Contingency Ranking of the National Grid of Sudan (NGS) using artificial neural networks technique

Badareldinn Alia Adam Alnor
Lecturer, Department of Electrical Technology, Kassala College, Sudan Technological University, Sudan.

Dr. Mansour Babiker Idris
Associate Professor, Faculty of Engineering, Dep. of Electrical Engineering, University of Kassala, Sudan.

Abstract:

The demand for electrical power has become constantly increasing, and to cover this increasing demand for electrical power, the national grid of Sudan has expanded in the past few years at large rates, through new expansion on transmission and distribution networks. This situation formed a great complication and pressure on the network, which had a great impact on the stability of the system and the security operation of some of its parts. This paper aimed to provide contingency ranking for an important part of the national grid of Sudan with voltage levels 500kV and 220kV. using artificial neural network (ANN) technique. The Modeling and simulation were done using MATLAB program. The results shown the weaknesses elements of the network. This study concluded that artificial neural network (ANN)is posse a high accuracy and speed compared to the traditional methods, when the artificial neural network (ANN) is trained in excellent form.

key words:contingency analysis, artificial neural networks, MATLAB.

ترتيب الاضطراب للشبكة القومية السودانية باستخدام تقنية الشبكات العصبية الاصطناعية

بدرالدين على ادم النور: محاضر – قسم الهندسة الكهربائية – كلية كسلا التقانية –جامعة السودان التقانية
د. منصور بابكر ادريس: استاذ مشارك – قسم الهندسة الكهربائية والإلكترونية– جامعة كسلا

مستخلص:

أصبح الطلب على القدرة الكهربائية في تزايد مستمر، ولتغطية هذا الطلب المتزايد على القدرة الكهربائية توسعت الشبكة القومية السودانية في السنوات القليلة الماضية بمعدلات كبيرة، من خلال التوسعات الجديدة في شبكات النقل والتوزيع. هذا الوضع شكل تعقيدا وضغطاً كبيرين على الشبكة، مما كان له إثر كبير على استقرار النظام والتشغيل الامن لبعض اجزاءها .هدفت هذه الورقة الي تقديم ترتيب للاضطراب لجزء مهم من الشبكة القومية السودانية ذات مستويات الجهد 500KV و220KV. باستخدام تقنية الشبكات العصبية الاصطناعية. تم إجراء النمذجة والمحاكاة باستخدام برنامج ماتلاب. أظهرت النتائج عناصر الضعف في الشبكة. وقد خلصت هذه الدراسة الي أن تقنية الشبكات العصبية الاصطناعية ذات دقة وسرعة عالية مقارنة بالطرق التقليدية، عندما يتم تدريب الشبكة العصبية الاصطناعية (ANN) بشكل ممتاز.

الكلمات المفتاحية: تحليل الطواري، الشبكات العصبية الاصطناعية، الماتلاب

1- Introduction:

The power system is one of the most complicated networks, it consists of many interconnected elements such as generators transmission lines transformers circuit breakers. etc. Therefore the major important objectives of the operators of the power system is to make this system work in reliable, stable way, with high efficiency and safety (1-3). To achieve these objectives the operator must know the effect of the outage of power system elements, these is done by contingency analysis [4]. The result achieved from contingency analysis is used to save the power system by avoiding additional cascade outages [5]. A fast and simple technique used to detect the critical contingencies is applied full ac load flow method (e.g. Fast Decoupled Newton Raphson Method). [6] But after expansion of the power system and increasing of load demand, this approach is less efficient for identifying the critical contingencies because it consumes big computation time (7). Reduction of the computation time is achieved by identifying the most sever contingencies which is known as contingency ranking, which sorts the possible contingency events in groups (secure and not secure) (8). So, to identify the system security a comprehensive study of the system component outage is required. This paper presents contingency ranking for the 500KV and 220KV levels of NGS using new proposed artificial neural network (ANN), and detecting weak elements using N-1 contingency, using full AC power flow solution base Newton Raphson power flow to calculate voltage and line power flow performance indices. Which are used as an input to the new proposed ANN.

2- Contingency Analysis:

The virtual role of determining the effects of generators and transmission lines outages on bus voltage magnitudes and MVA line flows is term contingency (9). One method of Contingencies is ranking them according to their performance index (PI) (10). The contingency is also used to investigate the severity of critical outages (11). Contingency analysis is very important in power system security evaluation (12). Power system security is most significant characteristic for power system planning, operation and control (13).

