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e-ISSN: 2289-8131 Vol. 9 No. 2-3 161 **Determination of Generator Steady State Stability Limit** Using Losses Concept and RBFNN Rusilawati<sup>1,2</sup>, Adi Soeprijanto<sup>1</sup>, Ontoseno Penangsang<sup>1</sup>, D.F. Uman P1 <sup>1</sup>Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. <sup>2</sup>Department of Electrical Engineering, Akademi Teknik Pembangunan Nasional, Banjarbaru, Kalimantan Selatan, Indonesia. rusilawati14@mhs.ee.its.ac.id Abstract In the multimachine circumstances, it is difficult to analyze **the steady state stability of each generator.**

In **previous research**, analysis of the steady state stability limit has been carried out but it only looked at the stability of the overall system. Therefore, to analyze the stability of each generator, the multimachine system must be changed into a Single Machine to Infinite Bus (SMIB) system by collecting all the loads into one central load in the infinite bus. The method to change from the multimachine system to SMIB system was presented in this paper. The multimachine system was converted into an equivalent impedance ( $r_{eq}$  and  $x_{eq}$ ) and an equivalent load based on losses concept.

After  **$r_{eq}$  and  $x_{eq}$  is calculated**, the value of the maximum generation of each generator units was determined using the steady state stability limit concept. By means of maximum generation, **the maximum output power limit can be generated without causing** instability. Generator Saguling, which is one of the generators in the Java-Bali system 500 kV was used as a observed generator. Radial Basis Function Neural Network (RBFNN) was applied to determine **the maximum generation of** generator Saguling on the variety load.

Therefore, the determination **of the maximum generation** limit of generator Saguling can be determined directly at any time change of the load demand. ETAP simulation was

used to validate the calculation results of the proposed method. Index Terms The Losses Concept; Equivalent Resistance; Equivalent Reactance; Generator Steady State Stability Limit; RBFNN. I. INTRODUCTION Electric power systems that have a lot of machines usually distribute power to the load through the interconnected system.

The main purpose of the interconnected system is to maintain the continuity and the availability for the increasing needs of electric power. The growing of the power system can result in poor performance when the system is disturbed[1]. It is necessary to find preventive measures to avoid severe contingencies in the power system operation and the power a given steady state [2]. Steady-state stability limit of the power system is the steady state operating condition in which the power system is still in a stable condition, but a small change of the parameters of the operation will lead to instability of the system [1-4].

Load flow method can be used to determine the steady-state stability limit of a power system by increasing the load until the load flow process becomes not convergent [5]. Continuation Power Flow Method (CPF) has also been frequently used to determine the relationship between the loading parameters to voltage at each bus [6]. Practical studies to determine the stability analysis have also been developed to decrease the mathematical equations of the Jacobian Dynamic [7] and dynamic simulation [8].

In previous research, analysis of the steady-state stability limit has been carried out [5-8], but still these researches look at the stability of the overall system only, making it difficult to analyze the stability of each bus or generator. Therefore, to analyze the stability of each generator, the multimachine system must be changed into a SMIB system by collecting all the loads into one central load in the infinite bus. In this paper, determination of the maximum generation which is a generator steady state stability limit of units generator using the losses concept is provided.

Maximum generation of generator is influenced by several factors: source voltage, phase angle and networks impedance value. Equivalent network impedance can be determined by knowing the losses in the network, then the multimachine system can be changed into SMIB system with an equivalent impedance and an equivalent load. Note that the determination of equivalent impedance value using losses concept has been used in [9-14] to determine the Voltage Stability Index (VSI) for SMIB system.

And the example to demonstrate the features of steady state stability in a single machine connected to a infinite busbar has been used in [15]. However, the change from the multimachine system to SMIB system is not provided. The method to change from the multimachine system to SMIB system is presented in this paper.

Determination of the maximum generation, which is a generator steady state stability limit of units generator can be calculated after the network impedance is obtained and multimachine system is changed into the SMIB system.

