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Stability of Sabah Grid System

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Abstract

A power system operating condition should be stable, meeting various operational criteria, and be secured in the event of any credible contingency at any time. However, in the present day, most of the power systems are being operated closer to their stability limits due to economic and environmental constraints. Consequently, the power system networks are at risk to the disturbances that lead to the major blackout or in worst case scenario may causing the grid system totally collapse. Therefore, maintaining a stable and secure operation of power system is very important and challenging issue. In the literature there are a numbers of works proposing a variety of methodologies for conducting the analysis of stability problems. In this article, the authors use the steady state and dynamic analysis for the stability problem in Sabah Grid System. Several case studies are also presented in this article to demonstrate the system stability.

Keywords: ***Stability analysis; Steady state analysis; Dynamic analysis; Sabah grid system; Power system stability.***

1. Introduction

Over the past years, stability problem has caused many blackouts to the power grid system in various countries all over the world. For the past five years, there are a few major blackout events happened in the Sabah grid System due to the stability problem that led to the Sabah total blackout.

The load demand in Sabah is continually increasing every year but the transmission capacity has not grown as much as the demand. The aging existing equipment in the transmission network is being operated closer to their stability limits. As a result, the power system networks are at risk to the disturbances that lead to the major blackout or in worst case scenario may causing the grid system totally collapse. Since the transmission line in Sabah Grid System has no N-2 contingency, in the event of failure of the remaining line, the other transmission line will be overloaded and tripped. Apart from the transmission line failure as mentioned above, loss of generation in the power grid will also cause the power system failure. A generation capacity in the system should overcome any increase in load demand. Insufficient

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generation capacity in the system will created a low spinning reserve in the system. Spinning Reserve is needed to maintain system frequency stability during emergency operating conditions and unforeseen load swings. Based on the Sabah and Labuan Grid Code, the total spinning reserve requirement is equivalent to the available largest set that connected to the grid system and ready to meet electric demand within a specified time according to the dispatch instruction.

Loss of generation can occur due the cascading failure in the power grid that make the system frequency fluctuated, voltage instability which cause the generator tripping and machine failure. In view of these threats, power utility company in Sabah has to ensure the system stability can be maintained in the face of continuing strong growth in electricity demand in Sabah.

The stability of a power system refers to the ability of a system to return back to its normal condition when it came to certain disturbances occur. The stability studies can be classified in two major areas which are the steady state stability and dynamics stability. The steady state stability is defined as the ability to recover synchronism after encountering slow and small disturbance while dynamic stability is the ability to recover synchronism after encountering small disturbance in a long time frame [1]. Many researchers have been studying and proposing a variety of methodologies for conducting the analysis of stability problem [2-6]. To determine when a system is operating close to the instability boundary, stability analysis is conducted using the methods which can be classified into steady state analysis and dynamics analysis. In this paper, the methodology to conduct the stability analysis is done using the PSS/E software. Several case studies have been conducted to demonstrate the system stability of the Sabah Grid. This stability study is specified for Sabah grid, which has not been determined before.

1.1 Power System Stability

Stability is the ability of the power system to maintain the state of equilibrium after the disturbance. The system is said to remain stable if the synchronism machines is able to stay synchronism after a large disturbance such as loss of the transmission line, equipment failure and lightning strike [7].

The power system stability can be classified as three main areas which are angle stability, frequency stability and voltage stability [8].

Power versus angle relationship plays important characteristic in power system stability. To illustrate this, the simple system is shown in Fig. 1.

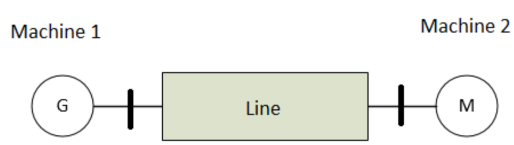

Fig. 1. Single line diagram.

