harmonics and increase the power factor according to the standards used.

C. Single Line Diagram of the Plant

The division of the East Kalimantan generation area includes East Kalimantan and North Kalimantan. In this area there are several generating areas with a total of 16 plants. Each plant generally has several generators. Such as the Tabang hydropower plant in Kutai Kartanegara, East Kalimantan. The Tabang Plant consists of 4 hydroelectric power plants with an engine capacity of 100 MW, producing a total of 400MW in the Tabang area. Of course, this power is channeled to meet other areas around Tabang such as Kembang Janggut, Muara Bengkal to Muara Wahau.

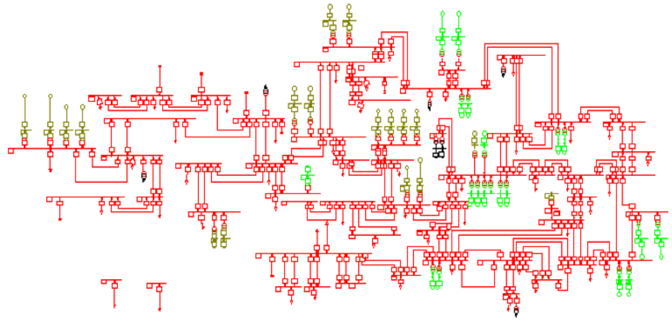

Figure 2 North and East Kalimantan Electricity System

The division of the Central Kalimantan generation area includes South Kalimantan and Southeast Kalimantan. In this area there are several generating areas with a total of 12 plants. Just like Kaltimra, there are several generating machines in one plant area. These plants also consist of steam (coal) power plants, hydroelectric power plants and gas power plants. Plants spread across the Central Kalimantan area are responsible for supplying electrical energy to at least 27 districts/cities located in the Central Kalimantan area.

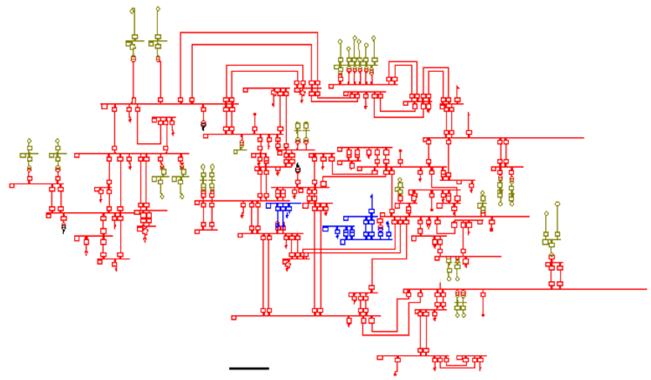

Figure 3 South and Center Kalimantan Electricity System

The division of the West Kalimantan generation area has an area of at least 147 km2. An area of 147 km2 covers 14 districts/cities in West Kalimantan province. In the single line diagram, it can be found that there are at least 5 generating plants that support 14 surrounding districts/cities. One of them is in the Parit Baru area in Kubu Raya Regency. In this area there are 10 PLTU generating machines connected to 500 kV to 11kV step down transformers via busbars in the Parit Baru area.

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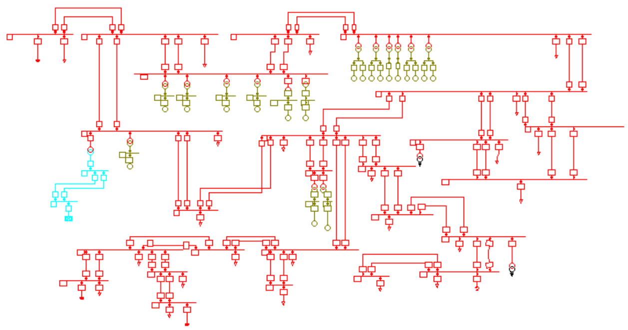

Figure 4 West Kalimantan Electricity System

IV. RESULT

A. Eigenvalue Analysis

The eigenvalue determines the dynamic characteristics that represent the stability of a mode in a power grid system. Mode itself is a form of representation on a particular oscillation in the system. Each mode has its own characteristics, including its associated frequency, amplitude, and waveform. Eigenvalue will determine the linear dynamics matrix of a mode under stable or unsteady conditions.

