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Evaluation of Power System Contingency Using Performance Index

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Abstract: *One of the acceptable techniques to reduce outage in power system is the continuous evaluation of the system contingency. This work evaluates power system contingency using the power-performance index. The direct current (DC) load flow equations were employed to evaluate the network sensitivity factors and line outage distribution factors. Hence, the orders of active power line outage violations in a given sample network were prioritized using the performance index (PI). Using the Nigerian 28-bus grid system as a case study, the contingency analysis was implemented on the MATLAB R2008a software environment by randomly introducing disturbances on generator buses 2, 21 and 28; and on line 12-14 because of their loads. The network sensitivity factors were determined and used to evaluate violations on the system transmission lines. An outage on generator bus 2 of the network resulted in power flow on line 12-14 increasing from 268.4 MW to 316.9 MW. The new power flow on the line 12-14 exceeded the power flow limit of 279.6 MW specified by 37.3MW showing violation of 11.8%. This was repeated for other introduced disturbances and the performance index determined to prioritize contingencies.*

Keywords: Line outage distribution factor, Network sensitivity factor, Performance Index, Power system security, System contingency

1. INTRODUCTION

The power generation-demand imbalance in Nigeria in recent times has led to among others, a continuous and severe outage which causes disruptions of service to the consumers of electricity. The power system is characterized by several outages leading to disruption of electricity supply. The overall effect of this disruption is the retarding economic growth being experienced in the country.

Power system security is the probability of the system's operating point, remaining within acceptable ranges, given the probabilities of changes in the system (contingencies) and its environment [1]. The reliability of the system is often affected by the failure of any of the components during its operation resulting into outages. The study on the effects of outages in terms of its severity is one of the major agenda of power system planning and operation [2].

The dynamic nature of the power system does not guarantee its total reliability. Hence, a detailed security assessment is essential to deal with the possible failures in the system, its consequences and the remedial actions [2]. Power system security involves system monitoring where the real time parameters of the system are monitored by using the telemetry systems or the Supervisory Control and Data Acquisition (SCADA) systems. One of the core components of power system security study is the contingency analysis where simulation is being carried out on the list of credible outage cases, in order to give the operators an indication of what might happen to the power system in the event of an unscheduled equipment outage. This analysis forewarns the system operators and could allow some remedial action before the outage event. Hence, power system security analysis is performed to develop various control strategies to guarantee the avoidance and survival of emergency conditions and to operate the system at lower cost. The system is said to be in an emergency condition whenever the pre-specified operating limits of the power system has been violated.

2. POWER SYSTEM SECURITY

The desire to maintain system security is one of the important factors in the operation of the power system. System security involves practices suitably designed to keep the system in operation when any of the components fails. A system that has a low probability black out (collapse) or equipment damage is called an operationally secure power system [3]. The emergency condition of a power system depends on the severity of the violations of operating limits (branch flows and bus voltage limits). The ability of the power system to withstand the effects of contingencies is an important part of the security study.

Contingency analysis is one of the three major functions carried out in an energy control centre; others being system monitoring and corrective actions [4]. System monitoring supplies the power system operators with pertinent up to date information on the conditions of the power system on real time basis as load and generation change [1]. Contingency analysis programs are now stored in modern operation computers and these foresee possible system outages before their occurrence. The contingency analysis programs study outage events and alert the operators to any potential overloads or serious voltage violations. This allows the system operators to locate defensive operating states where no single contingency event will generate overloads and/or voltage violations [1]. The corrective action analysis, which is the third major security function, permits the operator to change the operation of the power system, if a contingency analysis predicts a serious problem in the event of the occurrence of a certain outage. Therefore, this provides preventive and post contingency control. The shifting of generation from one station to another is an example of corrective action. This may result in change in loading or overloaded lines [1]. These three functions together consist of a very complex set of tools that help in the secure operation of a power system.

2.1 Contingency Analysis

Contingency analysis is the study of the outage of elements such as transmission lines, transformers and generators and investigation of the resulting effects on line power flows and bus voltages of the remaining system [5]. It is used to calculate violations caused by the outage of one transmission line or transformer which leads to overloads in other branches and/or sudden rise or drop in the voltage level of the system [6]. It is one of the major activities in the planning and operation of power system [7] as it provides tools for managing, creating, analyzing and reporting lists of contingencies [8]. Contingencies referring to disturbances such as transmission element outages may cause sudden and large changes in both the configuration and the state of the system. Contingencies may result in severe violations of the operating constraints. Consequently, an important aspect of secure operation is the planning for contingencies [9].

