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Steady-State Stability Limit (SSSL) Assessment when Wind Turbine Penetration to South Sulawesi System Using ANN

***Abstract**. The increase in electricity load continues to increase, as population growth, productivity, regional progress, households and industries that always use electricity. As a result of the increase in impact on load fluctuations that result in electric power systems approaching the stability limits of normal conditions, resulting in the instability of the generator to withstand the load. The condition of instability is affected by the contingency ability and the transfer of power from the generator which are interconnected to the load through the transmission network. The ability of the transmission system to determine the stability index can be solved using the REI-Dimo method. The performance of this method by determining the same Z value as the system on many buses becomes one busload centered. This paper presents an assessment of the steady-state stability limit (SSSL) in an electric power system using REI-Dimo based on the Artificial Neural Network (ANN) Method. The stability index in an electric power system is determined by REI-Dimo, then detraining and testing using ANN. ANN results can conduct an SSSL assessment with an error value of -0.2572 without wind turbines, the error value using wind -0.1691. This study was conducted on the South Sulawesi system that has been connected with a 75MW Wind Turbine in the sidrap area. The simulation shows that the proposed method can quickly and accurately determine the SSSL prediction in the power system.*

Streszczenie.** W wyniku wzrostu wpływu na wahania obciążenia, które powodują zbliżanie się systemów elektroenergetycznych do granic stabilności warunków normalnych, skutkuje to niestabilnością generatora w zakresie wytrzymania obciążenia. Na stan niestabilności ma wpływ zdolność awaryjna i transfer mocy z generatora, który jest połączony z odbiorem poprzez sieć przesyłową. Zdolność systemu przesyłowego do wyznaczania wskaźnika stabilności można rozwiązać za pomocą metody REI-Dimo. Wydajność tej metody poprzez określenie tej samej wartości Z jak system na wielu magistralach staje się jednym skupionym na obciążeniu magistrali. W artykule przedstawiono ocenę granicy stabilności w stanie ustalonym (SSSL) w systemie elektroenergetycznym za pomocą REI-Dimo w oparciu o metodę sztucznej sieci neuronowej (ANN). Wskaźnik stabilności w systemie elektroenergetycznym jest określany przez REI-Dimo, a następnie odtrenowanie i testowanie za pomocą ANN. Wyniki SSN mogą przeprowadzić ocenę SSSL z wartością błędu -0,2572 bez turbin wiatrowych, wartość błędu przy użyciu wiatru -0,1691. Badania przeprowadzono na systemie Sulawesi Południowym, który został połączony z turbiną wiatrową o mocy 75 MW w rejonie Sidrap. Symulacja pokazuje, że proponowana metoda pozwala szybko i dokładnie określić predykcję SSSL w systemie elektroenergetycznym.* (Ocena limitu stabilności stanu ustalonego (SSSL) podczas dołączanmia turbiny wiatrowej do systemu w Sulawesi Południowym Indonezja przy użyciu sieci ANN***)

Keywords: Steady state stability limit, Penetration, REI-Dimo, Wind turbine, South Sulawesi System, ANN
Słowa kluczowe:stabilność systemu energetycznego, turbiny wiatrowe, sieci neuronowe.

Introduction

In an electric power system when operating there are predetermined limits, one of which is a steady-state stability limit, this condition is the limit of the ability of the system when changes in load or interference occur, the system can lose stability. The ability of the system to be able to operate in fulfilling the power to supply the load makes stability the main thing. Voltage conditions which are decreased due to changes in load and instability of steady conditions which may occur during a major disruption, this condition of the load variations greatly affect the system.