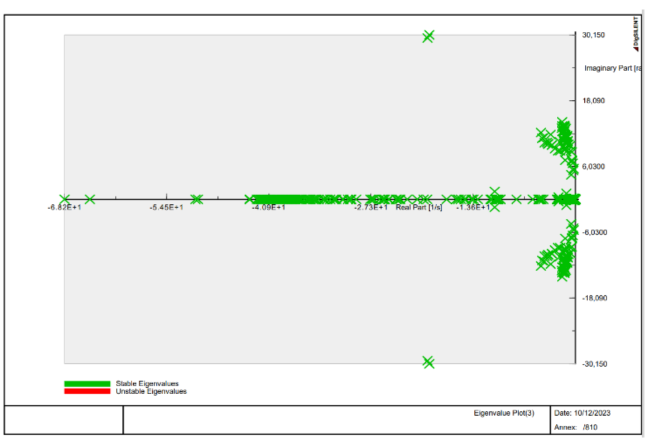

Figure 5 Eigenvalue of Kalimantan 500kV 2050 Electricity System Modes

The eigenvalue determines the dynamic characteristics that represent the stability of a mode in the electric power network system. The mode itself is a form of representation of a particular oscillation in the system. Each mode has its own characteristics, including frequency, amplitude, and associated waveform. The eigenvalue will determine whether the linear dynamics matrix of a mode is in a stable condition or not.

The value of an eigenvalue can be positive or negative. A positive eigenvalue indicates unlimited fluctuation in a mode. This causes significant instability and disruption of each participating factor in such a mode. On the other hand, if the eigenvalue in a mode is negative, then this indicates that fluctuations in the system tend to dampen themselves and will reach stability.

The Eigenvalue of a mode is taken from several factors, such as system stability (Real Part), which if it shows a positive value, represents instability and conversely, a negative value shows stability. The next factor is the Imaginary Part which is related to the oscillation frequency of a system, which provides information on the value or level of oscillation of a mode. Then another frequency is the damping ratio or damping ratio which is the ratio between the real part and the imaginary part which provides information on how fast the oscillation mode in the system dampens the system itself. And many other factors.

It can be seen in the picture above that the diagram shown is a diagram between the imaginary part (Y Axis) and the real part (X Axis). Each green X mark on the diagram is an indication of the eigenvalue of each mode. It can be seen that the eigenvalue of each mode is negative in the real part and this indicates that each mode in this network system is stable. If there is a red X, it means instability.

B. Local Mode Analysis of Power Plants

Determining the local mode is by analyzing the combined swings of several generator units in an area or one generating station unit. In the condition of multiple generators in one plant location, local mode indicates the occurrence of opposite oscillations between one generator and another. Analysis of local mode in Kalimantan electricity network as described in the literature by analyzing the frequency of the generator with a frequency range of 0.7 Hz – 2 Hz. So by analyzing the frequency shown on the generator through the frequency indicated by the generator. A total of 117 modes in the Kalimantan electricity system are experiencing local mode. The oscillating frequency occurs in the frequency range of 0.7 Hz - 2.0 Hz.

Table 1 Local Area Modal Analysis

Mode	Real Part(1/s)	Imaginary Part(rad/s)	Damped Frequency(Hz)	Damping Ratio(%)	Damping Time Const.(s)
Mode 00184	-1.778229239	12.47071404	1.984775784	0.141164517	0.562357191
Mode 00185	-1.778229239	-12.47071404	1.984775784	0.141164517	0.562357191
Mode 00186	-1.595785109	12.44680455	1.98097047	0.127167525	0.626650791
Mode 00187	-1.595785109	-12.44680455	1.98097047	0.127167525	0.626650791
Mode 00192	-1.498440745	12.41185271	1.975407711	0.11985631	0.66736039
Mode	-1.498440745	-12.41185271	1.975407711	0.11985631	0.66736039

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00193					
Mode 00168	-4.601777801	12.22488129	1.945650286	0.352294191	0.21730732

C. Inter Area Mode Analysis of Power Plants

Inter area mode is the swinging of several generators in one part of the system against generators in another. This is due to two or more generators being paired in a connected and interconnected manner. The basic difference between local mode and inter area mode is that inter area mode occurs under the condition that multi generators oscillate as opposed to other multi generators in other plants. Inter-area analysis can be done by observing the frequency of oscillations that occur in the range between 0.1 to 0.8 Hz.

