Contingency analysis of the National Grid of Sudan (NGS) using fuzzy logic approach

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Abstract:

In the past few years, the national grid of Sudan (NGS) has witnessed a significant increase in demand for electrical power, in addition to new expansions in the transmission and distribution networks, and the complexities of electrical interconnection with some neighboring countries. This situation made the network operate at minimum levels of stability and security at some of its parts. This paper presents the contingencies analysis of NGS using fuzzy logic approach. The proposed fuzzy logic model was applied to NGS at voltage levels, 500 KV and 220 KV. The results show that there are many contingencies that causes transmission lines overloading and buses voltage violation. Moreover, some cases of the contingencies may cause complete blackout. The results also show that the fuzzy logic method is fast and effective in evaluating the network situation. Simulation was carried out using performance indexes and fuzzy logic in a MATLAB environment.

key words: Contingency analysis, Performance indicators, Fuzzy logic, MATLAB.

تحليل الاضطراب للشبكة القومية السودانية باستخدام منهجية المنطق الغامض

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المستخلص:

في السنوات القليلة الماضية، شهدت الشبكة القومية السودانية (NGS) زيادة كبيرة في الطلب على الطاقة الكهربائية، بالإضافة إلى التوسعات الجديدة في شبكات النقل والتوزيع، وتعقيدات الرابط الكهربائي مع بعض البلدان المجاورة. جعل هذا الوضع الشبكة تعمل عند مستويات الحد الأدنى من الاستقرار والأمان في بعض أجزائها. تقدم هذه الورقة تحليل الاضطراب لـ NGS باستخدام منهج المنطق الغامض. تم تطبيق نموذج المنطق الغامض المقترح على NGS عند مستويات الجهد ٥٠٠ كيلو فولت و٢٢٠ كيلو فولت. أظهرت النتائج أن هناك العديد من حالات الاضطراب التي تسبب تحميل زائدة لبعض خطوط النقل وانتهاك الجهد. علاوة على ذلك، قد تسبب بعض الحالات لحالات الاضطراب تعتيمًا تامًا. تظهر النتائج أيضًا أن طريقة المنطق الغامض سريعة وفعالة في تقييم حالة الشبكة. تم إجراء المحاكاة باستخدام مؤشرات الأداء والمنطق الغامض في بيئة MATLAB.

الكلمات المفتاحية:تحليل الاضطراب، مؤشرات الأداء، المنطق الغامض، ماتلاب.

1-Introduction:

Electrical power system is one of the most complicated engineering systems, it consists of many interconnections of elements, including (Generators, transmission lines, distribution lines, transformers and circuit breakers. etc.) this situation of interconnection elements brought many new problems, most of which have been solved (1).So, such problems meet the electrical engineers operating in the field of electric industry forms challenging and complications in designing future power systems to deliver the growth of amounts of electrical energy in a safe, clean, stable, reliable and economical manner (2).The electrical power network is a complicit nonlinear system that works in a continuously changing situation (3). The performance of the power system components depends on specific operating conditions, by increasing the demand of electrical power makes these components work in critical operating conditions, so the network's operating engineers must make the system safe, stable and highly reliable (4). Therefore, a detailed study of system safety is required. The purpose of this paper is to provide a framework for defining 'contingency analysis' and to illustrate how they are effective in power system. The charge-in voltage and line power flow after contingences is investigated, using full AC power flow solution base Newton Raphson power flow and performance index (PI) applying new proposed fuzzy logic approach. Contingency analysis is one of the important tools uses in all power system essential stage planning, operation, maintenances, etc., it is forming a vital part in modern energy management system. Contingency is a term defined by Ejebe and Wollenberg as study of the power system component outage and reporting these effects on all remaining elements of the system [5]. Contingency describes also as specified change in the grid occurring within a short period of time [6]. Contingency is a method used to measure the effect of power system component outages such as generators, transformers, transmissions lines, etc. And determine the result of the outage in lines loading and buses voltage levels in the network against their particular limits [7]. Some Contingencies likes unexpected generators outages or line outages often lead to voltage limit violation or blackout [8]. Power system Security is the capability of a power systems to supply its load without dangers stressing in their elements or permitting electric variables to stay within acceptable ranges under certain pre-specified contingencies [7]. In general, the term security means the ability of the power system to withstand the disturbances that occurring in the system due to any perturbations. [9]

