J. Basic. Appl. Sci. Res., 2(7)6403-6410, 2012
© 2012, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Stability Analysis for a Warrant of Power Supply Security through Interconnection

Rini-Nur Hasanah* and Hadi Suyono

Department of Electrical Engineering, Faculty of Engineering, University of Brawijaya, Malang, East Java of Indonesia

ABSTRACT

Stability studies are commonly done on large systems. There has been relatively little research dedicated to stability study of small-size power systems. On the other side, such kind of study is paramount for any decision taken leading to further system's expansion. The consideration taken normally includes the transient and steady-state stabilities. Each of those studies requires a thorough analysis. As a part of complete stability analyses, this paper presents the steady-state stability analysis of a small-size power system. The system under consideration supplies an industrial area producing crude oil and natural gas and comprises two islanded power plants. It is well-known that supply to loads from power systems which are not interconnected are prone to discontinuity, therefore the power supply security of the production area must be guaranteed. The study began with modelling each of the plants in the system. Power flow analyses were carried through and system response to the occurrence of a three-phase short-circuit fault was investigated. An improved system configuration was proposed by interconnecting the two islanded power plants. The same three-phase short-circuit fault occurrence was also applied. The design of the new interconnected system and its response to the same type of fault justified the need to integrate the two islanded power systems in a form of interconnected system.

KEYWORDS: interconnected power system, islanded power system, power flow analysis, steady-state stability

INTRODUCTION

Power system stability is an important factor to ensure the power supply security of a system; however, there has been relatively little research on it, especially on small systems such as in an industrial area or enterprises [1-4]. Such system has generally private power plants which are connected to some external power grid. Because of the possible occurring disturbance, when disconnected from the external grid, certain frequency collapse might be engendered, bringing furthermore the possibility of large-scale black-out. Voltage profile is another important indicator of power system quality. Reference [1] shows the results of investigation on the dynamic process of voltage collapse in a general interconnected network model under the assumption that system frequency remains unchanged. It is shown that locking the tap-changers at an appropriate time helps the system voltage to reach a steady state, and therefore avoid the collapse. Another approach to model interconnected national energy systems using the concept of energy hubs has been proposed and showed its applicability to demonstrate the possibility to import or export electricity and/or gas between countries [5].Steady-state stability studies examine the stability of the system under small incremental variations in parameters or operating conditions about a steady-state equilibrium point. In all stability studies the objective is to determine whether or not the rotors of the machines being perturbed return to constant speed operation [6-11]. Obviously, this means that the rotor speeds have departed at least temporarily from its synchronous speed [12]. The possibility to get the information about steady-state stability was showed in [13], enabling to relate the existence of a dynamic equilibrium point to the existence of a load flow solution.

Santan Terminal Chevron Kalimantan Operation (Chevron-KLO) is an area of production of crude oil and natural gas, whose activity covers processing, collecting, and distributing crude oil and natural gas from the oil fields Attaka, Melahin, Kerindingan and Serang in the province of East Kalimantan. The electrical energy needed for the production process is supplied by two power stations, i.e. the Liquid Extraction Plant (Lex Plant) and the Process Plant. The two power systems are currently not interconnected each other, so that in case of emergency need the excess of power production in one system could not be sent to the other system, and vice-versa. To guarantee the power supply security, we suggest reconfiguring the two plants into an interconnected system. The consideration which follows would be whether the system is still stable when a disturbance occurs. A steady-state stability analysis on the new interconnection system design is required. The purpose is to predict the new system performance when it experiences a fault, so that certain measures could be taken to anticipate and avoid some undesirable consequences, being potential to produce a total blackout of the area under service.

In this paper, a steady-state stability analysis is carried out following a three-phase short-circuit fault on the system. The analysis aims to determine the condition of system frequency and voltage before, during, and after

***Corresponding Author:** Rini-Nur Hasanah, Department of Electrical Engineering, Faculty of Engineering, University of Brawijaya, Malang, East Java of Indonesia. Email: rini.hasanah@ub.ac.id

the fault, both before and after the interconnection of the two plants. Analyses of the role of turbine governor (TG) and automatic voltage regulator (AVR) on the power system stability are also discussed.