Contingency analysis is an important tool for detecting possible overloading conditions, requiring the power system planner computational speed and ease of detection. Results of this analysis are usually ranked based on some indices calculated during the analysis and the Engineer's choice determines the performance index calculated [10]. Various analytical methods are available for carrying out contingency analysis and these include DC load flow method, AC load flow method, Z – matrix method and performance index method. However, for the purpose of this work, DC load flow method was employed since only active power and flat voltage profile were considered.

3. THEORETICAL ANALYSIS

Due to the complexity of the involved algorithms in security study and the desired to employ computer programme, a DC power flow technique was used in this work.

3.1 DC Load Flow

The DC power flow is a method of calculating the real power flow or Megawatts (MW) flow on transmission lines and transformers. In this case, the non-linear AC load flow equations were linearized to obtain the DC load flow equation with the bus voltage angle pre-determined [9]. The π – representation of a transmission line is used in obtaining the DC load flow equations as shown in Figure 1.

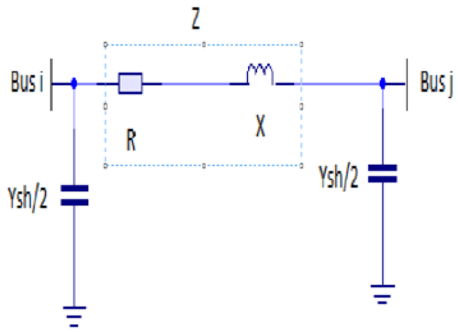

Figure 1: π-representation of a transmission line

The R, X, Z and Y_{sh} in the above Figure 1 respectively represents line series resistance, reactance, impedance and capacitance to ground in admittance form.

In formulating the DC load flow equations, some assumptions are made to ease the process of linearizing the AC load flow equations [11]. These include:

i. The voltage angular difference (θ) is small such that the sine and cosine values are approximately zero and one respectively (that is Sin $\theta \approx 0$ and Cos $\theta \approx 1$).
ii. There is a flat voltage profile that is all the voltages are put to 1 per unit.
iii. The line is lossless implying the line resistance is far less than reactance and is negligible (that is $R \ll X$).
iv. Tap settings are ignored.

Considering the π – representation of the transmission line presented in Figure 1, the apparent power, S, fed into the line i-j bounded by buses i and j is expressed by equations (1) to (3) [12, 13]:

$$S = P_{ij} + jQ_{ij} \quad (1)$$

$$S = VI \quad (2)$$

$$P_{ij} + jQ_{ij} = (V_i - V_j)I_{ij} \quad (3)$$

Where P_{ij} = Line active power
Q_{ij} = Line reactive power
V_i = Voltage at bus i
V_j = Voltage at bus j
I_{ij} = Line current

Application of Ohm's to Figure 1 gives equation (4) expressed as:

$$I_{ij} = (V_i - V_j)Y_{ij} \quad (4)$$

Where Y_{ij} = Line admittance

The use of equation (4) in equation (3) yields equation (5):

$$P_{ij} + jQ_{ij} = (V_i - V_j)^2 Y_{ij} \quad (5)$$

The line admittance Y_{ij} is expressed by equation (6) [14:

$$Y_{ij} = \frac{1}{Z_{ij}} = \frac{1}{R_{ij} + jX_{ij}} = G_{ij} + jB_{ij} \quad (6)$$

Where Z_{ij} = Line impedance
R_{ij} = Line resistance
X_{ij} = Line reactance
G_{ij} = Line conductance
B_{ij} = Line susceptance