Assuming that machine 1 represent the generator and machine 2 represent the synchronous motor. The equation below shows the nonlinear function of the power angle curve.

$$\frac{H}{\pi f_0}\frac{d^2\delta}{dt^2} = P_m - P_{max}\,sin\delta \qquad (1)$$

The function of angular separation δ between the rotors of the two machines is the power transferred from generator to the motor. For small disturbances, this equation may be linearized by considering small signal $\Delta\delta$ in power angle from the initial operating point at δ_o.

$$\delta = \delta_o + \Delta\delta \qquad (2)$$

Substituting to (1), yields

$$\frac{H}{\pi f_0}\frac{d^2(\delta_0+\Delta\delta)}{dt^2} = P_m - P_{max}\,sin(\delta_0 + \Delta\delta) \qquad (3)$$

$$\frac{H}{\pi f_0}\frac{d^2\Delta\delta}{dt^2} + P_{max}\,cos\delta_o\,\Delta\delta = 0 \qquad (4)$$

The $P_{max}\,cos\delta_o$ value is the slope of the power angle curve at the initial operating point known as the synchronizing power coefficient denoted as P_S. This coefficient will determine the system stability by

$$P_S = \left.\frac{dP}{d\delta}\right|_{\delta_o} = P_{max}\,cos\delta_o \qquad (5)$$

Substituting (5) to (4), yields

$$\frac{H}{\pi f_0}\frac{d^2\Delta\delta}{dt^2} + P_S\,\Delta\delta = 0 \qquad (6)$$

The solution of (6) depends on the roots of the characteristic equation, given as follow

$$S^2 = -\frac{\pi f_0}{H}\,P_S \qquad (7)$$

If is negative, one root is in the right-half of s-plane and the response is exponentially increasing and stability will lost. If is positive, two roots on the j-ω axis and the motion is oscillatory and undamped. The system is slightly stable with frequency of oscillation given in (8)

$$\omega_n = \sqrt{\frac{\pi f_0}{H}\,P_S} \qquad (8)$$

Fig. 2 show that the range if P_S positive is between 0 to 90° with a maximum value at no-load ($\delta_o = 0$).

This maximum power transferred is at angular displacement of 90° as shown in Fig. 2 referred as the steady-state stability limit. Further increase in angle results decreases in power transferred.

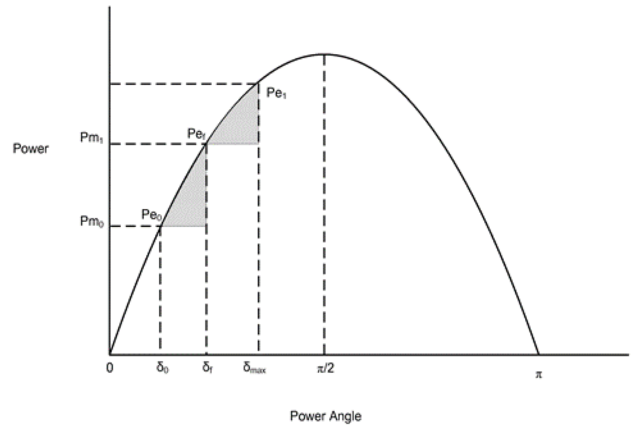

Fig. 2. Power-angle curve.

1.2 Overview of Sabah Grid System

The Sabah Grid System is made up of four voltage level consists of 33 kV, 66 kV, 132 kV and 275 kV which connected all major areas in Sabah and Federal Territory of Labuan. The licensed utility company in Sabah is responsible to develop, manage and operate the Sabah Grid System. The operation of the Sabah Grid System shall comply the requirement under the Sabah and Labuan Grid Code [9].

The Sabah Grid System is divided into two regions namely West Coast Grid (WCG) and East Coast Grid (ECG) with the bulk of the generation and load in the WCG. Presently, the ECG and WCG are interconnected through a double circuit of 275kV Kolopis – Segaliud transmission lines with a distance of 255 km. The topological of the Sabah Grid System is shown in Fig. 3.