3- Performance Indexes

The performance indices (PI) are utilized for investigate the power system state after occurring of contingences like generator outage, transmission line outage, circuit breaker and any significant equipment (11), In this work, two important indices are utilized and composite together to rank the severity of (NGS) contingencies, as follows:

1-1 Voltage performance index (PIV):

The voltage performance index (VPI) is widely used to measure the voltage violation (14). PI can be calculated from equation (1) below.

$$PIV = \left[\sum_{i=0}^{N} Wi\left(|V_i|_{new} - |V_i|_{spec}\right)/\nabla V_{i\,max}\right]^{2m}$$

$$PIV = \left[\sum_{i=0}^{N} Wi\left(|V_i|_{new} - |V_i|_{spec}\right)/\nabla V_{i\,max}\right]^{2m}$$

(1)

Where:

$N \equiv N \equiv$ Number of buses,

$Wi \equiv Wi \equiv$ Weightage factor for bus i,

$|V_i|_{new} \equiv |V_i|_{new} \equiv$ post outage voltage magnitude at bus i,

$|V_i|_{spec} \equiv |V_i|_{spec} \equiv$ Specified voltage magnitude at bus i (1.0 p.u.)

$V_{i\,max} \equiv V_{i\,max} \equiv$ Maximum allowable voltage change, which is computed as the difference between maximum voltage and difference between minimum voltage and specified voltage.

3-2 Apparent power performance index (PIA):

The apparent power performance index is one of greatest used indices (15), to determine line power flow, it is given by equation (2).

$$PIA = \sum_{i=0}^{n} Wi\left(S_{i\,new\,flow}/S_{i\,limit}\right)^{2m}$$

$$PIA = \sum_{i=0}^{n} Wi\left(S_{i\ new\ flow}/S_{i\ limit}\right)^{2m}$$

(2)

Where:

$n \equiv n \equiv$ Number of lines

$S_{i\ new\ flow} \equiv S_{i\ new\ flow} \equiv$ Post outage apparent power at line i

$S_{i\ limit} \equiv S_{i\ limit} \equiv$ MVA rating capacity of the line i

The m component in equation (1) and (2) in this work is selected as 1, and the value of WiWi is selected also as 1.

4- Artificial Neural Network (ANN):

Artificial neural networks (16,17) are observed parallel and distributed processing organizations, it involves a big number of simple and massively connected processors. There are many architectures introduced for solution of various pattern credit problems. Figure (1) shows single neuron.

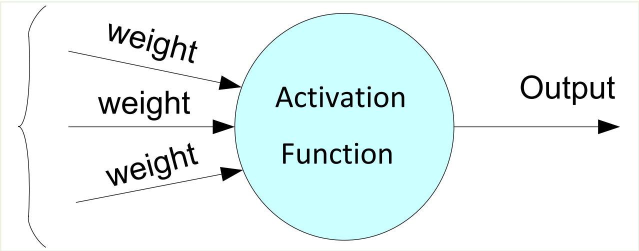


Figure (1) single neuron

5- Approach:

The proposed method gives the performance indexes PIV and PIA as an output of ANN when applying the results obtained from using the full AC load flow solution to determine the voltage violations and line apparent power flow loading as an input. Contingency ranking using the proposed approach is achieved using the flowing steps:

- Step one:

Get the power system parameters (Generators, transmission lines, transformers & compensation devices data) of the existing tested system which in this case is NGS.

- Step two:

Run the power system model power flow of NGS in MATLAB environment using m file script.

- Step three:

Obtain the results of load flow in base case

- Step four:

Assume a transmission line (N-1) outage and do load flow again.

- Step five:

Calculate PIV and PIA

- Step six:

Repeat the steps four and five, for all transmission lines outing one out at a time (N-1).

- Step six:

Apply the result obtained from (step five) in the proposed ANN.

6- Results and Discussion:

The study is applied to NGS e.g. typical (220KVand 500KV) , 83 buses and 81 transmission lines with 7 generator buses, 1slack bus (bus number 1) and 75 load buses as shown in Figure (2).