2- Performance Indexes:

Performance index (PI) is used to show the system situation after contingences such as generator outage, transmission line outage or any other important component in the system (10), as well as contingency ranking. There are many common widely used indexes such as voltage performance index, line flow performance index and apparent power performance index.

2-1 Voltage performance index:

Voltage performance index is expressed by equation (1), when the value of voltage magnitude is below the specified voltage, the significance is to give lower ranking (higher severity) for poor voltage at specific buses.

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

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

(1)

Where: -

$nb \equiv nb \equiv$ 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.

2-2 Line flow performance index:

The Line Flow performance (L.F.P) index introduced by M.Moghavvemi et al. (5) examines the stability of the power system, and its values vary in the range (0 to1), 0 means (no load state) and means 1 (voltage collapse state). Line flow performance index is obtained by equation (2)

$$PIF = \sum_{i=0}^{n} Wi\left(P_{l\,new}/P_{l\,limit}\right)^{2m}$$

$$PIF = \sum_{i=0}^{n} Wi\left(P_{l\,new}/P_{l\,limit}\right)^{2m}$$

(2)

Where:

$nl \equiv nl \equiv$Total number of series equipment.

$Wi \equiv Wi \equiv$Weightage factor for series elementll,

$P_{l\,new} \equiv P_{l\,new} \equiv$ New real power flow in the line,

$P_{l\,limit} \equiv P_{l\,limit} \equiv$ Real power flow limit of the line.

2-3 Apparent power performance index:

Apparent power performance index is expressed by equation (3),

$$PI_{MVA} = \sum_{i=0}^{n} Wi\,(S_{i\ new}/S_{i\ limit})^{2m}$$
$$PI_{MVA} = \sum_{i=0}^{n} Wi\,(S_{i\ new}/S_{i\ limit})^{2m}$$
(3)

Where:

$n \equiv n \equiv$ Number of lines

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

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

The value of the component m in equation (1), (2) and (3) is effective on contingency ranking (masking effect) (11).

3- Fuzzy Logic:

The fundamental of fuzzy logic theory was set by Lotfi Zadeh, from university of California in 1965, (12). It is the way in which the human brain works, it uses a set of logical values graduate between (0&1), The result accuracy of fuzzy logic output is affected by the number of linguistic terms used, in general the huge number give more accurate result than a little number of linguistic terms. The fuzzy logic is effectually used in many applications such power system control, planning optimization, operation diagnosis, system analysis, etc. (13,14, 15). Fuzzy logic script m file in MATLAB is used for fuzzy inference.

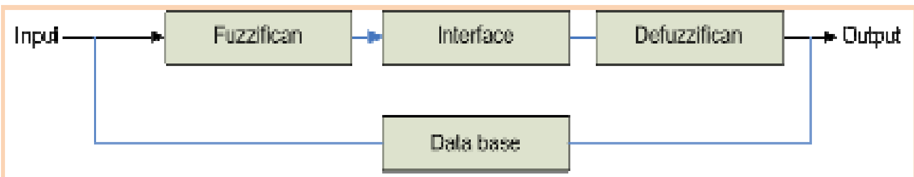

Figure (1) Fuzzy logic inference

4- Approach: -

The proposed method applied performance indexes and Fuzzy logic manner using full AC load flow solution i.e. newton-Raphson method (NR) to investigate voltage violations and line apparent power flow loading to evaluate the network and contingency ranking. The approach achieved by the flowing steps:

- Step one:

Get the power system parameters (Generators, transmission lines, transformers) of the existing tested system, in this case (NGS).