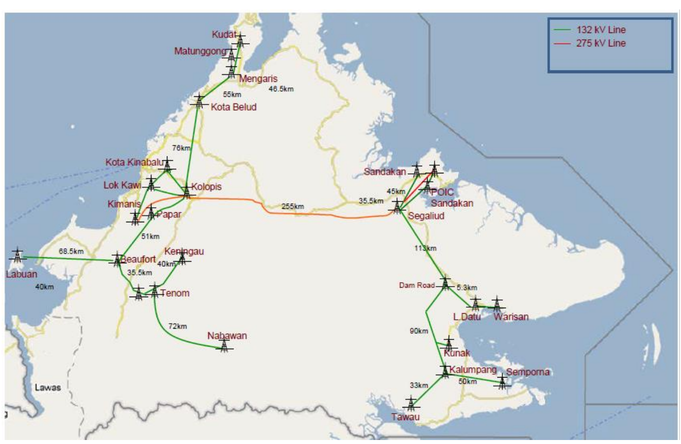

Fig. 3. Topological of the Sabah Grid System.

2. Methodology

The adopted methodology involves the modelling of the Sabah Grid System in the PSS/E software and simulates the case study to identify the stability issues of Sabah Grid System with respect to the existing transmission connection and the on-going generation project for the year 2019 [10]. The model of bus system [9] is simulated for steady-state load flow, short circuit analysis, dynamic stability, contingency analysis and performance limits.

2.1 Steady state analysis

The basic principle of the planning and operation is to ensure all the transmission equipment operates within their respective normal thermal ratings and voltage limits when the system is operating during normal condition. All the transmission equipment should also operate within its emergency thermal ratings and voltage limits immediately after a disturbance with the loss of an element without operator involvement. The system should be capable of such conditions for all times including operations during minimum and maximum forecasted load conditions. The steady-state analysis will check the following contingencies:

- N-1 contingencies that will be applied deterministically to all lines and transformers except for single radial connection of which contingencies will result an islanded operation.
- N-2 contingencies that will be applied deterministically on the parallel circuit network which are not causing any islanding on any part of the network.
- P-V Analysis – the steady state analysis of Sabah Grid System is accessed using P-V analysis to determine the maximum transfer that can be transferred from West Coast to East Coast region without violating the transmission line limit, while maintaining the network voltage within the planning and operation criteria.

2.2 Short circuit studies

The short circuit level on 66 kV, 132 kV, and 275 kV substations were calculated to identify substation with fault level that exceeds the short circuit rating. Typically, the three phase short circuit rating of a circuit breaker would be as follows:

- For the 275 kV, the circuit breaker rating shall be at 40 kA.
- For the 132 kV the circuit breaker rating shall be in the range of 16kA to 31.5 kA
- For the 66 kV the circuit breaker rating shall be in the range of 12.5kA to 25 kA.

Fault levels for three phase and single phase to ground faults were calculated in PSS/E using the automatic sequencing circuit calculation activity (ASCC). Only peak load condition is considered for simulation due to higher fault current contribution from more generations on-line as compared to trough load condition. Substations where the fault level exceeded their short circuit rating are identified.

2.3 Dynamic stability analysis

The dynamic simulation of a physical process has four basic steps:

- **Development of the bases case:** The base case of the study is for the year 2019. This base case represents the network data, therefore, for the dynamics security assessment requirements, the detailed plants data used such as generators, speed governor, Static VAR Compensator (SVC), and excitation system data are also modelled.
- **Review of stability criteria and list of contingencies:** The criteria used in the study are required to ensure that system studies perform follow the standard criteria spelled out in the Sabah and Labuan Grid Code, therefore the system performance satisfies the adequacy, security and reliability consideration. In addition, the

specified list of contingencies will be simulated to show the stability impact of those contingencies on the Sabah Grid System.