An algebraic manipulation of equation (6) results in equations (7) and (8) given by:

$$G_{ij} = \frac{R_{ij}}{R_{ij}^2 + X_{ij}^2} \quad (7)$$

$$B_{ij} = \frac{-X_{ij}}{R_{ij}^2 + X_{ij}^2} \quad (8)$$

Upon the assumption that $X_{ij} \gg R_{ij}$, equations (7) and (8) are respectively modified as equations (9) and (10):

$$G_{ij} \approx 0 \quad (9)$$

$$B_{ij} \approx \frac{-1}{X_{ij}} \quad (10)$$

The real power flow from equation (3) is given by equation (11) and further modified as expressed by equations (12) to (14) using first and second of the above highlighted assumptions in this section of the work:

$$P_{ij} = G_{ij} V_i^2 - V_i V_j \left[G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j)\right] \quad (11)$$

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin(\theta_i - \theta_j) \quad (12)$$

$$P_{ij} = \frac{\theta_{ij}}{X_{ij}} = \frac{\theta_i - \theta_j}{X_{ij}} \quad (13)$$

$$P_{ij} = \frac{1}{X_{ij}} (\theta_i - \theta_j) \quad (14)$$

Where θ_i and θ_j are respectively bus i and bus j voltage phase angles.

Equation (14) is the linearized version of the AC line active power flow and was used to calculate phase angles of the bus voltages in this work.

The power injected at bus i is expressed by equations (15) and (16) [9, 15]:

$$P_i = \sum_j^N P_{ij} \quad (15)$$

$$P_i = \sum_j^N \frac{1}{X_{ij}} (\theta_i - \theta_j) = \sum_j^N \frac{\theta_i - \theta_j}{X_{ij}} \quad (16)$$

Where N is the total number buses connected to bus i.

Equation (16) can be written in either matrix forms expressed by equations (17) and (18):

$$\begin{bmatrix} P_1 \\ P_2 \\ \cdot \\ \cdot \\ \cdot \\ P_N \end{bmatrix} = B_x \begin{bmatrix} \theta_1 \\ \theta_2 \\ \cdot \\ \cdot \\ \cdot \\ \theta_N \end{bmatrix} \quad (17)$$

$$\begin{bmatrix} \theta_1 \\ \theta_2 \\ \cdot \\ \cdot \\ \cdot \\ \theta_N \end{bmatrix} = [X] \begin{bmatrix} P_1 \\ P_2 \\ \cdot \\ \cdot \\ \cdot \\ P_N \end{bmatrix} \quad (18)$$

Where $B_x = \sum_j^N \frac{1}{X_{ij}}$ with $B_{x_{ij}} = -\frac{1}{X_{ij}}$; for i $\neq$ ref, j $\neq$ ref and $B_{x_{ij}} = 0$; for i = ref, j = ref. P is the injected real power from bus i and θ is the phase angle of voltage at bus i.

The expressions in equations (17) and (18) are the DC load flow equations.

3.2 *Calculation of the Network Sensitivity Factors*

The network sensitivity factors are used to compute the violations and overload on the lines and generators in a given network. These factors are derived from the DC load flow equations [5]. The sensitivity factors are the generator shift factor and the line outage distribution factor.

3.2.1 *Generator shift factor*

The generator shift factor is used to calculate the effect of change in generation on the line flows. It is obtained from the DC load flow equations [9, 15, 16]. From equation (18), equations (19) and (20) were obtained:

$$\theta = [X]P \quad (19)$$

$$\Delta\theta = [X]\,\Delta P \quad (20)$$

Assuming that the change in generation is compensated by a change in generation at the reference bus and all other generators remain fixed, to calculate the generator shift sensitivity factor for generator at bus i, the perturbation on bus i is set to +1 while the perturbation on all other buses is set to zero [16]. On this basis, equation (21) is obtained.

$$\Delta\theta = [X]\begin{bmatrix}+1\\ \\ -1\end{bmatrix}^{row\ i}_{ref\ row} \quad (21)$$

Therefore, the linearized generation shift distribution factor using the DC load flow model is obtained from equation (22) [9, 15, 16]:

$$a_{ijn} = \frac{\Delta P_{ij}}{\Delta P_n} \quad (22)$$

Where a_{ijn} = Linearized generation shift distribution factor for the (i-j)[th] line for a change in output of n[th] generator
ΔP_{ij} = MW change in power flow on the line i-j
ΔP_n = Change in generation at bus n