- Step two:

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

- Step three:

Obtain the values of voltage magnitude at all buses, line power flows at base case of NGS

- Step four:

Assume a transmission line (N-1) outage and do the power flow analysis.

- Step five:

Calculate the performance index of voltage from equation (1) and Calculate the performance index of apparent power from equation (3)

- Step six:

Repeat the steps four and five, for all transmission lines outage one.

- Step six:

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

4-1 Severity of Line loading:

Line loading severity index was obtained using equation (2) utilizing their value for the m component (m=1, m=2 and m=3). Fuzzy logic notion that used for line loading severity index classification, is divided in six categories. Table (1) show the fuzzy logic notion

Table (1) fuzzy logic notion of Line loading

No	Term	Abbreviation
1	Very more severe	VMS
2	More severe	MS
3	Above severe	AS
4	High severe	HS
5	Low severe	LS
6	Very low severe	VLS

Source: Prepared by the researchers (2022)

4-2 Severity of Voltage profile:

Voltage profile severity index was obtained using equation (1) utilizing their value for the m component (m=1, m=2 and m=3). Fuzzy logic notion that used for voltage violation severity index classification, is divided in six categories. Table (1) shows the fuzzy logic notion.

Table (2) fuzzy logic notion of voltage profile severity

No	Term	Abbreviation
1	Very low severe	VLS
2	Low severe	LS
3	Above severe	AS
4	More severe	MS
5	Very more severe	VMS
6	Very-Very more severe	VMS

Source: Prepared by the researchers (2022)

4-3 Total Severity

The total severity of the contingences is obtained using the summation of severity of line loading and severity voltage profile

5- Results and Discussion:

The result of voltage magnitude in (P.U) and line power flow in MVA for 500KV and 220kv transmission lines buses of the base case of NGS (post contingency), using NR load flow solution is optioned using MATLAB script.

5-1 Bus voltage magnitude:

Table (3) and figure (1) show voltage magnitude of the NGS in base case, Table (3) voltage magnitude of the SNG in base case

Bus no	voltage	Voltage Magnitude	Bus no	Voltage Levels	Voltage Magnitude
1	500	1.05	26	220	0.984610877
2	220	1.099761935	27	220	0.9449081
3	220	1.099478735	28	220	0.953131271
4	220	1.113407661	29	220	0.944433439
5	220	1.134303228	30	220	1
6	220	1.136304966	31	220	0.998192375
7	220	1.15553064	32	220	1.010261958
8	220	1.169772564	33	220	1
9	500	1.092149904	34	220	1.006280454
10	220	1.017277273	35	220	1.015453075
11	220	1.192069996	36	220	1.022936721
12	220	1.011781123	37	220	1.029725546
13	220	1.000740666	38	220	1.042750471
14	220	1	39	220	1.048535724
15	500	1.053216145	40	220	1.061843302
16	500	1.055282883	41	220	1.064131012
17	220	1.000789742	42	220	1.007367295
18	220	1.003503095	43	220	1.009245349
19	220	0.994298891	44	220	1.008766179
20	220	0.99252356	45	220	1.0019441
21	220	0.985964064	46	220	1.001768787
22	220	0.999278124	47	220	1.007686519
23	220	1.007571261	48	220	1.008753717
24	220	1.002813337	49	220	1
25	220	0.987654537	50	220	1.009201993

Source: Prepared by the researchers (2022)