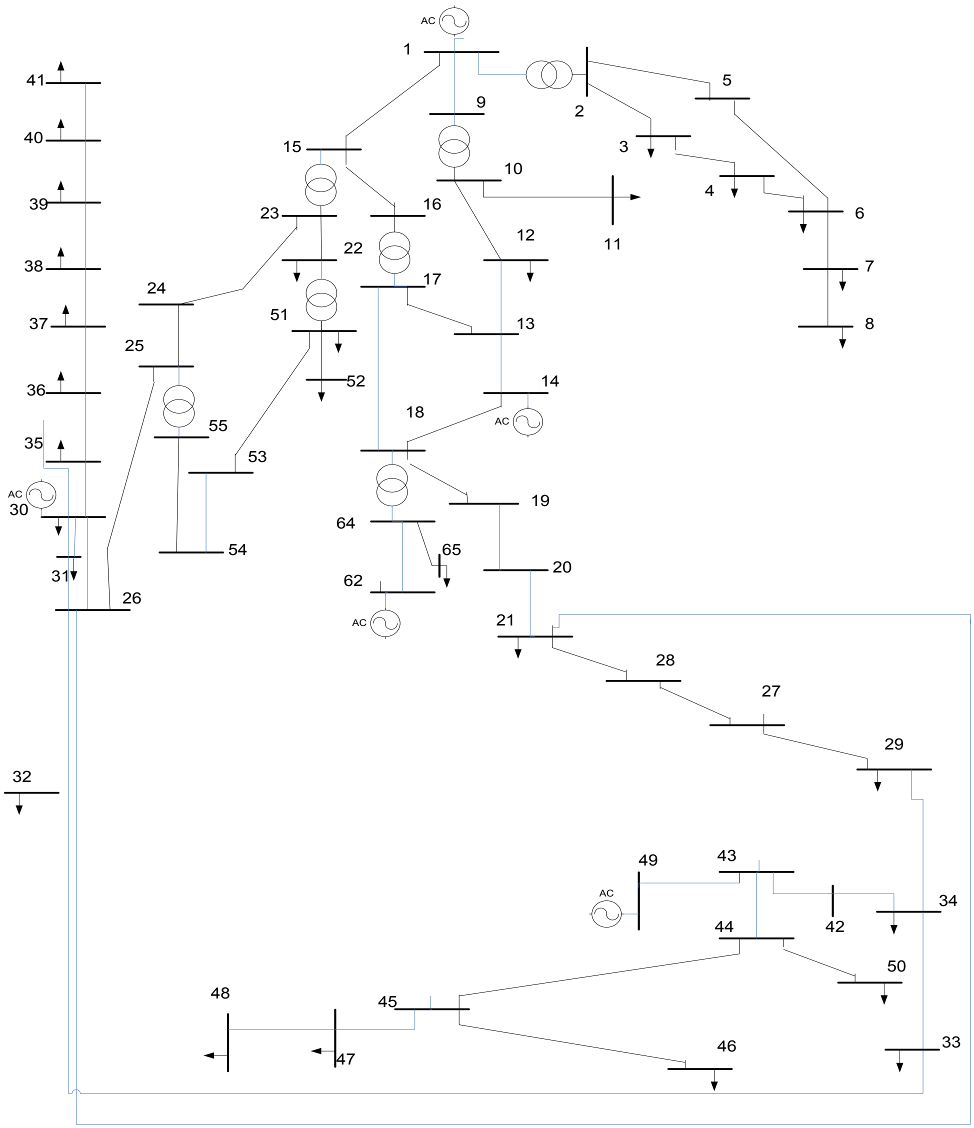


Figure (2) Single Line Diagram of 220KVand 500KV of NGS

The results of buses voltage magnitude in (P.U) and line power flow in MVA for 500kv and 220kv of NGS, after doing load flow of the bas case, are shown in figures (3) and figure (4) respectively.