- **Perform dynamic simulations:** There are many methods can be used for solving the dynamic stability problem; time domain and direct solution. Since the time domain has a complete information result, such as the step by step response and many parameters can be captured, thus the time domain solution is chosen for solving the dynamic stability problem. In this study, PSS/E software is used to perform the dynamic stability analysis.
- **Result and analysis:** The result from the simulation will be analyzed to arrive at some conclusion and recommendation. The conclusion will be discussed to identify stability problem and reasons for the problems. The recommendations provide options solutions for the stability problem

3. Base Case Modelling

This study is based on the power system model of Sabah Grid System for the year 2019. The load, generation and transmission system development for the years considered in this study are described as follows.

3.1 System load demand

The load demands modeled in this study in 2019 is 718.3 MW for west coast and 310.7 MW for east coast.

3.2 Generation development plan

The highest maximum demand ever recorded in the Sabah Grid System is 945 MW. Currently, the total dependable capacity is 1290 MW and the largest generating unit in Sabah Grid System is 95 MW per block (which consist of 65MW gas turbine and 30 MW steam turbine).

The Sabah Grid System owner has the plan to gradually decommission all the diesel generating units which are connected to the Sabah Grid System. However, there are other generation resources from the large scale solar and other renewable energy also has been considered in the base case. This is to create more variance in the generation mix and not only depending on the gas fired power plants.

3.3 Performance criteria and limits

A balance approach with due prudence has been exercised in its formulation and adoption of the performance criteria and limits. The Sabah & Labuan Grid Code (SLGC) was used as guiding document to establish the performance criteria and limits.

3.3.1 Voltage

The voltage limits applicable for the pre-disturbance/pre-fault state of the transmission system are defined in Table I below:

Table 1: Pre-Disturbance Voltage Limits.

Nominal Voltages	Maximum	Minimum
275kV	1.05 p.u	0.95 p.u
132kV	1.05 p.u	0.95 p.u
66kV	1.05 p.u	0.95 p.u

The voltage limits applicable for the post -disturbance/post-fault state after an event resulting in the loss of single element of the transmission system are defined in Table 2 below:

Table 2. Post-Disturbance Voltage Limits.

Nominal Voltages	Maximum	Minimum
275kV	1.10 p.u	0.90 p.u
132kV	1.10 p.u	0.90 p.u
66kV	1.10 p.u	0.90 p.u

3.3.2 Rotor angle stability limits

The relative rotor angle of any two generating units in the system must not exceed 180 degrees at any point of time before and after an event resulting in the loss of single element.

4. Result and Analysis

4.1 Steady-state analysis

Steady state simulation study is required to see the overall Sabah Grid System. In the steady simulation, it covers the loss of one transmission line or loss of one power transformer during operation.

The base case is simulated to identify which substation in the Sabah Grid System to be overloaded when only one line is in service and another remaining line is assumed as off line due to fault or routine maintenance of the line.

4.1.1 N-1 and N-2 contingency analysis

Based on the steady state simulation, it is observed that there is no N-1 contingency violation for the 275kV and 132kV networks. However, there are a few N-1 contingencies violation for 33kV network in Sandakan where the remaining line loading is above 50% of the line rating. It is also observed that all parallel connected transformers will comply the N-1 contingency and no transformer loading is above 50% of the transformer rating. The N-2 contingency shall not apply to 275kV Kolopis to Segaliud lines because it will result the system will split into two islands. There are few N-2 contingencies on the ring 33 kV in Sandakan. The reason behind the existing constraint is due to the lack of local generation source to supply the 33 kV network.

4.1.2 Short circuit analysis

The study result for the Short Circuit Analysis shows that the short circuit currents are approaching short circuit ratings for Karamunsing 33 kV. The short circuit currents are actually not high but the ratings of circuit breakers are actually lower than typical values. This is true for old substations whereby short circuit ratings of their breakers are non-typical and lower than usual.