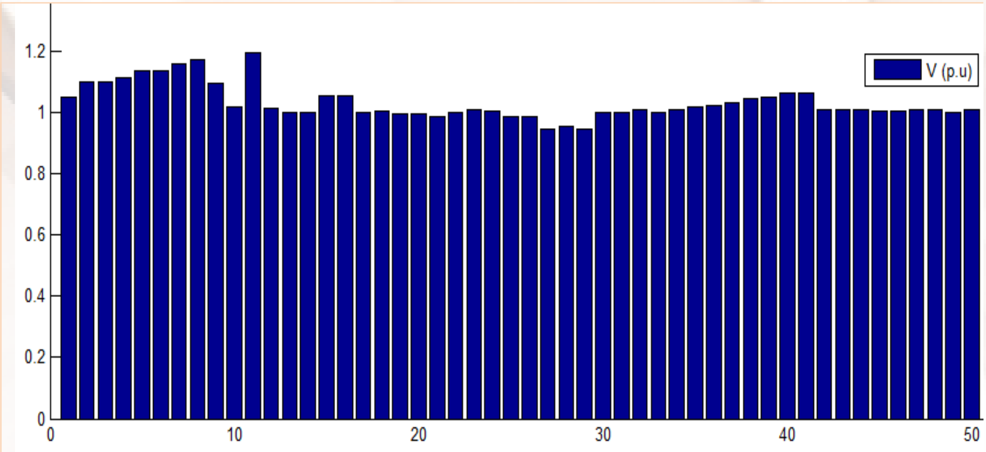

Figure (1) Voltage Magnitude of 500kv and 220kv Buses of NGS

5-2 Apparent power flow:

Table (3) and figure (2) show the power flow of the NGS in base case.

Table (3) Power Flow& Power Loading of NGS in the base case

No	Trans-mission line		Power Flow (MVA)	Rated power		No	Trans-mission line		Power Flow MVA	Rated power	
				MVA	%					MVA	%
1	2	3	87.123	187	46.59	26	21	28	146.969	187	78.59
2	3	4	64.675	187	34.59	27	28	27	58.637	187	31.36
3	5	2	49.362	187	26.40	28	27	29	9.038	187	4.83
4	6	4	25.456	187	13.61	29	26	30	65.634	275	23.87
5	6	5	44.025	187	23.54	30	30	31	18.354	275	6.67
6	6	7	61.192	187	32.72	31	30	32	63.200	275	22.98
7	7	8	45.453	213.84	21.26	32	32	33	46.936	275	17.07
8	9	1	311.276	1064	29.26	33	33	34	106.681	187	57.05
9	11	10	80.724	187	43.17	34	34	29	40.817	187	21.83
10	12	10	114.19	213.84	53.40	35	30	35	101.111	275	36.77
11	12	13	80.524	187	43.06	36	35	36	75.540	275	27.47
12	13	14	50.801	187	27.17	37	36	37	68.146	275	24.78
13	1	15	836.138	1064	78.58	38	37	38	45.892	275	16.69

No	Trans-mission line		Power Flow (MVA)	Rated power		No	Trans-mission line		Power Flow MVA	Rated power	
				MVA	%					MVA	%
14	16	15	248.574	1064	23.36	39	38	39	30.135	275	10.96
15	17	18	310.587	213.84	145.24	40	39	40	37.923	275	13.79
16	17	13	54.825	275	19.94	41	40	41	15.585	275	5.67
17	18	19	256.162	275	93.15	42	34	42	56.856	275	20.67
18	18	14	205.246	275	74.63	43	42	43	52.527	275	19.10
19	19	20	98.512	31.57	312.04	44	44	43	44.477	275	16.17
20	20	21	99.001	187	52.94	45	44	45	43.511	275	15.82
21	23	22	216.606	275	78.77	46	45	46	16.598	275	6.04
22	23	24	292.948	275	106.53	47	47	45	18.078	275	6.57
23	24	25	293.103	275	106.58	48	47	48	17.678	275	6.43
24	26	25	150.529	213.84	70.39	49	43	49	39.589	275	14.40
25	26	21	107.604	111.669	96.36	50	44	50	11.298	275	4.11

Source: Prepared by the researchers (2022)