Generator Saguling, which is one of the generators in the Java-Bali system 500 kV was used as a observed generator. RBFNN was applied to determine the maximum generation of generator Saguling on the variety load. Therefore, the determination of the maximum generation limit of generator Saguling can be determined directly at any time change of the load demand. II. BASIC THEORY A. Concept of Single Machine Steady State Stability Electric power system is defined as a collection of some of the power stations and substations, which are interconnected by transmitting nets with each other.

Interconnection system in operating system aims to obtain a combination of electric power generation as economical as Journal of Telecommunication, Electronic and Computer Engineering 162 e-ISSN: 2289-8131 Vol. 9 No. 2-3 possible, hence achieving a balance between the power available and the power is needed. System interconnection between the generators of the power system is shown in Figure1. Figure 1: System interconnection of electric power systems To analyze the steady state stability of each generator, firstly, the multimachine system must be changed to SMIB system.

The method to change the multimachine system to SMIB system will discuss in Section 3. If the system is considered to have no power loss, the power generated equals to the power delivered to the infinite bus. The equation for PG written as: (1) Figure 2 shows a generator connected to an infinite bus. Bus voltage is the constant magnitude when the net is very large (infinite). Assuming the generator is operating at fixed excitation, maintaining fixed and fixed  $X_e$ , then PG The characteristics power angle is shown in Figure 3. The maximum power is delivered to an infinite bus occurred at  $0$ .

Equation (1) can be written as:  $P_G = P = P_{max}$  (2) Figure 2: A generator connected to an infinite bus Figure 3: Characteristics of the real power and the power angle  $P_{max}$  is the steady-state stability limit of the system, which is the maximum power that can be delivered under slow disturbance. If an attempt is made to transmit power over this power limit, the synchronism is lost. The maximum power is also referred to as the pull-out power [4]. (3) where  $X$  is the reactance transfer between  $E$  and  $V$ ,  $X = X_d$  eq (4)  $E = V + j I X$  (5) where  $X_d$  eq is equivalent reactance,  $E$  is generator terminal voltage,  $I$  is inducted current and  $V$  is generator bus voltage, respectively.

It can be concluded that the maximum power that can be transferred by the generator is very dependent on the reactance network. If the generator transfers beyond this

maximum power limit, it can lead to the instability as loss of synchronization on the generator. If the load still increases, the stator and rotor magnetic coupling will be lost.

B. Radial Basis Function Neural Network Radial Basis Function Neural Network (RBFNN) was applied to determine the limit of the maximum generation of generator at any time change of the load demand.

Radial Basis Function Neural Network (RBFNN) is one of the artificial neural network models. RBF is a function commonly used in the regression. RBF function is applied in multi layer neural network perceptron called RBFNN. These networks have the advantage of being much simpler than the perceptrons while keeping the major property of universal approximation of functions. Numerous techniques have been developed for RBFNN learning. In addition, RBFNN can handle the nonlinear data that is likely equal to the conditions in the real time. RBFNN has one nonlinear hidden layer and the linear output only, so it can accelerate the computing [16].

Figure 4 shows the architecture of the RBFNN. Figure 4: The architecture of the RBFNN RBFNN models consist of three layers: the input layer, the hidden layer, and the output layer. Input layer receives an input vector  $x$ , which is then taken to a hidden layer which will process the input data as a nonlinear activation function. The output of the hidden layer is further processed in the output layer as a linear. RBFNN model uses the base functions as activation function for each neuron in the hidden layer.

Determination of Generator Steady State Stability Limit Using Losses Concept and RBFNN e-ISSN: 2289-8131 Vol. 9 No. 2-3 163 III. METHODOLOGY A.