4.1.3 P-V analysis

Based on the result obtained in Fig. 4, the point of voltage collapse is at 180 MW additional power transfer. In the event of the power transfer reach to a total of 333 MW, the system will collapse due to the voltage at Segaliud Substation reach to its maximum voltage rating. Therefore, taking into consideration of the 15% margin, the maximum allowable power transfer shall not exceed 250MW. However, for operation purpose, the power transfer is capped to 216 MW due to the limitation of transformer rating at Segaliud Substation.

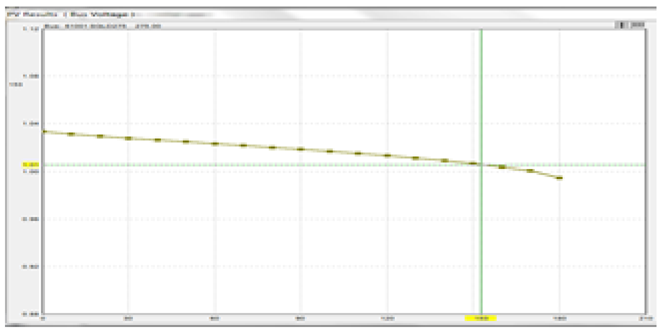

Fig. 4. P-V curve for West - East power transfer.

4.2 Dynamic analysis

This study performed the case studies for an extreme condition is assumed to occur where both transmission lines are tripped or out of service.

The following scenarios have been selected in this transient stability studies. The selection of scenarios is based on the line and transformer rating limitation, radially interconnected and the line length.

- 275kV Kolopis–Segaliud double circuit transmission lines are the only connection between West and East of Sabah. Its line rating is 2 x 641 MVA, allows power transfer up to 576 MW However, West to East power transfer is currently limited to maximum 216 MW to comply with the N-1 criteria of the power transformer at Segaliud. The length of this line is about 255 km.
- 132kV Segaliud–Dam Road double circuit transmission lines are the only transmission line connecting to Tawau, Kunak and Lahad Datu area. The length of the line is about 232 km.
- 132kV Segaliud-Sandakan double circuit lines are the only line to supply the Sandakan area from the grid system. However, supply to Sandakan area is further limited to approximately 138 MW due to the lower line rating. The line distance is about 72 km.

5. Case Study

5.1 Loss of both lines 275 kV Kolopis to Segaliud

Loss of double circuit lines can be due to few situations for example one of the lines is under planned maintenance and the other remaining line is suddenly having fault or lightning strike and flash over occurs to trip the both circuit. Although this situation occurrence is very small, the impact to the Sabah Grid System will be catastrophic.

The first scenario for this case study is the 275 kV Kolopis to Segaliud line. In the event of the both interconnection lines are loss, the two regions will be separated. As seen in Fig. 5, the voltage for grid system in the East coast has increased exceeding to its voltage limits after 5 seconds and lead to system collapse when both 275 kV interconnections are loss.

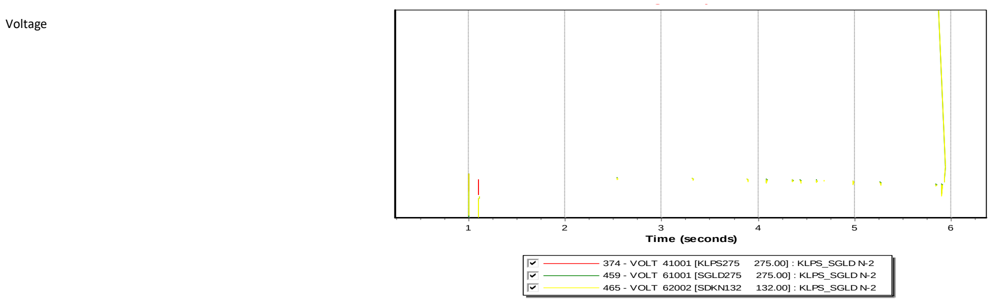

Fig. 5. Voltage response when 275kV Kolopis to Segaliud double circuit transmission lines are tripped.