MATERIALS AND METHODS

Power Flow Analysis

Power flow analysis is used to obtain the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each line. Various methods upon which solution to the power-flow problems are based are available [12].The starting point in obtaining the data to be used is the single-line diagram of the systems

Power System Stability

Power system stability represents the property of a power system to remain in a state of operating equilibrium under normal operating condition and to regain an acceptable state of equilibrium after being subjected to a disturbance [14-16]. Stability studies which evaluate the impact of disturbances on the electromechanical dynamic behaviour of the power system are of two types, transient and steady state [12].

Steady-state stability indicates the ability of a power system to maintain the synchronism among its generators after a small disturbance. Transient stability indicates the ability of a power system to maintain its synchronization after a large disturbance occurring instantaneously for about one first swing, being considered that the automatic voltage regulator and the governor have not been working.

Voltage Stability and Voltage Collapse

The ability of a power system to maintain steady-state acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance determines the voltage stability. Voltage collapse is usually the results of a sequence of events accompanying voltage instability leading to a low-voltage profile in a significant part of the power system [14].

Frequency Stability

Frequency stability is concerned with the ability of a power system to maintain steady frequency within a nominal range following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to restore balance between system generation and load, with minimum loss of load [15].

Methods

Beginning with the model of the system to design, the data from the two power plants to be interconnected are needed. The data cover the single line diagram including generators, transformers, transmission lines, and loads, and also the system parameters including voltage, power, impedance, as well as frequency [6-11]. Additional data could be those of the dynamic data of the generators, of the governor control system, and also of the automatic voltage regulator [17-18].

The model is furthermore used to simulate the performance of system when a disturbance is applied. The type of disturbance considered is a three-phase short-circuit fault. The desired results of the simulation would be in the form of static and graphical data of the frequency and voltage conditions with respect to time, before, during, and after the fault, both for the condition before and after interconnection of the two power plants.

RESULTS AND DISCUSSION

Modeling and Data Processing

The Santan Terminal is supplied from two separate power plants, the Lex Plant and the Process Plant. Under full-production operating condition, the Lex Plant operates 5 of its 6 total generators available, whereas the Process Plant operates 3 of its 5 existing generators. The generators which are not operated are used for replacement or emergency backup generators. In Appendix, Fig. A and Fig. B show respectively the single-line diagram of the two islanded power plants supplying the Chevron-KLO, Lex Plant and Process Plant, before interconnection. The integration of the two plants is done by connecting three generator buses of 4.16 kV in the way that A bus is connected to the C bus, whereas B bus to C bus. All value/data of the generator, transformer, and the transmission line are expressed in p.u. [12].

Power Flow Analysis

Based on the line diagram and data of the power system, the simulation of power flow was performed to determine the initial conditions of the system prior to analysing power system stability. Power flow simulation is carried out on each of the Lex Plant and the Process Plant, and also on the two plants after interconnection. The results are shown in Table 1- Table 3.

TABLE 1 LEX PLANT POWER FLOW RESULTS

No.	Bus	V	θ	P_{gen}	Q_{gen}	P_{load}	Q_{load}
		(p.u.)	(°)	(p.u.)	(p.u.)	(p.u.)	(p.u.)
1.	A	1	0	1.88	1.161	0	0
2.	B	1	-0.012	1.40	1.208	0	0
3.	PM AC	0.99	-0.221	0	0	0.425	0.232
4.	TR-04	0.986	-0.012	0	0	0.200	0.150
5.	TR-10	0.984	-0.766	0	0	0.180	0.126
6.	TR-11	0.986	-0.852	0	0	0.150	0.113
7.	TR-3	0.985	-0.68	0	0	0.095	0.074
8.	TR-4	0.992	-0.735	0	0	0.190	0.143
9.	TR-6	0.968	-0.459	0	0	0.200	0.150
10.	TR-7	0.973	-1.571	0	0	0.300	0.217
11.	TR-9	0.989	-1.419	0	0	0.125	0.087
12.	TR-A	0.986	-0.592	0	0	0.425	0.308
13.	TR-B	0.985	-0.842	0	0	0.420	0.315
14.	TR-C	0.984	-0.841	0	0	0.450	0.361
15.	TR-D	0.989	-0.883	0	0	0.110	0.083
Total generation:		P_g = 3.2840 p.u.; Q_g = 2.3682 p.u.					
Total load:		P_L = 3.2696 p.u.; Q_L = 2.3569 p.u.					
Total losses:		P_{LOSS} = 0.0143 p.u.; Q_{LOSS} = 0.0113 p.u.					