Reduction of The Multimachine System to SMIB System Using Losses Concept and Determination of Generator Steady State Stability Limit Electric power system is a large system with multi generators (multimachine). If the generator stability analysis should be carry out in multimachine system, it will be very difficult. Therefore, the multimachine system as shown in Figure 5 must first be changed to a Single Machine to Infinite Bus (SMIB) system. The multimachine system is converted into an equivalent impedance and an equivalent load as shown in Figure 6.

Figure 5: Java-Bali multimachine system 500 kV Figure 6: Single Machine to Infinite Bus (SMIB) system The procedure to change the multimachine system to SMIB system and to calculate the maximum generation ( $P_{max}$ ) of each generator unit can be explained as follows: 1. Prepare loading value data by regulating the loading such that it does not exceed the generating capacity of the observed generator (the one that stability will be analyzed and which the equivalent impedance will be calculated). 2. Running the load flow with all generators are switched off except the observed generator. Obtain the active power ( $P$ ), the reactive power ( $Q$ ), the active power losses ( $PL$ ) and the reactive

power losses (QL). 3.

Calculate the current value  $I$  of the observed generator using the following equation: (6) where:  $I^* = I$  conjugate  $S_{in} = P + jQ =$  generated complex power of generator  $V_i =$  voltage of bus  $i$ . 4. Equivalent current is equal to the observed generator current. 5. Calculate the equivalent value of  $r_{eq}$  and  $x_{eq}$  using the losses concept as shown in the following equations:  $Z_{eq} = \frac{P_{loss}}{I^2}$  (7)  $r_{eq} = \frac{P_{loss}}{I^2}$  (8)  $x_{eq} = \frac{Q_{loss}}{I^2}$  (9) where:  $S_L = P_L + jQ_L$ ; with  $S_L$ ,  $P_L$  and  $Q_L$  are complex power losses, active power losses and reactive power losses between two bus, respectively.  $Z_{eq}$ ,  $r_{eq}$  and  $x_{eq}$  are equivalent impedance, equivalent resistance and equivalent reactance, respectively. 6. Calculate  $E$  using (5). 7.

Determine the maximum generation of observed generator which is the generator steady state stability limit using (3). 8. Repeat above procedure for observed generator for variety loading value until several loading data that will be used as training value on RBFNN are received. B. Training and Testing of RBFNN Several data that went through the above procedure were used as training value on RBFNN. Input data are variety loading and output data are  $r_{eq}$ ,  $x_{eq}$  and  $P_{max}$ .

After the training, testing was then performed on RBFNN to test the accuracy of the results obtained. IV. SIMULATION AND RESULT A. Reduction of The Multimachine System to SMIB System Using Losses Concept The simulation using the 500 kV transmission system of Java-Bali that consists of 1 swing bus, 7 generator bus and 17 load bus. Figure 5 shows a picture of SLD (Single Line Diagram) of Java-Bali system 500 kV. There are 8 generators in the Java-Bali system 500 kV. The generator was connected to the load bus through the lines with the different conductor type.

The generator on bus 11 e.g. generator Saguling was used as observed generator. The simulation steps to change the multimachine system to SMIB system can be explained as follows: 1. Prepare loading value data by regulating the loading so that it does not exceed the generating capacity of the observed generator. 2. Run the load flow with all generators switched off except the observed generator. The results of the load flow with all generators switched off, except the observed generator on bus 11 are presented in Table 1. 3. From Table 1, we can see that the generated power of generator Saguling was 536.027 MW and 211.426 MVar.

Voltage of bus 11 was 1,00 pu. The active power losses was 1,027 MW and the reactive power losses was -220,448 MVar. 4. The calculated result for the current value  $I$  of the observed generator using (6) was 665,358 A. 5. The  $r_{eq}$  value and the  $x_{eq}$  value can calculate using (7), (8) and (9) and we received  $0,0000092792 - j 0,00199184$ . Journal of Telecommunication, Electronic and Computer Engineering 164 e-ISSN: 2289-8131 Vol. 9

No. 2-3 B. **Determination of Generator Steady State Stability Limit** 1. Calculate E using (5). 2. We can determine **the maximum generation of** observed generator which is the generator steady-state stability limit using (3), and obtained 668,929 MW. 3.