Due to the imbalance generation capacity which is more generation capacity from West Coast Region, East Coast is fully depending on the 275 kV interconnection to transfer a huge power capacity from West Coast to East Coast of Sabah. In this state, when both 275 kV lines are loss, the generation sources at East Coast grid will be tripped as shown in Fig. 6. This is caused by the load demand in the East Coast network exceeded the generation capacity which led to total collapse of the East Coast. When the system is separated into two islands, the West Coast grid, will remain stable where the voltage is remaining at the allowable range due to numerous of generation sources located in the West Coast region to supply the load demand. However, Grid Operator needs to control the generation capacity in the West Coast to avoid over voltage in the system.

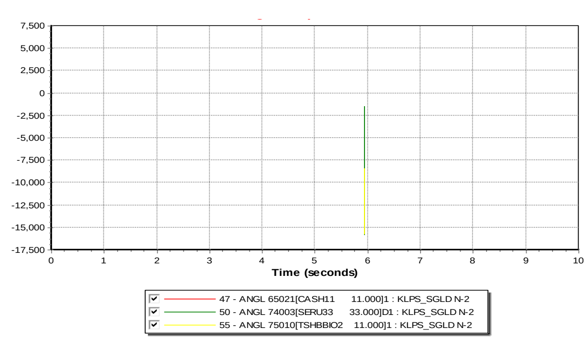

Fig. 6. Angle response when 275kV Kolopis to Segaliud double circuit transmission lines are tripped.

5.2 Loss of both lines 132kV Segaliud to Dam Road

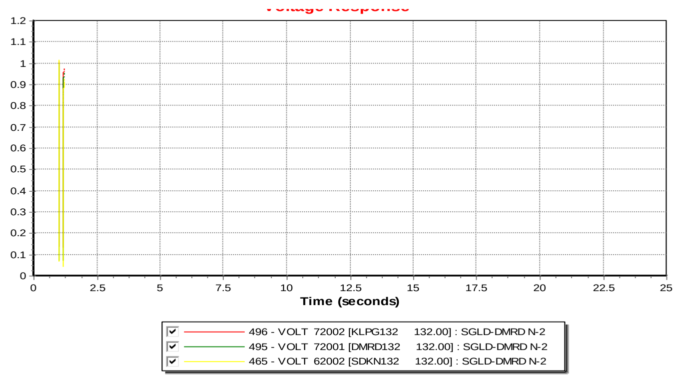

Fig. 7. Voltage response when 132kV Segaliud to Dam Road double circuit transmission lines are tripped.

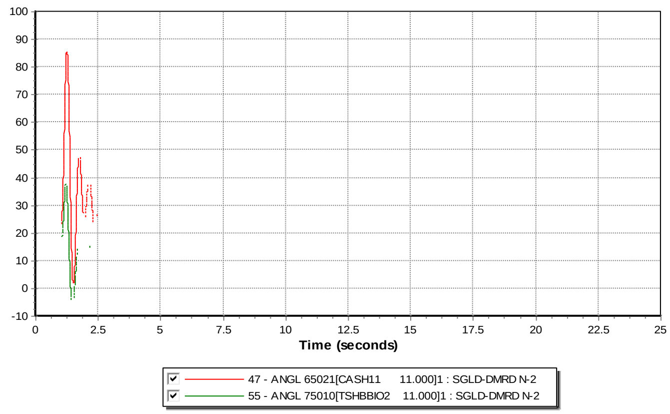

Fig. 8. Angle response when 132 kV Segaliud to Dam Road double circuit transmission lines are tripped.

Fig. 7. shows the voltage response when 132 kV Segaliud to Dam Road double circuit transmission lines are tripped or disconnected. It is observed that the grid system voltage response is still stable where the voltage is back to its normal condition when the fault is cleared. The local generation at Tawau, Kunak, and Lahad Datu areas are able to support the grid system stability. The rotor angle response of all generating set in the grid system is also back to its normal condition as it is observed that there is no generator set that will out of phase or tripped during this event occurred. The result for angle response is as show in Fig. 8.