Using equation (14) in equation (22), equations (23) to (25) are obtained as:

$$a_{ijn} = \frac{\Delta}{\Delta P_n}\left(\frac{1}{x_{ij}}(\theta_i - \theta_j)\right) \quad (23)$$

$$a_{ijn} = \frac{1}{x_{ij}}\left(\frac{\Delta\theta_i}{\Delta P_n} - \frac{\Delta\theta_j}{\Delta P_n}\right) \quad (24)$$

$$a_{ijn} = \frac{1}{x_{ij}}(X_{in} - X_{jn}) \quad (25)$$

Where $X_{in} = \frac{\Delta\theta_i}{\Delta P_n} = i^{th}$ element from $\Delta\theta$ vector
$X_{jn} = \frac{\Delta\theta_j}{\Delta P_n} = j^{th}$ element from $\Delta\theta$ vector
X_{ij} = Reactance of line i-j

The new value of line flow is obtained from equation (26) [9, 15, 16]:

$$P_{ij}^{new} = P_{ij}^{old} + a_{ijn}\,\Delta P_n \quad (26)$$

Where P_{ij}^{new} = Flow on (i-j)[th] line after the n[th] generator outage
P_{ij}^{old} = Flow on (i-j)[th] line before the n[th] generator outage

Hence, the line flow limits are compared with the new values of flows.

3.3 *Line Outage Distribution Factor*

This is used to check the overloading of a line due to the occurrence of an outage on any transmission line. It is also obtained from the DC load flow equations [9, 15, 16]. It is expressed as given in equation (27):

$$d_{ijk} = \frac{\Delta P_{ij}}{P_k^{old}} \quad (27)$$

Where d_{ijk} = Line outage distribution factor for line i-j after an outage of line k
ΔP_{ij} = Change in MW flow in line i-j due to the outage of line k
P_k^{old} = Flow in line k before its outage

A line outage may be modelled by adding two power injections to the system, one at each end of the line to be dropped as illustrated in Figure 2 [16].

From Figure 2, equation (27) can be re-written as equations (28) to (30) [9]:

$$d_{ijk} = \frac{\frac{1}{x_{ij}}(\Delta\theta_i - \Delta\theta_j)}{P_k^{old}} \quad (28)$$

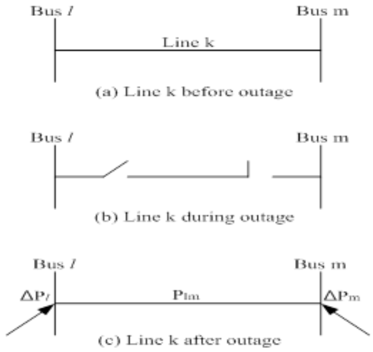

Figure 2: Line outage modelling

Since line k is bounded by buses *l* and m, equation (28) is re-written as equation (29):

$$d_{ijk} = \frac{1}{x_{ij}}\left(\frac{\Delta\theta_i}{P_{lm}} - \frac{\Delta\theta_j}{P_{lm}}\right) \quad (29)$$

Where $P_{lm} = \frac{1}{x_{lm}}(\theta_l - \theta_m)$ is the power flow in line k bounded by buses *l* and m.

$$d_{ijk} = \frac{1}{x_{ij}}(\delta_{ilm} - \delta_{jlm}) \quad (30)$$

Where δ_{ilm} *and* δ_{jlm} are sensitivity factors at buses i and j respectively as result of change in power flow in line k bounded by buses *l* and m with $\delta_{ilm} = \frac{x_{il}x_{lm}}{x_{lm} - x_{ll}}$ for m = reference bus and $\delta_{ilm} = \frac{x_{im}x_{lm}}{x_{lm} - x_{mm}}$ for *l* = reference bus.

The new value of line flow is given by equation (31) [9, 15, 16]:

$$P_{ij}^{new} = P_{ij}^{old} + d_{ijk}P_k^{old} \quad (31)$$

3.4 *Calculation of Performance Index*

The active power performance index (PI) reflects the violation of line active power flow. It is given by equation (32) [2, 7]:

$$PI = \sum_L \left(\frac{P_{ij}^C}{P_{ij}^{lim}}\right)^{2l} \quad (32)$$

Where L = Total number of transmission lines
P_{ij}^C = Real power flow on line i-j for a particular contingency

P_{ij}^{lim} = Real power limits of line i-j
I = Positive integer

The performance index (PI) can be calculated for each line in the network. The performance index, also called severity index [17] is a measure of system-wide effect of a contingency event in the system. The selection procedure then involves ordering the performance index table from the largest value to the least [9, 18]. This then will be used to prioritize the lines and will reveal the line that is to be given much attention.