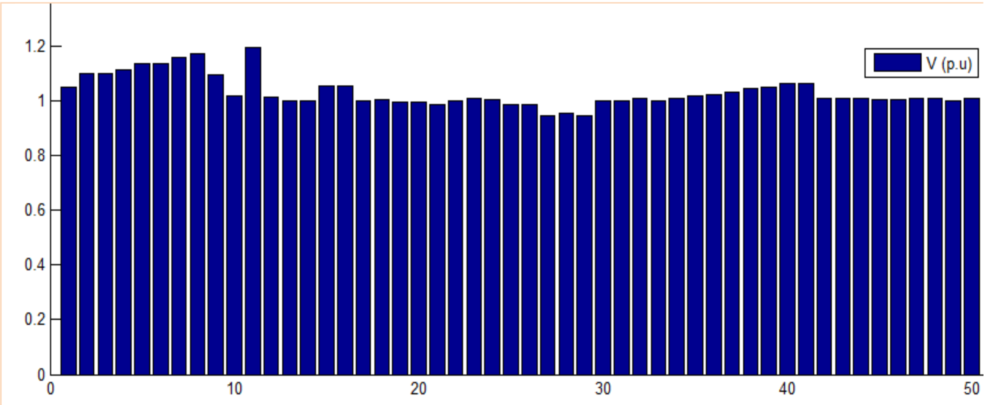


Figure (3) Bus voltage magnitude of 500kv and 220kv of NGS in the base case

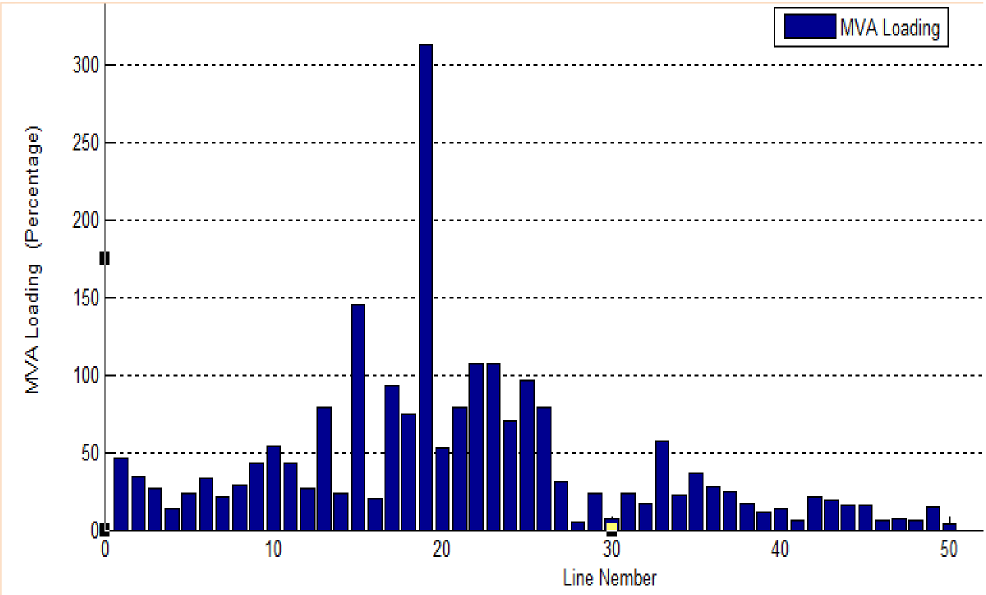


Figure (4) & MVA Loading of NGS in the base case

6-1 Results of contingency ranking using (PIV&PIA):-

Fifty scenarios of (N-1) contingencies are considered. Table (1) show the contingency ranking for NGS with voltage levels of 500KV and 220KV using (PIV&PIA), using equations (1) and (2) with component (m=1).

Table (1): Contingency ranking using (PIV&PIA)