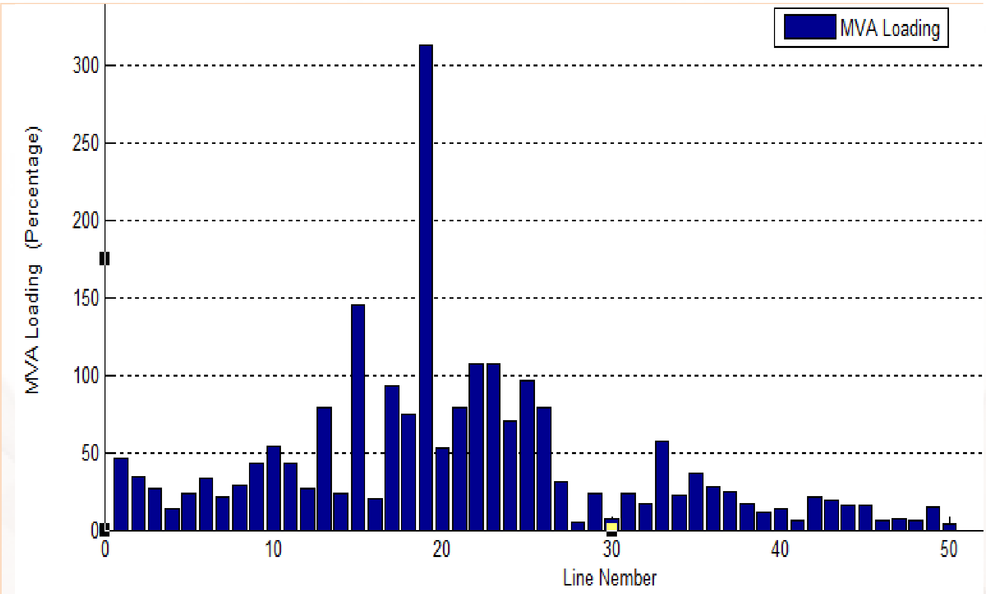

Figure (2) Power flow and Loading of NGS in the base case

Fifty scenarios of contingencies have been done in a section of NGS to rank and investigate the situation of the network. Table (4) shows the contingences and severe buses voltage violation in the system.

Table (4) Total severity index using component (m=1, m=2&m=3)

No	Trans-mission line		converge	TSI M=1	TSI M=2	TSI M=3
1	2	3	no	no	no	no
2	3	4	yes	20.809812	64.772107	498.5029
3	5	2	yes	25.362703	82.183304	556.6599
4	6	4	yes	23.937501	77.7094	541.6585
5	6	5	yes	20.107729	63.608704	496.9598
6	6	7	yes	118.54367	10062.309	1000497
7	7	8	yes	69.36423	5062.9552	5.00E+05
8	9	1	yes	20.52156	50.174006	156.1735
9	11	10	yes	71.830473	5071.5373	500568.2
10	12	10	yes	21.892741	47.258561	197.7441
11	12	13	yes	22.887111	56.991213	280.3629
12	13	14	yes	23.99709	78.458043	577.0097
13	1	15	no	no	no	no
14	16	15	yes	23.52578	40.57346	105.949
15	17	18	yes	23.537594	48.93073	172.2734
16	17	13	yes	23.43031196	73.23964625	524.6350509
17	18	19	yes	23.32531	51.670997	181.8188
18	18	14	yes	25.815053	75.332325	419.5741
19	19	20	yes	19.903329	29.828448	69.73551
20	20	21	yes	19.969078	29.826124	69.49792
21	23	22	yes	29.86464	58.116347	150.2913
22	23	24	yes	45.664081	1230.2291	5.87E+04
23	24	25	yes	45.993985	1235.5247	5.91E+04
24	26	25	yes	36.698153	668.78594	2.30E+04