The limits on the ability of the stability of the electric power system are closely related to the ability to transfer electricity from the power plant to the load. On [1] has examined the transmission of electrical power by wind turbines and on [2-6] have examined the optimal power flow using the Monte Carlo Combined Simulation, and the results obtained are not convergent quickly. Of the two methods above that have mutual weaknesses in the operation of the electric power system Mathematically steady state has been developed, but this method requires a long time to solve computational problems, so the computational method was developed by Paul Dimo to solve problems in the electric power system. In the 1970s, P. Dimo, by proving the possibility of defining the equivalent of REI in the field of electric power systems. In an equivalent network called Transformers Equivalent introduced in 1977 by researchers who joined the EPRI group, an alternative to the REI equivalent concept that uses transformers ideally for network impedance [7]. In several studies, the determination of the stability index in the system has been carried out using the Dimo method [8, 9]. The REI-Dimo method used to analyze the changes that occur when a system experiences a problem. REI-Dimo is also used to determine the steady state stability limit on a 500kV system [10]. On [11] REI-Dimo was applied to the determination of stability index in [12] Therefore, it is observed from the literature that in this study using ANN in the analysis of steady state stability limits has been widely used over the past few decades [13-15] but in the ANN literature applied to one type of stability margin. For example in [14] and [16] ANN is used to predict the power tightness margin (P). Basically in [17] ANN is applied to assess the voltage stability index or also the L Index. The objective of this work is to Therefore, this paper presents the calculation of stability limits for optimization problems for the REI-Dimo method using ANN. The optimal solution of this problem to assess stability using ANN is applied to the South Sulawesi system of 44 buses and 15 generator systems that have been connected to the wind turbine as a case study. In this paper, the following stages are arranged. In the initial section outlining the background, in part 2, the study of the stability model in the power system, steady-State Stability Limit, and Determination of steady-state and transient stability, wind turbine, then the methodological study used in section 3 includes Rei-Dimo equivalent, design of Artificial Neural Network (ANN) model. For part 4 explain the simulation results. Finally, it is not the last part that concludes this paper.

Research method

A. Stability In Power System

In an electric power system it is defined that, there are three stable conditions, such as:

1. Reliability is the ability of a system to distribute active and reactive power or energy continuously from the generator to the load.
2. Quality is the ability of the electrical power of the system to produce a predetermined amount.
3. Stability is the ability of the system to return to normal operation after a disturbance and change in load.

In Figure 1, representing the South Sulawesi system that interconnects the wind turbine network, there are several power plants connected to each other and the output power in the form of active and reactive power in the form of voltage and frequency must be ensured in a balanced state between supply and dimand. In Table 1, it is the data generator and load system of South Sulawesi with a 75 MW wind turbine.

B. Steady-State Stability Limit

The system consists of a collection of developments that convert using interconnection networks to supply the overall load. Normal systems do not have power losses, ie the power sent by the generator is equal to the power received on an infinite bus. Contributions to PG can be issued as follows:

(1) $$P_G = \frac{|E||V|}{X}\sin\delta$$

Bus voltage $|V|$ is a fixed if the network is very large or infinite. Assuming the generator operates on fixed excitation and keeping $|E|$ fixed, and X remains, the PG is a function of the power angle. The maximum power to the infinite bus occurs at δ=90^o. Equation (1) can be written as follows:

(2) $$P_G == P = P_{MAX} \sin$$

Table-1. Data Generator and South Sulawesi system load

------Load------		---Generation---	
MW	M var	MW	Mvar
3.5	0.2	-20.977	90.922
17.1	4.1	0	0
23.3	3.7	0	0
9.6	4.8	0	0
24.4	6.2	14.3	-54.41
18.7	4.7	0	0
0	0	31.1	-11.525
26.5	10.3	70	120.294
0	0	60.4	49.4
10.1	2.4	0	0
22.1	8	0	0
0	0	0	0
18.9	10.6	75	0
33.1	15.4	0	0
18	5.8	0	0
63.3	18.3	21	64.688
68.3	17.7	0	0
0	-20	0	0
11.4	0	5.2	18.869
24.3	2.6	0	0
45.5	2.8	0	0
0	0	0	0
0	0	0	0
19.7	4.7	12.6	18.365
0	0	0	0
26.5	7.7	0	0
15.7	3.6	20	114.386
55.2	16.7	0	0
20.6	4.7	79	20.832
18.6	5.5	0	0
0	0	196.1	7.236
17.4	3.4	0	0
27.1	6.5	0	0
21.9	4.6	4	53.704
32.1	8.2	0	0
14.1	3.4	0	0
28.4	11.5	265.2	-48.162
11.9	1.5	8.2	48.139
49.2	0	4	126.328
0	0	0	0
0	0	195	55.638
0	0	0	0
4.9	0.5	0	0
11	1.8	0	0
812.4	**181.9**	**965.123**	**674.705**