No	Trans-mission line		converge	PIV	SIV	(PIV+ SIV)	Rank
1	2	3	no	not-converge	not-converge	not-converge	2
2	3	4	yes	9.588922128	18.20911068	27.79803281	49
3	5	2	yes	14.13930694	18.42493949	32.56424643	33
4	6	4	yes	12.96126381	18.13944409	31.10070791	43
5	6	5	yes	8.990422445	18.32718752	27.31760996	50
6	6	7	yes	107.7841423	17.98932664	125.7734689	12
7	7	8	yes	58.58238617	17.98848097	76.57086714	20
8	9	1	yes	14.4923925	19.60449094	34.09688344	26
9	11	10	yes	60.67945557	17.85433404	78.53378961	19
10	12	10	yes	12.35135336	17.84470177	30.19605513	48
11	12	13	yes	13.08571707	17.89755093	30.983268	45
12	13	14	yes	12.79837739	18.05009005	30.84846744	46
13	1	15	no	not-converge	not-converge	not-converge	1
14	16	15	yes	13.17731941	18.9113894	32.08870881	35
15	17	18	yes	12.64578692	18.86627589	31.51206281	41
16	17	13	yes	12.66736492	18.00751444	30.67487936	47
17	18	19	yes	13.46931239	24.42808601	37.8973984	23
18	18	14	yes	12.66243056	20.05369449	32.71612505	31
19	19	20	yes	12.99042879	18.62073759	31.61116639	40
20	20	21	yes	13.05815052	18.64010155	31.69825207	37
21	23	22	yes	19.26193887	32.13366215	51.39560102	22
22	23	24	yes	14.13494596	21.50026659	35.63521256	25
23	24	25	yes	14.37966018	21.56804861	35.94770879	24
24	26	25	yes	12.80152348	19.35697701	32.15850049	34
25	26	21	yes	12.91113481	18.81473754	31.72587235	36
26	21	28	yes	35.29409847	28.82825732	64.12235578	21
27	28	27	yes	13.69956399	19.51846331	33.21802731	30
28	27	29	yes	12.84726106	18.16590468	31.01316574	44
29	26	30	yes	14.21053131	19.41053511	33.62106642	28
30	30	31	yes	62.64677973	18.0454098	80.69218953	16
31	30	32	yes	12.98242178	18.68347365	31.66589543	39
32	32	33	yes	12.98737917	18.70081849	31.68819767	38
33	33	34	yes	12.50067103	20.19629147	32.69696251	32
34	34	29	yes	12.74938861	18.5716369	31.32102551	42
35	30	35	yes	361.9616303	17.34733083	379.3089611	4
36	35	36	yes	311.9618512	17.36634512	329.3281963	5
37	36	37	yes	261.9617684	17.41667707	279.3784455	7
38	37	38	yes	211.9617776	17.70823119	229.6700088	8
39	38	39	yes	161.9845111	17.82888931	179.8134004	9
40	39	40	yes	111.9670571	17.86532599	129.8323831	11
41	40	41	yes	62.07891745	18.02574333	80.10466078	18
42	34	42	yes	12.9488422	21.07806826	34.02691045	27
43	42	43	yes	12.94134747	20.54280728	33.48415475	29
44	44	43	yes	362.7085929	17.39855533	380.1071482	3
45	44	45	yes	262.7328125	17.4096829	280.1424954	6

No	Trans-mission line		converge	PIV	SIV	(PIV+ SIV)	Rank
46	45	46	yes	62.65500676	17.929388	80.58439476	17
47	47	45	yes	112.6646985	17.83385031	130.4985489	10
48	47	48	yes	62.63427211	18.13271732	80.76698943	15
49	43	49	yes	62.59809819	18.87264217	81.47074035	13
50	44	50	yes	62.63516864	18.14107331	80.77624194	14

Source: Prepared by the researchers (2022)

6-2 Results of contingency ranking using the Proposed ANN:

The ANN architecture implemented in this work is designed using hidden input and output layers, in MATLAB environment, applying artificial neural networks tools.

6-2-1 The Input layer:

In this paper, bus voltage magnitude and apparent power flow over the transmission lines are selected, as input vectors to the proposed artificial neural network. The input vector (x] consists of bus voltage magnitude of all buss (slack, generator and load buses,) as shown in equation (3), and the input (R] represents the apparent power flow as shown in equation (4). Figure (4) show the inputs of the proposed ANN.

$[X] = V_1, V_2, \dots V_n [X] = V_1, V_2, \dots V_n$

(3)

Where:

$V \equiv V \equiv$ voltage magnitude in (V)

$n \equiv n \equiv$ the number of system buses

$[R] = L_1, L_2, \dots L_n [R] = L_1, L_2, \dots L_n$

(4)

$L \equiv L \equiv$ Line loading in (MVA)

$n \equiv n \equiv$ the number of system lines

6-2-2 The Middle Layer:

The selection of the number of hidden layers and the number of neurons in each layer it is not built on a fixed method, but depends on the experimentation and simulation of system. Here in this paper the details of hidden layers are shown in the table (2) bellow.

Table (2):The details of used hidden layers.

No	Item number	Net1	Net2
1	number of hidden layers	1	1
2	number of neurons in each layer	10	15

Source: Prepared by the researchers (2022)

6-2-3 The Output Layer:

The output vector (O] of the proposed ANN contains two elements, which are the voltage and apparent power performance indices *PIVPIV* and *PIAPIA* .as shown figure (5) below.