Repeat the above procedure for observed generator for variety loading value until we get several loading data that will be used as training value to RBFNN. Table 1 The load flow results for observed generator Power Flow Solution by Newton-Raphson Method Maximum Power Mismatch = 1.15256e-006 No. of Iterations = 3 Bus No. Voltage Mag. Angle Deg Load Generation Injected MW Mvar MW Mvar Mvar

1	0.994	-0.726	7.258	4.440	0.000	0.000	0.000	2	0.994	-0.730	33.349	22.398	0.000	0.000	0.000	3	0.994	-0.697	36.052	25.753	0.000	0.000	0.000	4	0.994	-0.664	25.806	17.859	0.000	0.000	0.000	5	0.995	-0.546	33.064	21.214	0.000	0.000	0.000	6	0.995	-0.572	36.052	17.859	0.000	0.000	0.000	7	0.995	-0.586	30.645	16.774	0.000	0.000	0.000	8	0.996	-0.425	0.000	0.000	0.000	0.000	0.000	9	0.997	-0.298	39.041	31.278	0.000	0.000	0.000	10	0.999	-0.120	32.257	24.174	0.000	0.000	0.000	11	1.000	0.000	0.000	0.000	536.027	211.426	0.000	12	0.999	-0.204	27.988	34.633	0.000	0.000	0.000	13	0.996	-0.732	18.833	13.419	0.000	0.000	0.000	14	0.991	-1.612	15.607	35.817	0.000	0.000	0.000	15	0.992	-1.734	0.000	0.000	0.000	0.000	0.000	16	0.988	-2.001	40.891	31.278	0.000	0.000	0.000	17	0.988	-2.009	9.962	8.979	0.000	0.000	0.000	18	0.995	-0.688	0.000	0.000	0.000	0.000	0.000	19	0.996	-1.248	13.140	1.677	0.000	0.000	0.000	20	0.992	-1.703	24.857	24.075	0.000	0.000	0.000	21	0.990	-1.963	16.983	20.326	0.000	0.000	0.000	22	0.988	-2.109	39.800	26.838	0.000	0.000	0.000	23	0.987	-2.059	6.167	19.043	0.000	0.000	0.000	24	0.994	-0.716	34.724	28.318	0.000	0.000	0.000	25	0.989	-1.957	12.523	5.723	0.000	0.000	0.000	Total	535.000	431.874	536.027	211.426	0.000	C.
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Training and Testing of RBFNN In this paper, 19 training data and 5 testing data of the generator Saguling as observed generator were used on RBFNN. Input data are variety loading and output data are req, xeq and Pmax. **Table 2 shows the** calculation results **based on losses concept** compared with RBFNN training results for Pmax. The calculation results **based on losses concept** compared with RBFNN training results for req, xeq and Pmax are shown in Figure 7, Figure 8 and Figure 9, respectively.

Table 2 Comparison between calculation results **based on losses concept** and RBFNN training results

No Loading (MW)	Computation Results (MW)	RBFNN Training Results (MW)
1 11500	652.4989497	652,498949700000
2 11700	638.8104266	638,810426600000
3 11800	632.1822908	632,182290800000
4 11900	625.6934648	625,693464800000
5 12000	619.3405428	619,340542800000
6 12588	595.1294518	595,129451800000
7 12535	593.9498319	593,949831900000
8 12199	613.3813059	613,381305900000
9 12550	593.3139323	593,313932300000
10 13096	567.969285	567,969285000000
11 13108	564.5329447	564,532944700000
12 12863	578.7680179	578,768017900000
13		