TABLE 2 PROCESS PLANT POWER FLOW RESULTS

No.	Bus	V	θ	P_{gen}	Q_{gen}	P_{load}	Q_{load}
		(p.u.)	(°)	(p.u.)	(p.u.)	(p.u.)	(p.u.)
1.	C	1	0.000	1.173	0.890	0.000	0
2.	PI 204	0.997	-0.329	0.000	0.000	0.316	0.178
3.	TR-01	0.978	-1.174	0.000	0.000	0.250	0.175
4.	TR-02	0.973	-1.318	0.000	0.000	0.170	0.128
5.	TR-05	0.982	-0.929	0.000	0.000	0.200	0.145
6.	TR-08	0.987	-0.694	0.000	0.000	0.150	0.109
7.	TR-13	0.988	-0.611	0.000	0.000	0.080	0.06
Total generation:		P_g = 1.1720 p.u.; Q_g = 0.7499 p.u.					
Total load:		P_L = 1.1662 p.u.; Q_L = 0.7882 p.u.					
Total losses:		P_{LOSS} = 0.0059 p.u.; Q_{LOSS} = -0.0383 p.u.					

TABLE 3 SANTAN TERMINAL POWER FLOW RESULTS

No.	Bus	V	θ	P_{gen}	Q_{gen}	P_{load}	Q_{load}
		(p.u.)	(°)	(p.u.)	(p.u.)	(p.u.)	(p.u.)
1.	A	1.000	0.000	1.856	1.135	0.000	0.000
2.	B	1.000	-0.011	1.400	1.214	0.000	0.000
3.	C	1.000	0.006	1.200	0.699	0.000	0.000
4.	PI 204	0.997	-0.324	0.000	0.000	0.316	0.173
5.	PM AC	0.998	-0.221	0.000	0.000	0.425	0.232
6.	TR-01	0.978	-1.081	0.000	0.000	0.250	0.175
7.	TR-02	0.973	-1.226	0.000	0.000	0.170	0.128
8.	TR-04	0.986	-0.766	0.000	0.000	0.200	0.150
9.	TR-05	0.982	-0.836	0.000	0.000	0.200	0.145
10.	TR-08	0.987	-0.601	0.000	0.000	0.150	0.109
11.	TR-10	0.984	-1.042	0.000	0.000	0.180	0.126
12.	TR-11	0.986	-0.689	0.000	0.000	0.150	0.113
13.	TR-13	0.988	-0.519	0.000	0.000	0.080	0.060
14.	TR-3	0.985	-0.926	0.000	0.000	0.095	0.074
15.	TR-4	0.992	-0.650	0.000	0.000	0.190	0.143
16.	TR-6	0.968	-1.762	0.000	0.000	0.200	0.150
17.	TR-7	0.973	-1.609	0.000	0.000	0.300	0.217
18.	TR-9	0.989	-0.783	0.000	0.000	0.125	0.087
19.	TR-A	0.986	-0.842	0.000	0.000	0.425	0.308
20.	TR-B	0.985	-1.032	0.000	0.000	0.420	0.315
21.	TR-C	0.984	-0.883	0.000	0.000	0.450	0.361
22.	TR-D	0.989	-0.706	0.000	0.000	0.110	0.083
Total generation:		P_g = 4.4560 p.u.; Q_g = 3.0479 p.u.					
Total load:		P_L = 4.4358 p.u.; Q_L = 3.1451 p.u.					
Total losses:		P_{LOSS} = 0.0202 p.u.; Q_{LOSS} = -0.0972 p.u.					

The three tables show that the voltage profiles both before and after interconnection are still acceptable based on the international standard, which requires the voltage values during normal condition to be in the range of 0.95-1.05 p.u.

The results show that the total losses of the two plants before interconnection are less than those after interconnection. It is reasonable as there are some unavoidable losses being produced because of the additional transmission lines needed to interconnect the two systems.