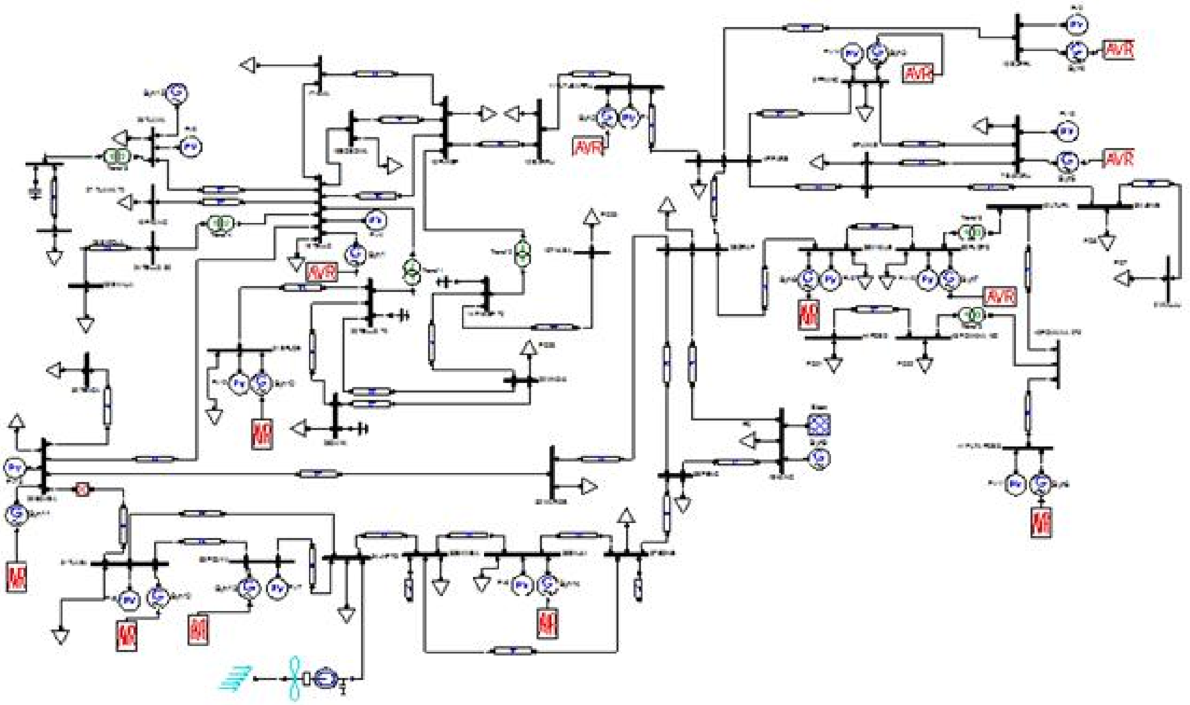

Fig.-1. South Sulawesi System

C. Wind Turbine

The model equation for mechanical power output from wind turbines obtained from wind power can be calculated as follows:

(3) $$P_w = 0.5\rho\pi R^2 V_w^3 C_P(\lambda,\beta)$$

Wind power output (Pw), rotor blade radius (R), wind speed (Vw),

(4) $$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda$$

With

(5) $$\lambda = \frac{\omega_r R}{V_w}$$

wind power output (P_{wt}) Rotor blade radius (R) Wind speed (V_w) The power coefficient depends on the tip ratio)λ) calculates based on air density (ρ) power coefficient (Cp) blade pitch angle (βas stated in (3), (4) and (5) here c1 to c6 is the coefficient of wind turbine characteristics and r is the wind turbine rotational speed [9]

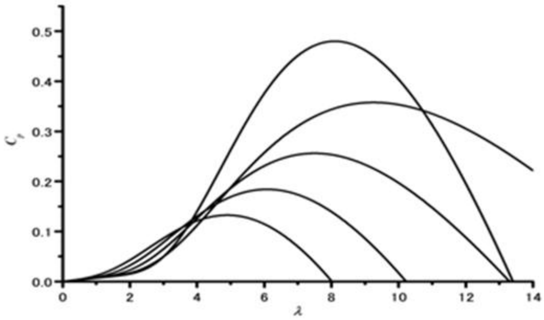

Fig.-2. Characteristics of Wind Turbine

D. Overview Of The Methodology Used

The use of the REI-Dimo methodology in power systems has been widely used on [8, 18, 19] this is based on REI-Dimo using a very unique concept to inject linearity types of transmission networks with constant administration, then combining transmission networks into a single non-linear injection applied to a fictional bus called the REI bus. This process is a fictitious network training, between the reduced bus and the fictional REI bus in a linear fashion, the network has no loss and can be reduced using Gaussian reduction. In this competition called zero power balance network which is the main concept in REI-Dimo [20]. In Figure 3 thevenin circuit concept is a Paul Dimo concept that aims to combine the load system into a fictitious load center by considering the nature and balance of the basic power of the system.