4. RESULTS AND DISCUSSION

The Nigerian 330 kV power system network under consideration shown in Figure 3 along with the load and transmission line data shown in Tables 1 and 2 respectively were obtained from the National Control Centre [19]. The network comprises twenty-eight (28) buses, nine (9) of which are generation buses and nineteen (19) of which are load buses. In this system, bus 1 was used as the reference or slack bus. The initial power flow of the network at steady state condition using the system's load and transmission line data with the percentage line flow limit taken as 96% (acceptable range of 95% - 105%) is presented in Table 3. While generator outages were introduced on buses 2, 21 and 28, line outages were introduced on lines 2-7, 5-19 and 13-14. The contingency analysis was carried out using the mathematical models described in previous section and implemented on the MATLAB R2008a software environment. The new line flows were calculated and compared to the line flow limit in each case considered and the results presented graphically in Figures 4 and 5. The performance index for a single contingency of both the generator 2 outage and the line 5 – 28 outage was evaluated and presented in Table 4. The lines ranked 1 in both contingency cases was the least secure followed by the lines ranked 2 and in that order.

From the obtained values of the performance index presented in Table 2, the contingencies were ranked. The ranking was done in such a way that the highest value of performance index was ranked first for the selected outages. The first ranked line in each of the selected outages represented the line with the most severe case during disturbances. In other words, the least secure line has been ranked 1 and continuously in that order before finally ranking the most secure line. The most secure line in the event of generator outage was ranked 31 while the most secure line in the event of line outage was ranked 30, the highest ranking in both cases.