Mode	Real Part (1/s)	Imaginary Part (rad/s)	Damped Frequency (Hz)	Damping Ratio (%)	Damping Time Const. (s)
Mode 00306	-10.75386128	1.432627572	0.22800976	0.991242634	0.092989855
Mode 00307	-10.75386128	-1.432627572	0.22800976	0.991242634	0.092989855
Mode 00402	-1.200289323	1.103168709	0.175574753	0.736266352	0.833132463
Mode 00403	-1.200289323	-1.103168709	0.175574753	0.736266352	0.833132463

Table 3 Intra Area Modal Analysis

D. Participation Factor Analysis

In the study of electric power system stability analysis, there are various kinds of analysis of various conditions of an electric power system. One of them is Capital Analysis. Modal analysis is used to identify a frequency oscillation that can occur in a system. Capital analysis includes several identification of the state of a system such as frequency analysis, rotor angle, rotor speed, Imaginary Part, Real Part, and so on. With capital analysis, it will be known various kinds of oscillations that exist in a system.

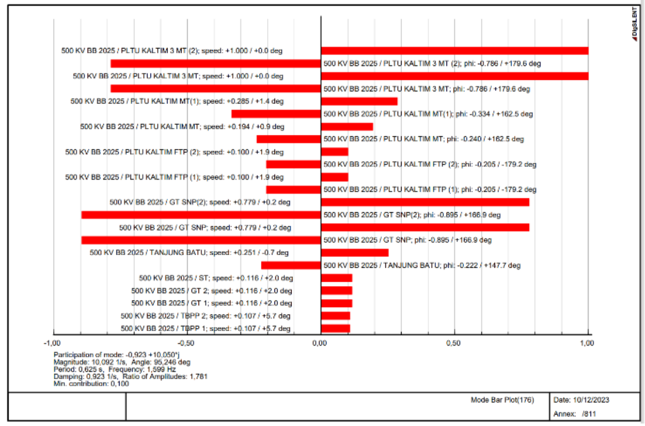

Figure 6 Mode Participation Factor Bar Plot

Participation Factor is an analysis that shows the large or small participation of various elements or factors in a "mode" in a particular electric power system. The mode itself is a form of representation of a particular oscillation in the system. Each mode has its own characteristics, including frequency, amplitude, and associated waveform. These participation factors help in understanding the extent of certain elements in each mode. The image above is a bar plot visualization of factor participation from one particular mode of the 500 kV Kalimantan 2025 electricity network system. It can be seen from the bar plot that each element in the system, such as generators, transmission lines, loads will have different participation factors in the analysis. certain. The bar graph will show the amount of contribution or participation of each element in the form of different bars in the graph, such as the rotor speed and rotor angle of each plant or generator in the system. With this, it can also be seen what type of electromechanical oscillation mode occurs in that mode, such as local area, inter plant, and inter area, and others.

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V. Conclusion

In the analysis of the stability of the small signal 500 KV Kalimantan electrical system, the important points were concluded as follows:

1. The analysis was carried out on the island of Kalimantan with the distribution of generators analyzed in the areas of West Kalimantan, Southeast East Kalimantan, North South Kalimantan.
2. A total of 117 modes in the Kalimantan electrical system experience local mode. The oscillation frequency occurs in the frequency range 0.7 Hz - 2.0 Hz
3. A total of 4 modes in the Kalimantan electricity system experience inter area mode. The oscillation frequency occurs in the frequency range 0.1 Hz - 0.7 Hz
4. The eigenvalues or characteristic values of the Kalimantan generator, analyzed using Power Factory

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software, show stable results. This conclusion can be seen from the real part and imaginary part values located in the graph on the left.

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