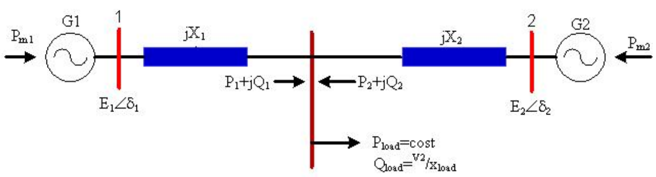

Fig. 3. Thevenin Circuit

SSSL index value and power obtained from the REI-Dimo method are then trained using ANN. Data input is the generator voltage, active power and reactive power of the generator, of the four values of REI-Dimo is the stability of the system that changes the load. For this research algorithm can be seen in Figure 4.

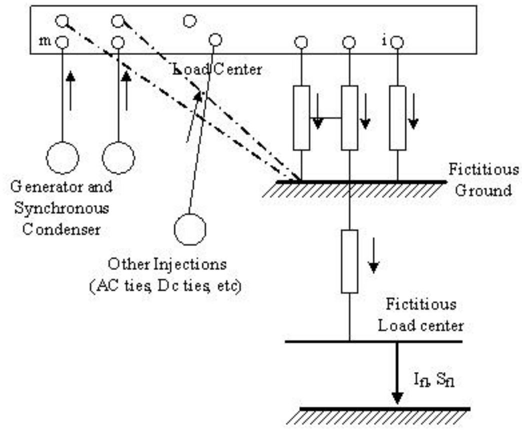

Fig. 4. Zero Power Balance Network

E. Design of Artificial Neural Network (ANN) Model

In this study using the ANN model to assess the stability limit in the South Sulawesi system due to wind turbine penetration. The ANN model in assessing requires practice to study between the number of inputs that are values to be given at the output.

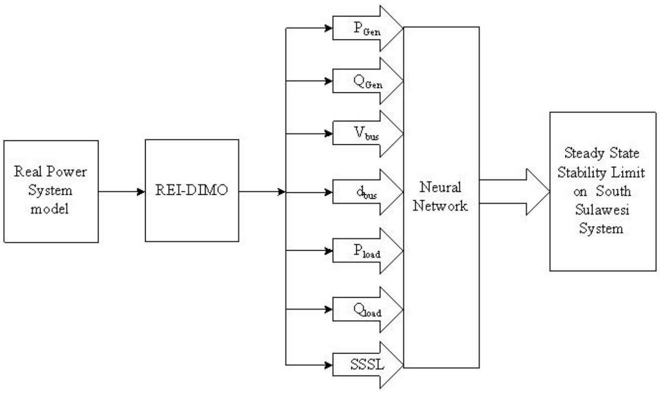

Fig. 5. Scheme of Research

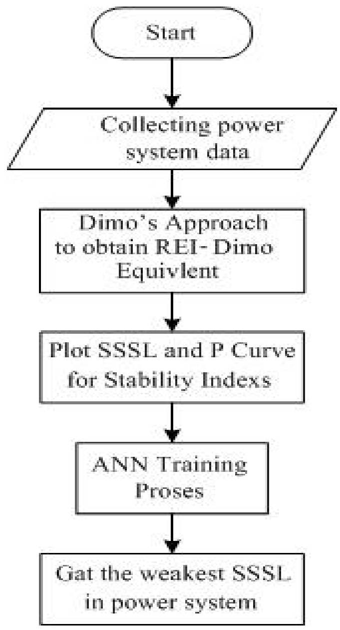

Fig. 6. Algorithm of Simulation

After trying many combinations of the number of hidden layers, the number of neurons in the hidden layer and the different transfer functions for the neurons in the hidden and output layers, an architecture suitable for ANN has arrived at. The architecture, which we found most suitable, has 81 inputs in the input layer, two hidden layers - one with 40 neurons and the other with 20 neurons. In Figure 7, the architecture used for ANN, there are inputs and three layers as follows:

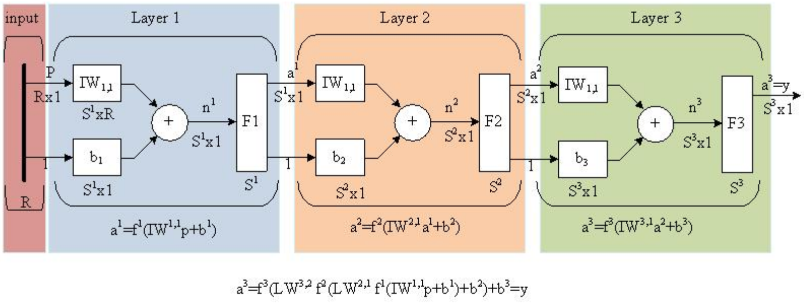

Fig.-7. ANN Architecture Used

Table-2. Results of the Rei-Dimo run

P_{Gen}	Q_{gen}	Voltage	Load Center	P_{load}	Q_{load}	SSSL
1336.226	269.003	1.0615	-0.2915	1650.994	794.902	-13.9422
1352.448	272.938	0.9831	-0.0845	1644.571	793.792	-13.9395
1368.696	276.576	0.9831	-0.0845	1661.556	800.19	-13.9171
1384.944	280.214	0.9831	-0.0845	1678.569	806.786	-13.8946
1401.192	283.852	0.9831	-0.0845	1695.607	813.582	-13.8718
1417.404	287.409	0.9831	-0.0845	1712.673	820.58	-13.8489
1433.688	291.128	0.9831	-0.0845	1729.765	827.78	-13.8258
1449.936	294.766	0.9831	-0.0845	1746.884	835.184	-13.8025
1466.184	298.404	0.9831	-0.0845	1764.031	842.793	-13.7791
1482.432	302.042	0.9831	-0.0845	1781.206	850.608	-13.7554
1498.608	305.608	0.9831	-0.0845	1798.408	858.63	-13.7316
1514.928	309.318	0.9831	-0.0845	1815.639	866.862	-13.7077
1531.176	312.956	0.9831	-0.0845	1832.898	875.303	-13.6835
1547.424	316.594	0.9831	-0.0845	1850.185	883.957	-13.6591
1563.672	320.232	0.9831	-0.0845	1867.502	892.823	-13.6346
1579.902	323.807	0.9831	-0.0845	1884.848	901.904	-13.6098
1596.168	327.508	0.9831	-0.0845	1902.223	911.002	-13.5849
1612.416	331.146	0.9831	-0.0845	1919.629	920.715	-13.5598
1628.664	334.784	0.9831	-0.0845	1937.064	930.448	-13.5344
1644.912	338.422	0.9831	-0.0845	1954.53	940.402	-13.5089
1661.106	342.006	0.9831	-0.0845	1972.027	950.578	-13.4832
1677.408	345.698	0.9831	-0.0845	1989.555	960.978	-13.4573
1693.656	349.336	0.9831	-0.0845	2007.114	971.603	-13.4311
1709.904	352.974	0.9831	-0.0845	2024.706	982.456	-13.4048
1726.152	356.612	0.9831	-0.0845	2042.329	993.538	-13.3782
1742.004	360.205	0.9831	-0.0845	2059.985	1004.851	-13.3515
1758.648	363.888	0.9831	-0.0845	2077.674	1016.397	-13.3245
1774.896	367.526	0.9831	-0.0845	2095.396	1028.177	-13.2973
1791.144	371.164	0.9831	-0.0845	2113.151	1040.193	-13.2699
1807.392	374.802	0.9831	-0.0845	2130.941	1052.448	-13.2422
1823.604	378.404	0.9831	-0.0845	2148.765	1064.944	-13.2144
1839.888	382.078	0.9831	-0.0845	2166.624	1077.682	-13.1863
1856.136	385.716	0.9831	-0.0845	2184.518	1090.664	-13.1508
1888.632	392.992	0.9831	-0.0845	2220.415	1117.372	-13.1006
1904.808	396.603	0.9831	-0.0845	2238.418	1131.102	-13.0716
1921.128	400.268	0.9831	-0.0845	2256.458	1145.085	-13.0423
1937.376	403.906	0.9831	-0.0845	2274.535	1159.324	-13.0128
1953.624	407.544	0.9831	-0.0845	2292.651	1173.822	-13.0121
1969.872	411.182	0.9831	-0.0845	2310.805	1188.508	-13.0103