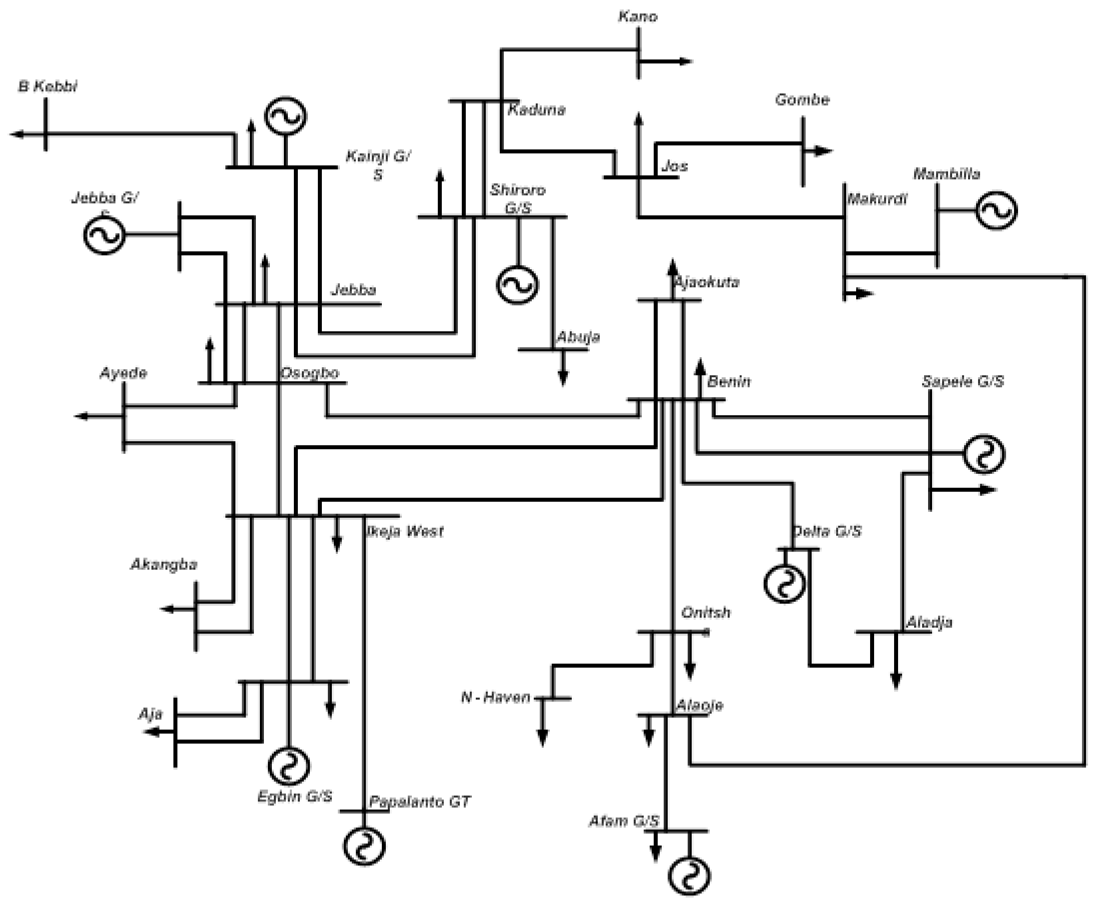

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Figure 3: The Nigeria 28-bus power network

Table 1: Load data of the Nigerian 28-bus power network

Bus Number	Bus Name	Load	
		MW	MVar
1	Egbin	68.90	51.70
2	Delta	0.00	0.00
3	Aja	274.40	205.80
4	Akangba	244.70	258.50
5	Ikeja-West	633.20	474.90
6	Ajaokuta	13.80	10.30
7	Aladja	96.50	72.40
8	Benin	383.30	287.50
9	Ayede	275.80	206.8
10	Osogbo	201.20	150.90
11	Afam	52.50	39.40
12	Alaoji	427.00	320.20
13	New-Heaven	177.90	133.40
14	Onitsha	184.60	138.40
15	B/Kebbi	114.50	85.90
16	Gombe	130.60	97.90
17	Jebba	11.00	8.20
18	Jebba G	0.00	0.00
19	Jos	70.30	52.70
20	Kaduna	193.00	144.70
21	Kanji	7.00	5.20
22	Kano	220.60	142.90
23	Shiroro	70.30	36.10
24	Sapele	20.60	15.40
25	Abuja	110.00	89.00
26	Makurdi	290.10	145.00
27	Mambila	0.00	0.00
28	Papalanto	0.00	0.00

Table 2: Transmission line data of the Nigerian 28-bus power network

Bus		Resistance (p.u.)	Reactance (p.u.)
From	To		
3	1	0.0006	0.0044
3	1	0.0006	0.0044
3	1	0.0006	0.0044
4	5	0.0007	0.0050
4	5	0.0007	0.0050
1	5	0.0023	0.0176
1	5	0.0023	0.0176
5	8	0.0110	0.0828
5	8	0.0110	0.0828
5	9	0.0054	0.0405
5	10	0.0099	0.0745
6	8	0.0077	0.0576
6	8	0.0077	0.0576
2	8	0.0043	0.0317
2	7	0.0012	0.0089
7	24	0.0025	0.0186

Bus From	Bus To	Resistance (p.u.)	Reactance (p.u.)
8	14	0.0054	0.0405
8	10	0.0098	0.0742
8	24	0.0020	0.0148
8	24	0.0020	0.0148
9	10	0.0045	0.0340
15	21	0.0122	0.0916
15	21	0.0122	0.0916
10	17	0.0061	0.0461
10	17	0.0061	0.0461
10	17	0.0061	0.0461
11	12	0.0010	0.0074
11	12	0.0010	0.0074
12	14	0.0060	0.0455
13	14	0.0036	0.0272
13	14	0.0036	0.0272
16	19	0.0118	0.0887
17	18	0.0002	0.0020
17	18	0.0002	0.0020
17	23	0.0096	0.0721
17	23	0.0096	0.0271
17	21	0.0032	0.0239
17	21	0.0032	0.0239
19	20	0.0081	0.0609
20	22	0.0090	0.0680
20	22	0.0090	0.0680
20	23	0.0038	0.0284
20	23	0.0038	0.0284
23	25	0.0038	0.0284
23	25	0.0038	0.0284
12	26	0.0071	0.0532
12	26	0.0071	0.0532
19	26	0.0059	0.0443
19	26	0.0059	0.0443
26	27	0.0079	0.0591
26	27	0.0079	0.0591
5	28	0.0016	0.0118
5	28	0.0016	0.0118