The power flow result of the new integrated system can be seen from the simplified configuration shown in Fig. 1. The largest flow occurs from the bus A to bus B with the flowing power of 0.2084 MW. That amount has still not exceeded the transmission thermal loading, i.e. 1.04 MW with assumption that the conductor used is of 250A capacity and 4.16kV nominal voltage. It means that the loading is just about 20% of its limit. As shown in Table 4, the flowing power in the two other lines is much less, i.e. 0.007 p.u. between the bus C and bus A, and 0.0209 p.u. between the bus C and bus B.

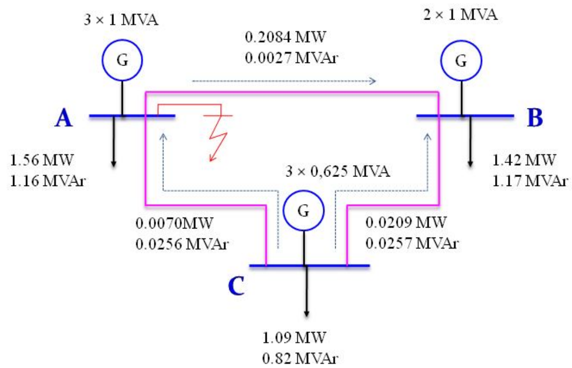

Figure 1 Power flow diagram of the integrated system

TABLE 4 POWER FLOW RESULTS OF THE NEW INTEGRATED SYSTEM

Origin	Destination	P (p.u.)	Q (p.u.)
Bus C	Bus A	0.0070	-0.0256
Bus C	Bus B	0.0209	-0.0257
Bus A	Bus B	0.2084	-0.0027

Stability Simulation

The simulation of power system stability before and after interconnection was done to determine the steady-state stability response, being indicated by the frequency and voltage conditions. The simulation was performed for the condition before, during, and after the disturbance. During the simulation, the 3-phase fault disturbance was applied at time 1s and ended at 100 ms later, whereas the total simulation time was 20 seconds.

During the frequency stability simulation, generators work at their fundamental frequency value before the application of a 3-phase short-circuit fault at the related buses. At the time of fault, a frequency increase is resulted. After the removal of disturbance, each generator takes a certain time to regain its normal operating frequency. The graphical results of simulation are shown in Fig. 2, Fig. 3, and Fig. 4 consecutively ('---' indicates the characteristic before interconnection, whereas '—' indicates that after interconnection).