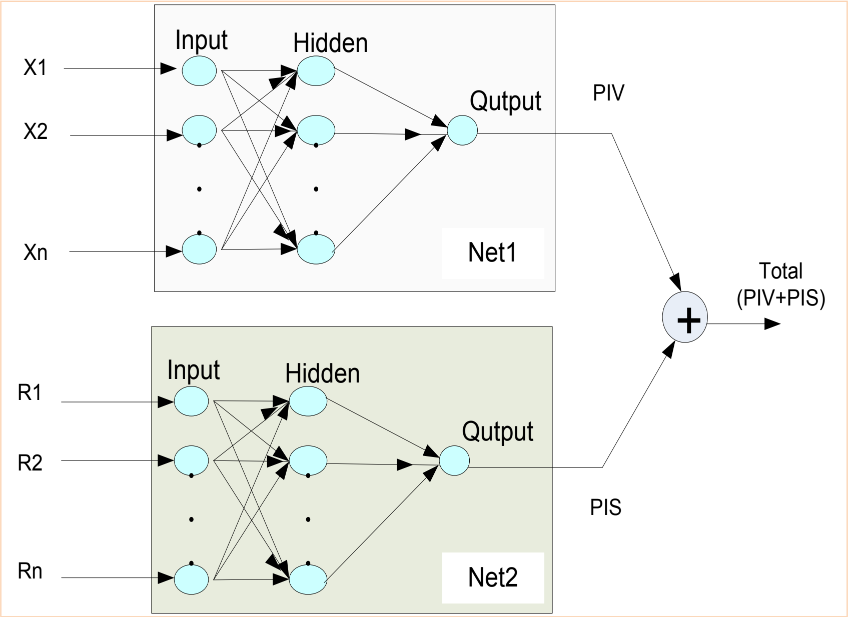


Figure (5) ANN in parallel processes for contingency ranking of NGS

6-2-4 Testing of the ANN system:

The proposed ANN for contingency ranking of NGS is illustrated in figure (6). The figure shows the components of ANN system. The first one is for PIV and it involve input layer, hidden layer and one output layer. The input layer has 83 neurons to receive the voltage magnitude at the 83 buses as its inputs. And the second one is for PIA and it involve input layer, hidden layer and one output layer. The input layer has 95 neurons to receive the loading of 95 element (transmission lines and transformers) as its inputs.

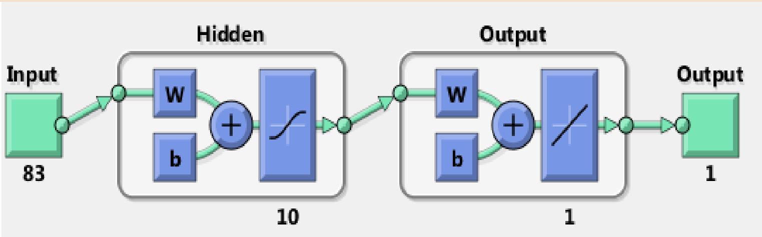
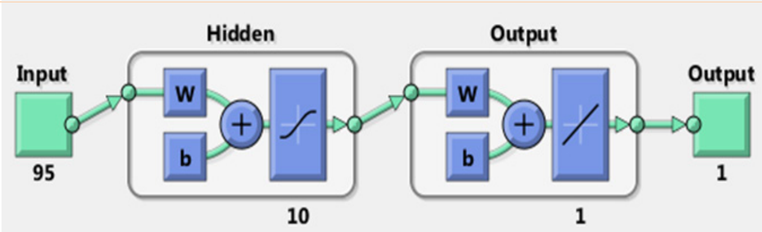
Net1	
Net2	

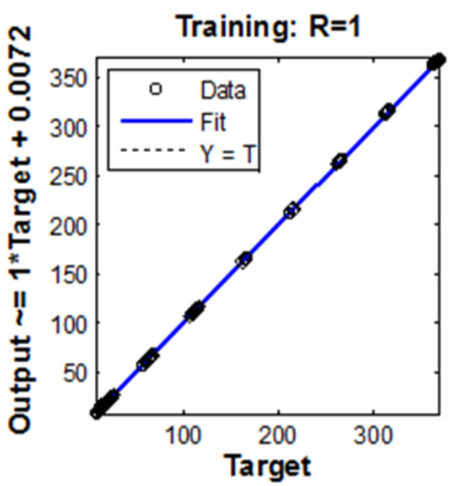
Figure (6) ANN system used for 500kV and 220KV of NGS

Similarly, the output layer of the first net has 1 neuron corresponding to the voltage magnitude outputs at these 83 buses. And the output layer of the second net has 1 neuron corresponding to the line loading outputs at these 95elements (transmission lines and transformers).