Table 3: Initial Power Flow (Steady State Condition) of the Network system

Line Code	Line	Line Reactance (p.u.)	Initial line flow before outage (MW)	Line flow Limit (MW)	Bus code	Initial power on bus (MW)
1	1-5	0.0176	-271.4	-282.7	1	--68.9
2	2-7	0.0089	296.6	309.0	2	6670.0
3	2-8	0.0317	373.4	389.0	3	--274.4
4	3-1	0.0044	-274.4	-285.8	4	--344.7
5	4-5	0.0050	-344.7	-359.1	5	--633.2
6	5-8	0.0828	-216.1	-225.1	6	--13.8
7	5-9	0.0405	-78.7	-82.0	7	--96.5
8	5-10	0.0745	-204.5	-213.0	8	--383.3
9	5-28	0.0118	-750.0	-781.3	9	--275.8
10	6-8	0.0576	-13.8	-14.4	10	--201.2
11	7-24	0.0186	200.1	208.4	11	3378.5
12	8-10	0.0742	35.9	37.4	12	--427.0
13	8-14	0.0405	94.1	98.0	13	--177.9

14	8-24	0.0148	-369.8	-385.21	14	--184.6
15	9-10	0.0340	-354.5	-369.3	15	--114.5
16	10-17	0.0461	-724.3	-754.5	16	--130.6
17	11-12	0.0074	378.5	394.3	17	--11.0
18	12-14	0.0455	268.4	279.6	18	- 495.0
19	12-25	0.0532	-316.9	-330.1	19	--70.3
20	13-14	0.0272	-177.9	-185.3	20	--193.0
21	15-21	0.0916	-114.5	-119.3	21	6617.7
22	16-19	0.0887	-130.6	-136.0	22	--220.6
23	17-18	0.0020	-495.0	-515.6	23	3318.6
24	17-21	0.0239	-503.2	-524.2	24	1169.7
25	17-23	0.0721	262.9	273.9	25	--110.0
26	19-20	0.0609	122.2	127.3	26	--290.1
27	19-25	0.0443	-323.1	-336.56	27	7750.0
28	20-22	0.0680	220.6	229.79	28	7750.0
29	20-23	0.0284	-291.4	-30.6		-
30	23-26	0.0284	290.1	302.19		6
31	25-27	0.0591	-750.0	-781.25		