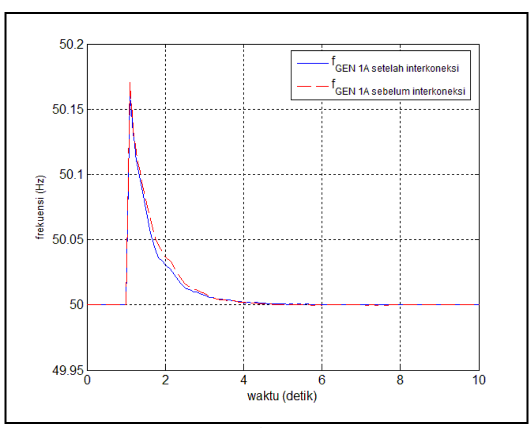

Figure 2 Frequency=f(t), generator GEN 1A

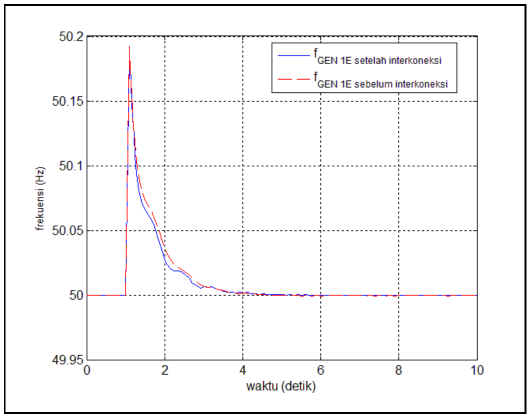

Figure 3. Frequency=f(t), generator GEN 1E

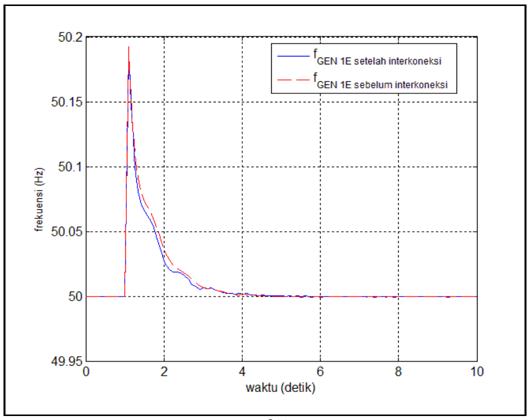

Figure 4 Frequency = f(t), generator G801 C

The figures indicate clearly the change of frequency value at the time of fault application and how long it takes to regain the normal frequency condition. They show also that all the three generators could finally reach their normal frequency value back after the removal of the disturbance.

Based on the results, comparison of the frequency values as well as the time taken to recover the normal frequency values of the three generators under consideration is shown in Table 5. For a 10ms duration of fault, both before and after interconnection, the systems could still be back to their normal operating state, but the frequency increase after interconnection is less than under islanded mode. It means that the frequency stability at Santan terminal after interconnection will be better than before the two power plants, Lex Plant and Process Plant, are integrated.

TABLE 5 COMPARISON OF FREQUENCY STABILITY

Generator	Before interconnection		After interconnection	
	f (Hz)	$r_{recovery}$ (second)	f (Hz)	$r_{recovery}$ (second)
GEN 1A	50.1683	4.1648	50.1643	3.3898
GEN 1E	50.1924	4.2898	50.1865	2.8898
G801 C	50.1986	7.0000	50.1410	4.8898

During the voltage stability simulation, it is the voltage condition at buses related to generators which was observed. The results of both before interconnection (indicated with line in '- - -') and after interconnection (indicated with line in '—') are shown in Fig. 5, Fig. 6, and Fig. 7 for the three buses considered in this study. It can be seen that before reaching the stable state after disturbance, there happened some oscillations around its normal voltage value.

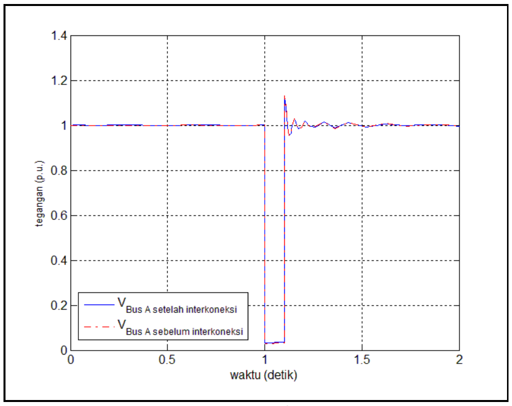

Figure 5 Voltage=f(t), at bus A

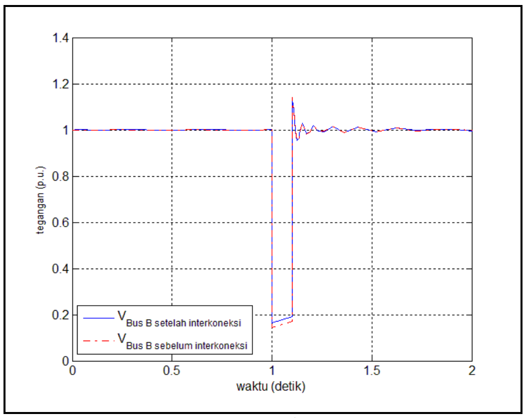

Figure 6 Voltage=f(t), at bus B

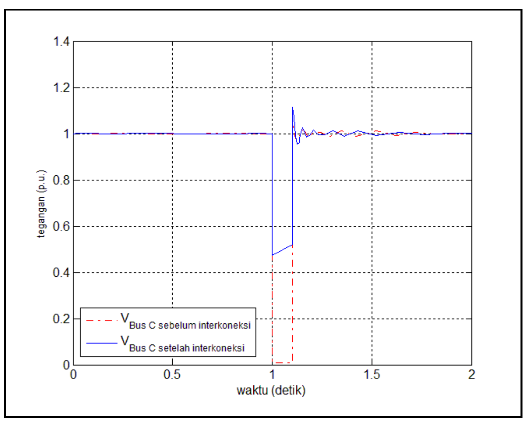

Figure 7 Voltage=f(t), at bus C

The comparison of bus voltage drop values (in p.u.) and its duration can be seen in Table 6. It shows that the stability can still be reached both before and after interconnection, but the voltage drops of generators after interconnection are less than those when the *Lex Plant* and *Process Plant* are still operated in islanded mode.