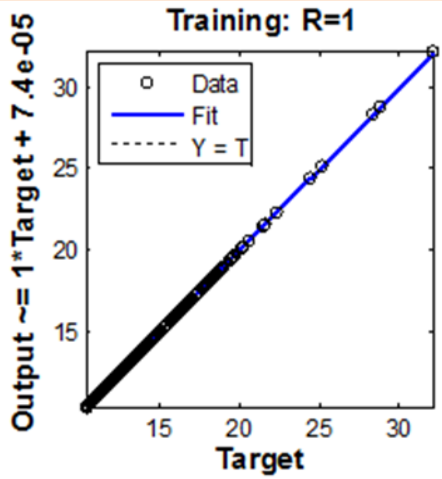
6-2-5Training progress of ANN system:

For the purpose of training the proposed ANN, initially 8 sets

(75%, 80%, 85%, 90%, 95%, 100%,105% and 110% of the normal load buss of NGS are used, including voltage magnitude at various load buses and corresponding voltage severity indexes of the base case (post contingency). The load demand at each bus is assumed to vary within ±5%±5% of base case steady state load flow solution of the NGS. These 8 sets form the inputs to the ANN. Then to each of these loading conditions, the corresponding outputs voltage magnitude and transmission line loading are obtained using Newton-Raphson load flow solution, these values are taken as input, and the corresponding voltage magnitudes and apparent power flow on the line are taken as target to train the proposed ANN. Figure (7) shows the training process of this proposed network. It converges within 12 iterations for net1 and 19 iterations for net 2 with an accuracy of 2.69e-05 and 8.25e-012 for net1 and net2 respectively. Figure (7) shows the training performance of the proposed ANN for the 500kVand 220KVoutages of NGS.



Net1

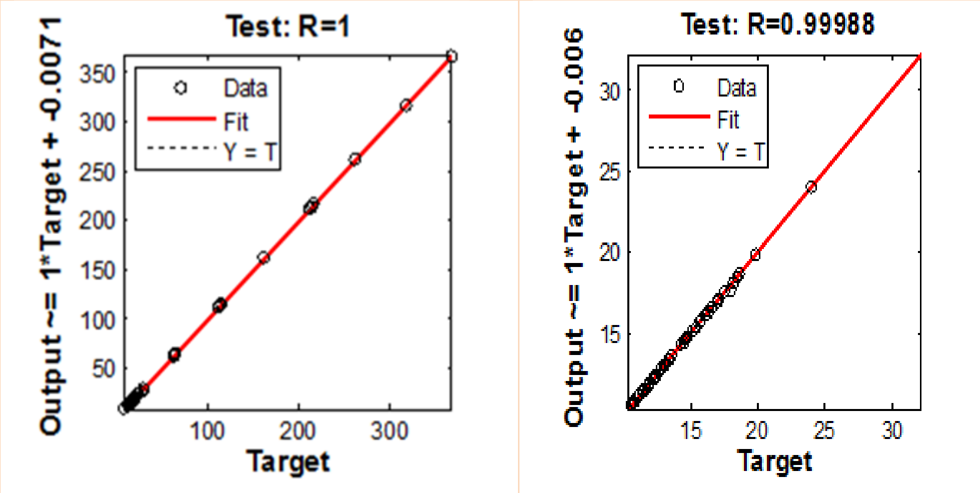


Net2

Figure (7) Training Process of the proposed ANN

Figure (7) above, shows that the excellent fit could be reached between the target and the actual outputs the of ANN, demonstrating that the ANN training progress is effective.

Figure (8) below shows the testing of the proposed ANN, it demonstrates the relationship between the targets and the actual Outputs of ANN.



Net1	Net2

Figure (8) The Relationship between the Targets and the actual Outputs of ANN

The ranking result of proposed ANN is achieved using two parallel networks. The first network evaluates severity index of voltage profile index and the second network evaluates line flow index. Table (3) shows the result of proposed ANN and composite index.