No	Trans-mission line		converge	TSI M=1	TSI M=2	TSI M=3
25	26	21	yes	34.095292	491.45629	1.42E+04
26	21	28	yes	45.928039	174.99557	940.6545
27	28	27	yes	24.50074	73.625486	506.7266
28	27	29	yes	23.273219	74.530255	540.4701
29	26	30	yes	26.224571	98.015697	897.6444
30	30	31	yes	73.306912	5069.7699	5.00E+05
31	30	32	yes	23.964746	75.860197	551.4537
32	32	33	yes	23.983609	75.926569	552.35
33	33	34	yes	26.938739	108.6134	1024.479
34	34	29	yes	24.470301	81.61218	628.342
35	30	35	yes	371.21832	35052.389	3.50E+06
36	35	36	yes	271.20111	25052.701	2.50E+06
37	36	37	yes	221.34333	20054.095	2.00E+06
38	37	38	yes	272.00296	25062.539	2.50E+06
39	38	39	yes	172.28978	15065.684	1.50E+06
40	39	40	yes	122.36408	10067.424	1.00E+06
41	40	41	yes	72.784879	5071.2793	5.00E+05
42	34	42	yes	25.578331	98.287615	898.763
43	42	43	yes	25.363424	94.395295	833.0771
44	44	43	yes	273.08671	25062.452	2.50E+06
45	44	45	yes	223.14978	20062.944	2.00E+06
46	45	46	yes	73.059976	5066.9924	5.00E+05
47	47	45	yes	122.89827	10064.788	1.00E+06
48	47	48	yes	73.565469	5073.8407	5.01E+05
49	43	49	yes	75.292724	5102.3664	5.01E+05
50	44	50	yes	73.643187	5073.8555	5.01E+05

Source: Prepared by the researchers (2022)

The result of proposed Fuzzy approach is achieved using composited severity index of voltage profile index and line flow index as shown in figure (3) below.

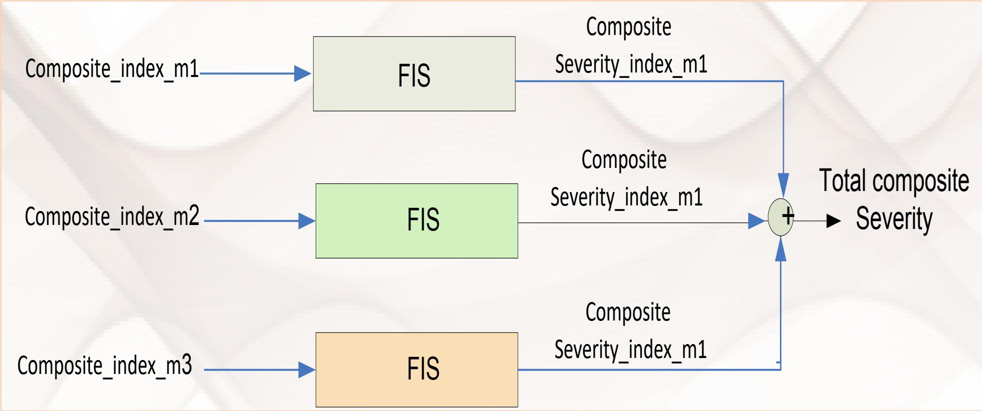

Figure (3) Fuzzy logic parallel processes of contingency ranking

The membership function of linguistics variables of the input and the out but of the fuzzy logic inference are shown in figures (4), (5), (6) and (7). The simplest (IF then rules), are shown in table (5) below to evaluate the severity of contingency. The Ranking of NGS contingencies based on Fuzzy logic approach is show in table (6).

Table (5) IF then rules of the fuzzy inference

Value of m	No	rules
Composite index m1 rule	1	If (Composite index m1 is VL) then (severe m1 is VLS)
	2	If (Composite index m1 is L) then (severe m1 is LS)
	3	If (Composite index m1 is H) then (severe m1 is AS)
	4	If (Composite index m1 is AH) then (severe m1 is MS)
	5	If (Composite index m1 is MH) then (severe m1 is VMS)
	6	If (Composite index m1 is VMH) then (severe m1 is VVMS)