TABLE 6 COMPARISON OF VOLTAGE STABILITY

Bus	**Before interconnection**		**After interconnection**	
	V (p.u.)	t_{drop} (mili second)	V (p.u.)	t_{drop} (mili second)
A	0.0281	100	0.0032	100
B	0.1437	100	0.1647	100
C	0.0085	100	0.4739	100

In order to observe the role of turbine governor (TG) and automatic voltage generator (AVR) on the stability of power system interconnection at Santan Terminal, a simulation was performed by applying a fault on one bus and observing the frequency stability of the related generators. Three different treatments have been applied before performing analysis: generators are equipped with the TG and AVR, generators without TG, and generators without AVR. The comparisons of frequency stability characteristics without governor (indicated with line in ‘—’), without AVR (indicated with line in ‘–. –. –.’), and with both governor and AVR (indicated with line in ‘- - -’) are shown subsequently in Fig. 8 and Fig. 9 for generators GEN 1A and G801 C subsequently. The resulted characteristics indicate clearly that the use of the TG and AVR contribute greatly in achieving the stability faster. Generator which was not equipped with governor was suffering long periods of oscillation after disturbance, and could not reach its stability state at the end of simulation time.

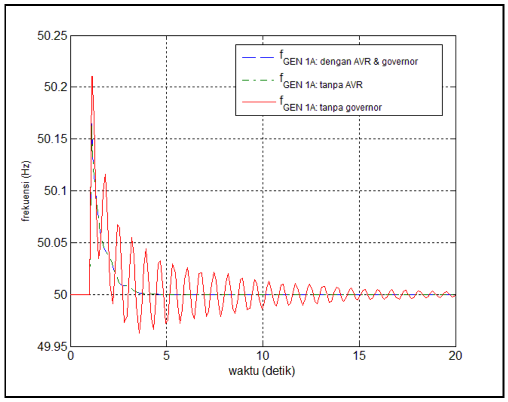

Figure 8 Characteristics of frequency=f(t), at generator GEN 1A

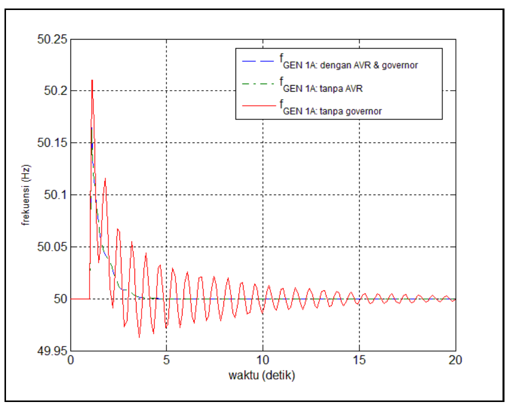

Figure 9 Characteristics of frequency=f(t), at generator G801 C

CONCLUSION

The performed steady-state stability analysis shows that the voltage profiles on the systems both before and after interconnection are still in the range allowed by standard. It can be concluded also that the frequency stability will be reached in the systems both under islanded and interconnected conditions. On the other hand, the losses after interconnection are higher than those before interconnection, which is however still reasonable due to the use of additional transmission lines to interconnect the two islanded systems. Finally, although the stability can still be achieved without interconnecting the two plants, in case of fault it would return to its normal condition and recover its stability state faster if the system is in an interconnected configuration. The better reliability would ensure the supply continuity to the production area under service.

REFERENCES

[1] K.T. Vu and C.-C. Liu, “Shrinking stability regions and voltage collapse in power systems,” IEEE Transactions on Circuits and Systems I: *Fundamental Theory and Application*, Volume: 39 , Issue : 4, pp. 271-289, Issue Date : Apr 1992.

[2] X. Shiwu, M. Guanglei, L. Ruifeng, and W. Jingtao," The application of regional stability control in steel enterprise power supply sytem," *Proceeding of International Conference on Sustainable Power Generation and Supply, 2009. SUPERGEN '09,* pp. 1-5, Issued 6-7 April 2009.