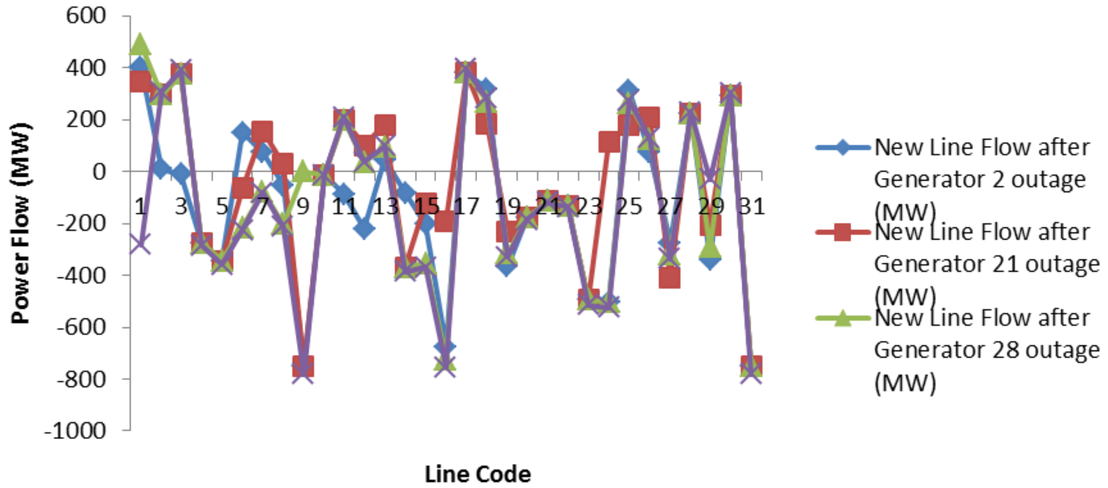

Figure 4: New line flow after outage on generator buses 2, 21 and 28

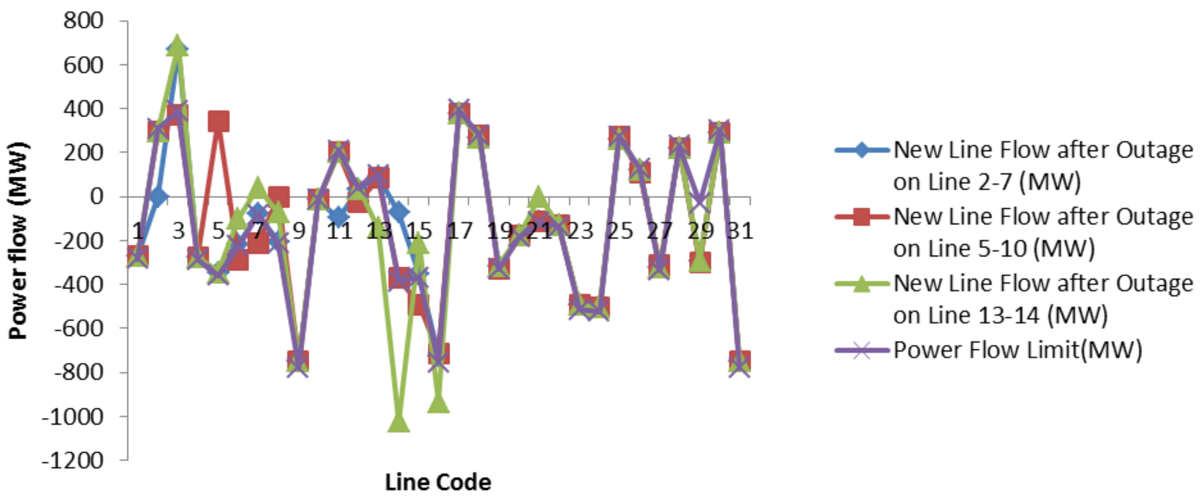

Figure 5: New line flow after outage on lines 2-7, 5-10 and 13-14

Table 4: Performance index for a single contingency case of generator outage and line outage

Lines	Performance Index due to Generator Outage	Ranking	Performance Index due to Line Outage	Ranking
1-5	0.6255	23	20.4059	3
2-7	0.9218	7	0.9218	11
2-8	0.9214	21	0.9214	27
3-1	0.9216	10	0.9216	14
4-5	0.9216	10	0.9216	14
5-8	0.1785	28	0.0001	31
5-9	1.7464	5	19.1116	4
5-10	0.0068	30	0.9217	12
5-28	0.9216	10	0.9216	14
6-8	0.9210	22	0.9210	28
7-24	0.9218	7	12.9980	6
8-10	5.6024	2	29.3732	2
8-14	2.7474	3	0.9219	10
8-24	0.9217	9	16.5220	5
9-10	0.2057	27	5.6152	7
10-17	0.1557	29	0.2035	29
11-12	0.9216	10	0.9216	14
12-14	0.5119	25	0.9215	25
12-25	0.5668	24	0.9215	26
13-14	0.9216	10	0.9216	14
15-21	0.9216	10	0.9216	14
16-19	0.9216	10	0.9216	14
17-18	0.0000	31	0.9216	14
17-21	0.9216	10	0.9216	14
17-23	0.5046	26	0.0040	30
19-20	2.2415	4	1.7508	9
19-25	1.3529	6	0.9217	12
20-22	0.9216	10	4.3796	8
20-23	53.0181	1	90.4990	1
23-26	0.9216	10	0.9216	14
25-27	0.9216	10	0.9216	14

5. CONCLUSION

This work presented the effects of both line and generator outages on a power system network using the contingency analysis. It was observed that changes in power flow will occur in the event of an outage. For instance, considering the effect of the line outage on line 13-14, the new line flow on line 2-8 after the outage was 687.7MW as against line limit of 389.0MW; this implied that there was a violation of 43.4% increase.

The changes in the line flow were calculated using the sensitivity factors. The shift values were ranked using power performance index which gave a good measure about the severity of the selected contingencies in the system. The ranking will assist the supply authority in taking necessary corrective actions to restore the lines to secured states.

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