5.3 Loss of both lines 132 kV Segaliud to Sandakan

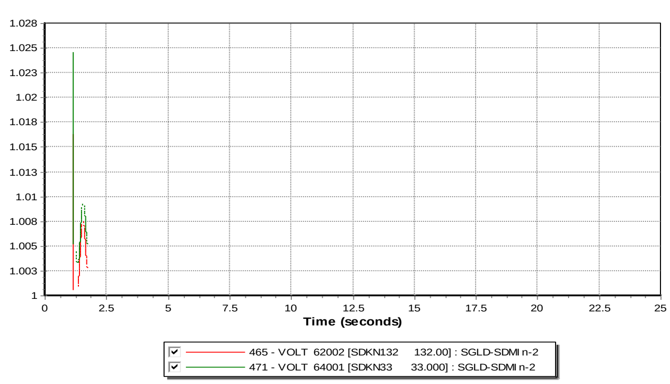

Fig. 9. Voltage response when 132kV Segaliud to Sandakan double circuit transmission lines are tripped.

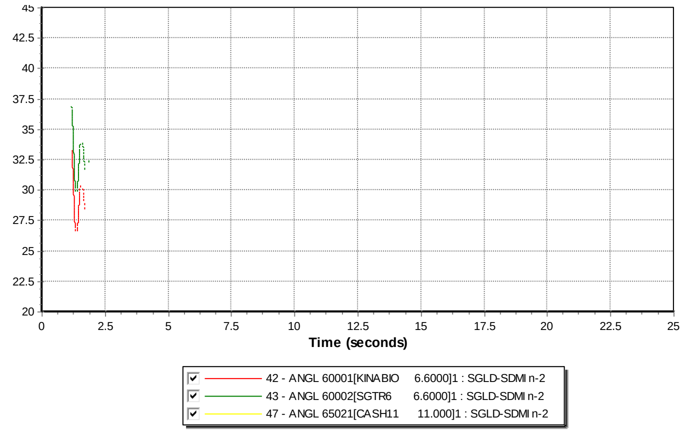

Fig. 10. Angle response when when 132kV Segaliud to Sandakan double circuit transmission lines are tripped.

Figs. 9 and 10 shows the simulation result for voltage response and angle response when both lines of 132 kV from Segaliud to Sandakan are tripped or disconnected. As seen, the voltage profile is still below the voltage limit and no fluctuation observed in the angle response. Hence, the Sandakan area is remained stable due to the load demand supplied by local generation.

6. Conclusions

This article basically presented the review of methodology for stability analysis and performed several case studies to demonstrate the Sabah Grid System stability using the PSS/E simulation package. Based on the results obtained in this simulation, the 275 kV transmission line connecting the West Coast and East Coast of Sabah is crucial to transmit power supply to the East Coast area without fail. In the event of both 275 kV lines are tripped or disconnected due to planned maintenance or forced outage, Sabah Grid System will split into two, and West Coast and East Coast Grid will be operated separately. During this condition, the voltage and angle response in the grid system becomes unstable where the voltage and angle are not within the allowable limits initiating the tripping of generators in the East Coast. When generators at East Coast tripped, voltage become low due to the insufficient reactive power supplied from the generator. This will contribute to equipment failure and trigger the cascading effect. Based on this result, the 275 kV interconnection between West Coast and East Coast is identified as the weakest point of interconnection in the Sabah Grid System. Therefore, additional interconnection to support the existing network is required to preserve the stability of the Sabah Grid System when a certain disturbance happen and affect the 275 kV interconnection lines. The other two case studies shows that although the lines are the only interconnection line to supply that area, local generation in that particular area will help the system to remain stable and operated within the allowable voltage and angle stability limits. Further study need to perform to investigate the voltage instability of the Sabah Grid System following loss of largest generation set and impact of large scale integration solar photovoltaics.

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