[3] Rini-Nur Hasanah, Hadi Suyono, Risqi Rotbi, "Justifying the Need of Interconnecting Power Systems: The Transient Stability Analysis", *International Journal of Academic Research*, Vol. 3. No. 6. November, 2011, Part II, Print Version: ISSN 2075-4124, Online Version: E-ISSN: 2075-7107.

[4] Hadi Suyono, Chairuzzaini, Mahfudz Shidiq, Rini Nur Hasanah, Harry Soekotjo Dachlan, R. Arief Setyawan, Adharul Muttaqin, Risqi Rotbi, "Analisis Penentuan Sudut Rotor Kritis pada Stabilitas Sistem Interkoneksi" (in Indonesian), *Prosiding Seminar Nasional: Science, Engineering and Technology (SciETec)* 2012. Program Magister dan Doktor Fakultas Teknik Universitas Brawijaya, Malang, 23-24 Pebruari, 2012, ISBN 978-602-97961-0-0.

[5] T. Krause, F. Kienzle, L. Yang, and G. Andersson, "Modeling Interconnected National Energy Systems using an Energy Hub Approach," *IEEE PES Trondheim PowerTech 2011 conference publication*, 19-23 June 2011, pp. 1-7.

[6] Hadi Suyono, Sallehhudin Yusof, Khalid Mohamed Nor, "Component-Based Development for Transient Stability Power System Simulation Software", *IEEE PECon03. Bangi, Malaysia*, December 2003.

[7] Hadi Suyono, Sallehhudin Yusof, Khalid Mohamed Nor, "Power System Transient Stability Analysis by Object Oriented and Component Based Methodologies", *Proceeding of the Fourth IASTED International Conference POWER AND ENERGY SYSTEMS. Rhodes, Greece*, June 28-30, 2004.

[8] K.M. Nor, H. Mokhlis, H. Suyono, M.A. Akher, T.A. Ghani, A.H.A. Rashid, "Development of Power System Analysis Software Using Object Components", *Proceeding of the IEEE TENCON 2005. Melbourne,* Australia, November 21-24, 2005.

[9] Hadi Suyono, Sallehhudin Yusof, Khalid Mohamed Nor, "Developing Transient Stability Program Using Component-Based Software Engineering", *Proceeding of the IEEE TENCON 2005. Melbourne*, Australia, November 21-24, 2005.

[10] Hadi Suyono, Khalid Mohamed Nor, Sallehhudin Yusof, Abdul Halim Abdul Rashid, "Use-case and Sequence Diagram Models for Transient Stability Software", IEEE PECon 2006, *First International Power and Energy Conference. Malaysia,* 28 and 29 November 2006.

[11] Hadi Suyono, Sallehhudin Yusof, Yuriy Kazachkov, Zaharulnain Osrin, Ashari Yusof, "Modeling of an HVDC Link Comprising of Long Sections of Submarine Cables and Overhead Lines", *International Regional Technical Meeting 2008,* Asia-Oceania Regional Council of CIGRE (AORC-CIGRE). Jakarta, May 2- 8, 2008.

[12] J.J. Grainger & W.D. Stevenson, *Power System Analysis*. Singapore: McGraw-Hill, 1994.

[13] P.W. Sauer and M.A. Pai, "Steady-state stability and load flow," *Proceedings of the 27th IEEE Conference on Decision and Control, 1988.,* pp. 2110 - 2113 vol.3, Issue Date : 7-9 Dec 1988.

[14] P. Kundur, *Power System Stability and Control*. New York: McGraw-Hill, 1994.

[15] L.L. Grigsby, *Power System Stability and Control*. New York: Taylor & Francis Group, LLC., 2007.

[16] J. Machowski, J.W. Bialek, & J.R. Bumby, *Power System Dynamics Stability and Control.* Chichester: John Wiley & Sons, Ltd., 2008.

[17] J. Arrillaga & C.P. Arnold, *Computer Analysis of Power Systems*. *Chiche*ster: John Wiley & Sons, Ltd., 1990.

[18] R. Natarajan, *Computer-Aided Power System Analysis*. New York: Marcel Dekker, Inc., 2002.