Value of m	No	rules
Composite index m2 rule	7	If (Composite index m2 is VL) then (Composite_severe_m2 is VLS)
	8	If (Composite index m2 is L) then (Composite_severe_m2 is LS)
	9	If (Composite index m2 is H) then (Composite_severe_m2 is AS)
	10	If (Composite index m2 is AH) then (Composite_severe_m2 is MS)
	11	If (Composite index m2 is MH) then (Composite_severe_m2 is VMS)
	12	If (Composite index m2 is VMH) then (Composite_severe_m2 is VVMS)
Composite index m3 rule	13	If (Composite index m3 is VL) then (severe m3 is VLS)
	14	If (Composite index m3 is L) then (severe m3 is LS)
	15	If (Composite index m3 is H) then (severe m3 is AS)
	16	If (Composite index m3 is AH) then (severe m3 is MS)
	17	If (Composite index m3 is VH) then (severe m3 is VMS)
	18	If (Composite index m3 is VVH) then (severe m3 is VVMS)

Source: Prepared by the researchers (2022)

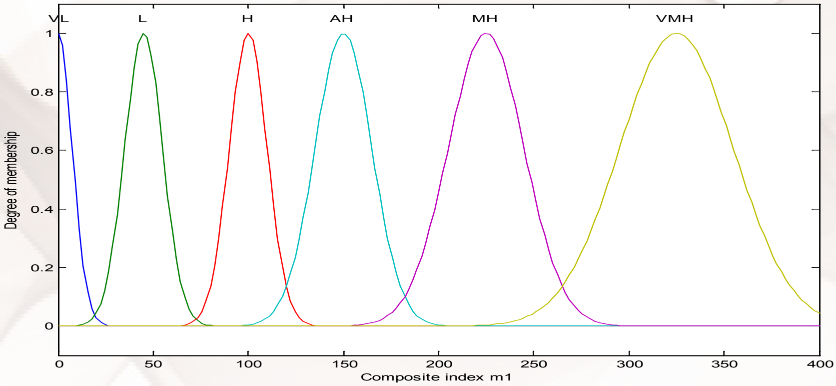

Figure (4) Composite index m1

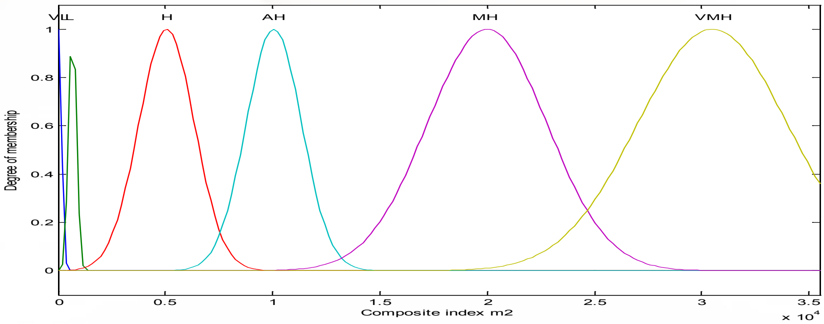

Figure (5) Composite index m2

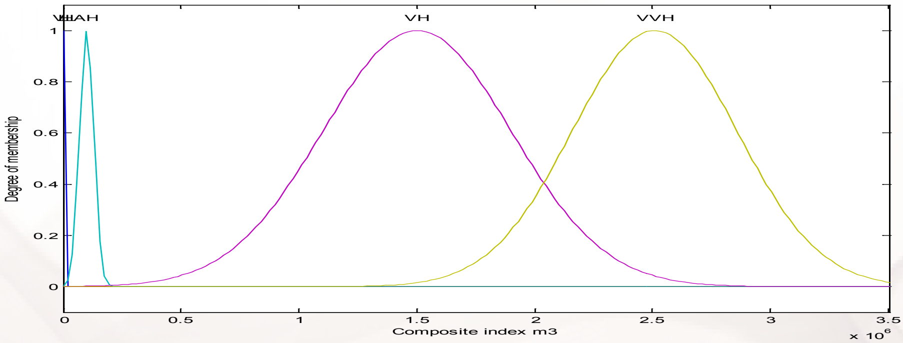

Figure (6) Composite index m2

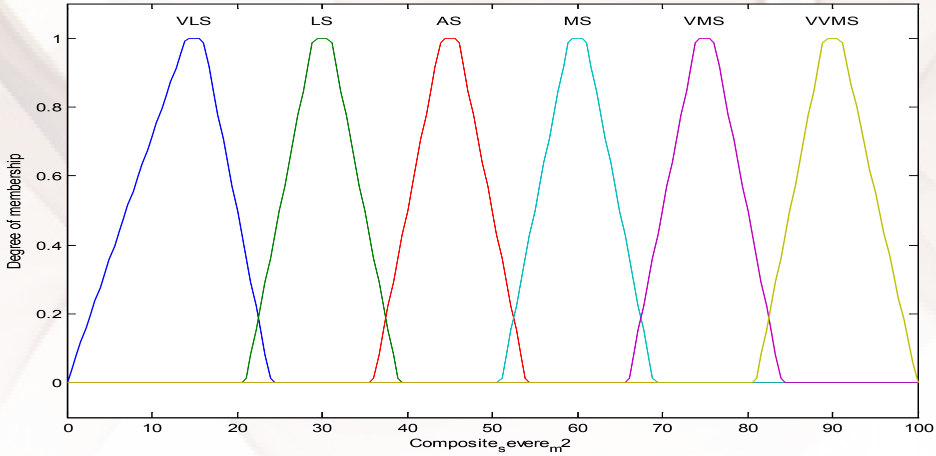

Figure (7) Composite severitiy index

Table (6) Ranking base Fuzzy logic approach of NGS

No	Trans-mission line		Fuzzy logic output Total severity	ranking	No	Trans-mission line		Fuzzy logic output Total severity	ranking
1	2	3	Not-converge	2	26	21	28	60.8099	26
2	3	4	50.3486	46	27	28	27	55.7284	34
3	5	2	56.1546	31	28	27	29	54.8276	42
4	6	4	55.4157	38	29	26	30	59.3465	27
5	6	5	48.443	48	30	30	31	159.2325	30
6	6	7	185.8186	12	31	30	32	55.454	37
7	7	8	152.1894	20	32	32	33	55.4693	36