12229 618,2484443 618,248444300000 14 11457 654,6639656 654,663965600000 15  
 11000 702,8536434 702,853643400000 16 11100 691,8111511 691,811151100000 17  
 11200 676,4524705 676,452470500000 18 11300 666,7990814 666,799081400000 19  
 11400 659,5700152 659,570015200000 Figure 7: Calculation results compared with  
 RBFNN training results for req Figure 8: Calculation results compared with RBFNN  
 training results for xeq **Determination of Generator Steady State Stability Limit** Using  
 Losses Concept and RBFNN e-ISSN: 2289-8131 Vol. 9 No. 2-3 165 Figure 9: Calculation  
 results compared with RBFNN training results for Pmax The calculation results compared  
 with RBFNN testing results are shown in Figure 10 and Table 3.

Figure 10: Calculation results compared with RBFNN testing results for req, xeq and  
 Pmax Table 3 Comparison between calculation results **based on losses concept** and  
 RBFNN testing results No Load (MW) Computation Results (MW) RBFNN Testing Results  
 (MW) 1 11.586 776,0435604 776,043560400002 2 12.143 622,0615119  
 622,061511900001 3 12.122 615,4316063 615,431606300001 4 11.531 655,0963933  
 655,096393300000 5 12.737 590,8099048 590,809904800000 Figure 10 and Table 3  
 show that the calculation results based on the losses concept compared with RBFNN  
 testing results lead to good performance. Load flow analysis in ETAP simulation was  
**used to validate the calculation** results.

The observed generator was turned on and others were turned off. Rated load increased  
 gradually until it reached a state where if the loading value is raised again **the load flow  
 process becomes** divergent. The generating value that is obtained before **the load flow  
 process** divergent is the maximum limit of the generation which is a **steady state  
 stability limit of the generator**. **The calculation results of** Pmax which is a **steady state  
 stability limit of** observed generator unit using the proposed method compared with  
 RBFNN testing results and ETAP simulation **result can be seen in** Table 4.

Table 4 Calculation results of Pmax **based on losses concept** compared with ETAP  
 simulation results Load (MW) Computation Results (MW) RBFNN Testing Results (MW)  
 ETAP Simulation Results (MW) 11.586 776,0435604 776,043560400002 701,865 12.143  
 622,0615119 622,061511900001 632,62 12.122 615,4316063 615,431606300001 627,865  
 11.531 655,0963933 655,096393300000 664,866 12.737 590,8099048 590,809904800000  
 510,585 Pmax calculation results obtained by the proposed method were not much  
 different compared with the results obtained by the ETAP simulation.

It can be concluded that, **the method to change** multimachine system into SMIB  
**presented in this paper** can be applied and determination of req and xeq value based on  
 the network losses concept can be done. By using the proposed method, **steady state  
 stability limit of** each generator in a multimachine system can be determined easily. V.

**CONCLUSION** The method to change from the multimachine system to SMIB system presented in this paper is easy to be applied in power system with multimachine system interconnection.

After the SMIB system is obtained, losses network value can be determine and then the equivalent impedance value can be calculated. Determination of the maximum generation, which is a generator steady state stability limit of units generator can be calculated after the network impedance is obtained. RBFNN is applied to determine Pmax of generator Saguling on variety of load demands given the great results. Therefore, the determination of the maximum generation limit of generator Saguling can be determined directly at any time change of the load demand.

The method to change multimachine system into SMIB presented in this paper can be applied and determination of req and xeq value based on the network losses concept can be done. By using the proposed method, steady state stability limit of each generator in a multimachine system can be determined easily. It will be very useful for guiding the operator in operating their generator safely. **ACKNOWLEDGEMENT** The authors are very grateful to the Power System Simulation Laboratory, Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia to all facilities provided during this research and the authors are very grateful to ITS Surabaya Indonesia through the PUPT ITS 2015 Grant Fund. **REFERENCES** [1] Chitra T. and Saurabh S. 2013. Analysis of Voltage Stability and Transfer Capability Enhancement of Transmission System Using Facts Controllers.

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