Simulation results

REI-Dimo has reduced the model based on size, the reduction results are used as SSSANN input according to the number of neurons available. There are two output neurons to be given input SSSL estimates. The number of hidden neurons is determined based on trial and error. In general, one of the weaknesses in the application of neural networks in electrical system problems depends on the voltage and load. Therefore, the dependence needs to be changed in the training process on network parameters resulting in changes in system behavior, namely the presence of wind turbine penetration. The proposed SSSANN input pattern is chosen in such a way as to determine the stability of the system due to wind turbine deterrence.

All data obtained from REI-Dimo include: Active power generation (P Gen) reactive power (Q gene), all bus voltages, active load power and reactive load power and voltage at the load center (load center V) SSSL index by REI -Dimo becomes the whole data by ANN. The table is the result of the value of error between the actual and ANN no wind turbine. The smallest error result is -0.2572, while the biggest error result is -2.6451. For table 4 is the Value of error between the actual and the ANN used Wind Turbine, with the smallest error value is -0.1691 and the largest error value is -1.5098, so it can be compared between the use of wind turbine and before using wind turbine there is a difference at the smallest value is -0.0881 while the largest error value has a difference of -1.1353.

Table 3. Value of error between the actual and the ANN no Wind Turbine

Actual Load MW	NN Fotecast MW	Error NN (%)
-10.8039	-10.8317	0.2572
-10.7713	-10.8240	-0.4893
-10.7384	-10.8191	-0.7516
-10.7051	-10.8160	-1.0360
-10.6716	-10.8141	-1.3352
-10.6378	-10.8130	-1.6468
-10.6036	-10.8125	-1.9700
-10.5691	-10.8125	- 2.3028
-10.5343	-10.8129	-2.6451

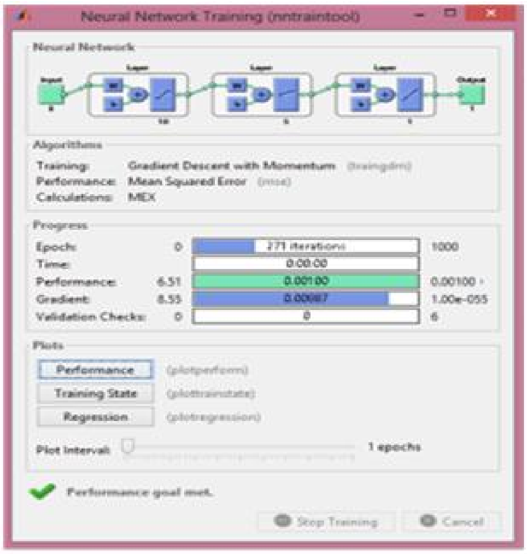

Fig. 8. Optimized ANN Model in MATLAB

Table 4. Value of error between the actual and the ANN used Wind

Actual Load MW	NN Foreecast MW	Error NN (%)
-13.4832	-13.5060	-0.1691
-13.4573	-13.4960	-0.2876
-13.4311	-13.4885	-0.4272
-13.4048	-13.4829	-0.5823
-13.3782	-13.4787	-0.7509
-13.3515	-13.4756	-0.9296
-13.3245	-13.4732	-1.1162
-13.2973	-13.4715	-1.3101
-13.2699	-13.4702	-1.5098