Table (3) shows the result of proposed ANN and composite index

No	Trans-mission line		ANNs output Net1+Net2	ranking	No	Trans-mission line		ANNs output Net1+Net2	ranking
1	2	3	No converge	2	26	21	28	62.08012624	21
2	3	4	27.81132405	49	27	28	27	33.2270427	30
3	5	2	32.57883426	33	28	27	29	31.01725043	44
4	6	4	31.11647163	43	29	26	30	33.62703415	28
5	6	5	27.33193242	50	30	30	31	80.7069698	16
6	6	7	125.7659211	12	31	30	32	31.67385739	39
7	7	8	76.28579897	20	32	32	33	31.69662647	38
8	9	1	34.1015293	26	33	33	34	32.70499835	32
9	11	10	78.53151109	19	34	34	29	31.33067332	42
10	12	10	30.20509631	48	35	30	35	379.2880582	4
11	12	13	30.99187456	45	36	35	36	329.3190508	5
12	13	14	30.85141325	46	37	36	37	279.3797377	7
13	1	15	No converge	1	38	37	38	229.6668013	8
14	16	15	32.36105339	35	39	38	39	179.8222462	9
15	17	18	31.52136431	41	40	39	40	129.8350605	11
16	17	13	30.69746966	47	41	40	41	80.11915325	18
17	18	19	37.86378068	23	42	34	42	33.96396694	27
18	18	14	32.72561724	31	43	42	43	33.49462723	29
19	19	20	31.65127474	40	44	44	43	380.1243574	3
20	20	21	31.74129253	37	45	44	45	280.1523188	6
21	23	22	51.41620572	22	46	45	46	80.59144881	17
22	23	24	35.64068337	25	47	47	45	130.4880515	10
23	24	25	35.95419826	24	48	47	48	80.76682045	15
24	26	25	32.16738301	34	49	43	49	81.47653515	13
25	26	21	31.73522391	36	50	44	50	80.77341394	14

Source: Prepared by the researchers (2022)

7- Conclusion:

Contingency ranking is performed for the 500KV and 220KV levels of NGS using new proposed ANN. The weaknesses of the elements system of these levels of NGS have been detected and the new capacities have been suggested for these cases of contingences. The results show the contingences number (13,2,44,35, and 36) are the most severe ones, among all these contingences the contingency no 13 is more severe because is connected directly to the slack bus. The results of contingency ranking of NGS using the proposed ANN approach is very fast and have excellent accuracy..

8- References:

(1) M.K. Verma and S.C. Srivastava, Approach to determine voltage control areas considering impact of contingencies, IEE Proc.-Gener. Transm. Distrib., 2005, Page 342.

(2) Swarup KS, Sudhakar G, Neural network approach to contingency screening and ranking in power systems. Neurocomputing, 2006, Page 105–118.

(3) Niazi KR, Arora CM, Surana SL, Power system security evaluation using ANN, feature selection using divergence, Electric Power Systems Research2004, Page 161–167.

(4) Scott Greene, Ian Dobson and Fernando L. Alvarado, Contingency Ranking for Voltage Collapse via Sensitivities from a Single Nose Curve, IEEE, 1997, Page 232.

(5) Baghaee, H.R. and Abedi, M, Calculation of weighting factors of static security indices used in contingency ranking of power systems based on fuzzy logic and analytical hierarchy process, International Journal of Electrical Power & Energy Systems, 2011, Page 855–860.

(6) Chary, D. M., Contingency Analysis in Power Systems, Transfer Capability Computation and Enhancement Using Facts Devices in Deregulated Power System, Ph.D. diss., Jawaharlal Nehru Technological University, 2011, Page 50–110.

(7) K. Shanti Swarup, G. Sudhakar, Neural network approach to contingency screening and ranking in power systems, ScienceDirect,2006, Page 105–118.

(8) Kassim al-anbarri, An approach for contingency ranking analysis of electrical power system, Conference Series Materials Science and Engineering , 2020, Page 1-10

(9) K. Purchala, L. Meeus, D. Van Dommelen, and R. Belmans, Usefulness of DC power flow for active power flow analysis, IEEE ,2005, Page1-6.

(10) Mitra P, Vittal V, Keel B, Mistry J. A, systematic approach to n-1-1 analysis for power system security assessment, IEEE, 2016, Page 71-80.

(11) P.Sekhar and S.Mohanty, power system contingency ranking using newton Raphson load flow method , IEEE ,2013. Page 1–4.

(12) R. Caglar, A. Ozdemir, F. Mekic, Contingency selection based on real power transmission losses, IEEE. 1999. Page 117.

(13) Wood, A. J.; Wallenberg, B. F., Power Generation, Operation and Control. 2nd ed, New York/USA: John Wiley& Sons, 1996, Page 296.

(14) G.C. Ejebe, B.F. Wollenberg, Automatic contingency selection, IEEE, 1979, Page 97–109

(15) Misra, R.K. and Singh, S.P. Efficient ANN method for post-contingency status evaluation, International Journal of Electrical Power & Energy Systems,2010, Page 54-62.

(16) G.W.Irwin, K.Warwick and K.j. Hunt, Neural Network Applications in control, Institution of Electrical Engineers, 1995, Page 2.

(17) P. Vas, Artificial-intelligence-based electrical machines and drives, Oxford University Press, 1999, Page 77-82.