8	9	1	49.5163	47	33	33	34	62.8739	25
9	11	10	156.0814	19	34	34	29	55.9683	33

No	Trans-mission line		Fuzzy logic output Total severity	ranking	No	Trans-mission line		Fuzzy logic output Total severity	ranking
10	12	10	52.7092	10	35	30	35	271.3407	3
11	12	13	54.2675	44	36	35	36	260.379	6
12	13	14	55.5313	35	37	36	37	232.4585	8
13	1	15	Not-converge	1	38	37	38	260.807	5
14	16	15	54.9502	41	39	38	39	211.7179	8
15	17	18	54.9638	39	40	39	40	190.3781	11
16	17	13	54.96	40	41	40	41	158.1361	18
17	18	19	54.7602	43	42	34	42	59.2181	28
18	18	14	56.151	32	43	42	43	58.0204	29
19	19	20	47.7857	19	44	44	43	261.2877	4
20	20	21	47.9731	49	45	44	45	232.4781	7
21	23	22	56.4997	30	46	45	46	158.722	17
22	23	24	128.8628	22	47	47	45	190.9509	10
23	24	25	129.2462	21	48	47	48	159.7469	15
24	26	25	120.4819	23	49	43	49	162.4642	13
25	26	21	105.8691	24	50	44	50	159.8968	14

Source: Prepared by the researchers (2022)

6- Conclusion

Contingency assessment and ranking are performed for the 500KV and 220KV voltage levels of the National Grid of Sudan (NGS). By using the new proposed fuzzy logic approaches. the weaknesses of the transmission system of these voltage levels of the NGS have been detected. A new transmission lines capacity for some case of contingences have been suggested to alleviate the transmission lines over loading. The result shows the contingences number (13,2,35,44, and 38) are the severe once, 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 the NGS using the proposed fuzzy logic approach is fast and have a good accuracy.

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