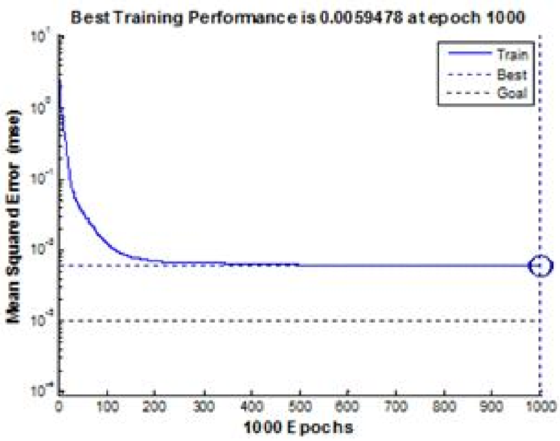

Fig.9. Best Training performance

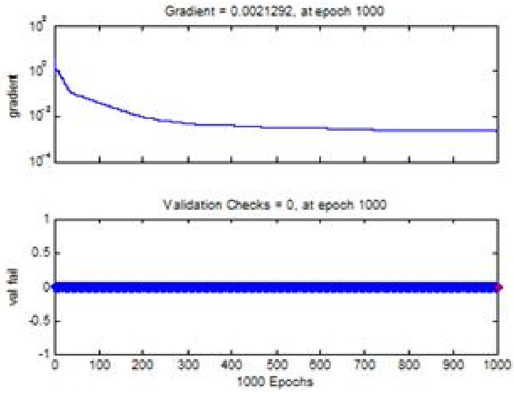

Fig.10. Gradient and validation

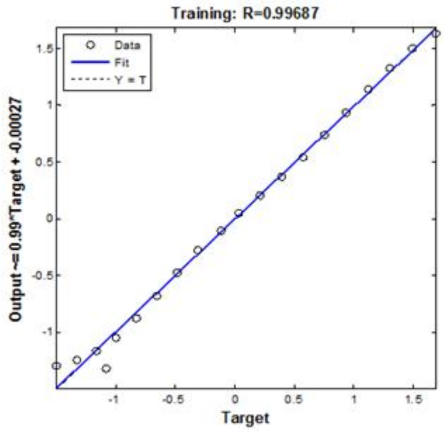

Fig.11. Training Output

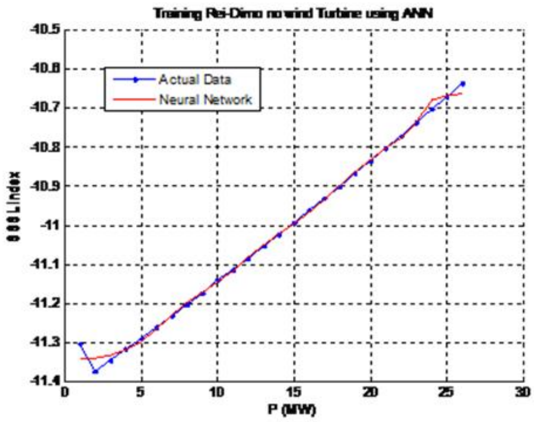

Fig.12. The results of training SSSL Rei-Dimo no wind turbine using ANN

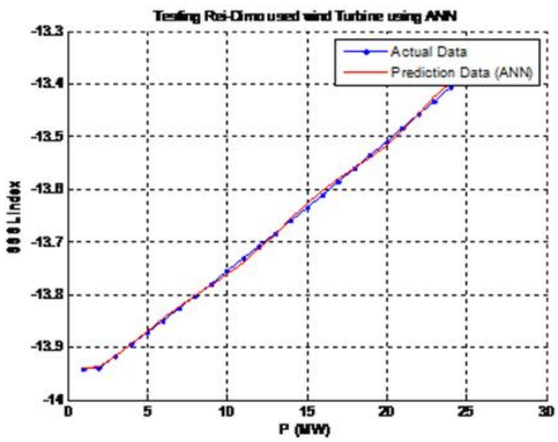

Fig.13. Results of Rei-Dimo SSSL Testing used wind turbine using ANN

In Figure 9, is the result of Best Training performance that has been done. The value of the best training performance is 0.0059478 with epoch at 1000. In Figure 10 it is Gradient and validation with a gradient value of 0.0021292 and validation checks is 0. In Figure 11 it is Training Output with a value of R 0.99687.

Conclusion

The proposed assessment of Rei-Dimo-based steady-state stability limits has been carried out with ANN rocks, having an important role in determining stability limits. Estimation results obtained from ANN show the ability of steady-state stability prediction technique predictions with a high level of accuracy that makes sense. ANN has a high level of calculation and fast processing with fault tolerance, very good for combination with the Rei-Dimo method. The results showed that Rei-Dimo and ANN had very good results with training and testing for SSSL. Linear regression in this method is more accurate and simpler for SSSL in electric power systems.

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