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Contingency Evaluation of a Peturbed Electric Network

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Abstract: *A single line contingency analysis and generator(s) outages were carried out on a 330kV power network using MATPOWER 4.1 embedded in MATLAB to carry out fast decoupled load flow studies in order to identify the voltage violation at various buses, determine power losses at the transmission lines and to compute the performance indices. The performance indices were further ranked in accordance with their severity indices. Voltages less than 0.95pu were assumed to be low voltages and voltages greater than 1.05pu were also assumed to be high voltages. It was also assumed that power losses greater than 5% are unacceptable. So a base case comparative analysis of the load flow studies using three conventional methods showed that Gauss Seidel could not converge in 0.93seconds and 1000 iterations, Newton Raphson converged in 0.15seconds and 6 iterations. However, Fast Decoupled Load Flow (FDLF) converged in 0.01second and 28 iterations. Further, a single line contingency analysis was also carried out on the transmission lines to investigate the performance indices of the lines which were later ranked in accordance with their severity. The outcome of the simulations showed that at a time when there was an outage of Kainji-GS, low voltages were found at Kano, Jos, Gombe, Kaduna, Katampe, Oshogbo, Ajaokuta, New Haven, Aiyede, Ikeja-West, Onitsha, and Akangba buses. And there were also power losses greater than 5% at Ikeja-West to Egbin, Ikeja-West to Benin, Oshogbo to Benin, Kaduna to Shiroro, Kano to Kaduna, Jos to Kaduna and Jos to Gombe.*
Key Words: *Contingency Evaluation, FDLF, Performance Index, Power Loss, Line outage.*

I. Introduction

A typical issue that confronts the integrated power project is outages on the transmission lines. Outages diminish the productivity of the transmission system as they cause power disturbance and interference [1]. Moreover, the incessant and unprecedented vandalisation of the power equipment of the Nigerian power systems resulting in cascaded outages of either the transmission line or the generator(s) in the recent time leaves much to be desired. Consequently, contingency evaluation is necessary to showcase the areas that may lead to total system voltage collapse and power losses. We are to carry out Fast Decoupled Load flow to determine the voltage magnitudes, real and reactive powers that enabled us to calculate the performance indices of each of the transmission lines and later rank them based on their severity. The study involves (N-1) secure otherwise called single line contingency evaluation on the Nigerian 330kV transmission grid. 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 [2].

II. Overview Of Contingency Evaluation

Nnonyelu et al [2] looked at the overloading at various transmission lines but could not bring to lime light the voltage instability of the network as well as the effect of power losses in the transmission lines. It has been established by Chan et al [3] that some transient-stability analysis concerns the transient behaviour of the power system when moving from the pre-contingency to post-contingency operating point. However, owing to computational economics, both direct methods [4, 5] and artificial-intelligence methods [6] have often been proposed for use in online transient-stability assessment. However, it is not easy to apply these methods to larger power systems involving complex models of plant and contingencies. But an application of a conventional load flow method, gives a fast and a reliable result. However, Newton-Raphson method may be used to solve the network equations but the method is computationally expensive because it needs to calculate the Jacobian at each iteration of the algorithm. To improve the computational performance, a fast decoupled solution technique is used to solve AC network equations iteratively [7]. It is a very fast and efficient method of obtaining power flow problem solution. In this method both speed as well as sparsity is exploited. It is an extension of N-R method formulated in polar coordinate with certain approximations which result into a fast algorithm for power flow solution. This method exploits the property of the power system where the MW flow-voltage angle and MVAR flow –Voltage magnitude is loosely coupled. In order words a small change in the magnitude of bus voltage does not affect the real power flow at the bus and similarly a small change in phase angle of the bus voltage has hardly any effect on reactive power flow. On the account of loose physical interaction between the MW and the MVAR flows in a power system, the MW-δ and MVAR-V calculations can be decoupled resulting to a very simple, fast and reliable algorithm [7]. The fastness is on the account of the sparsity feature of the admittance matrix that minimizes the computer memory requirement.

Most of the early iterative techniques were based on the Y-matrix of the G-S method [8]. It requires minimum computer storage and needs only a small number of iterations for small networks. However, as the size of the network is increased the number of iterations required increases dramatically for large systems. In some cases the method does not provide solution at all [9]. Hence the slow convergence of G-S method and its frequent failure to converge in ill- conditioned situations caused the development of Z-Matrix methods [10]. In spite of the fact that these methods have considerably better converging characteristics, they also have the demerit of needing a significantly large computer storage memory owing to the fact that Z-matrix is full, contrary to the Y-Matrix which is sparse. Consequently, the shortcomings led to the development of N-R algorithm to solve the simultaneous quadratic equations of power network .Contrary to the G-S algorithm, it needs a large time per iteration but only a few iterations and is significantly independent of the network size. However, in a realistic power system, there may be a large number of buses, for instance, 100 or more but each bus is connected to only a small number usually two or more of the remaining buses. That is to say that Y_{bus} of a large power system is very sparse. This implies that it has a large number of zero elements, hence the sparcity feature of Y_{bus} minimizes the computer memory requirement as only non-zero terms are considered for storage and results in faster computation. This idea leads to the development of Fast Decoupled power flow method. It is a very fast, reliable and efficient method of obtaining power flow problem solution. It exploits speed and accuracy in its methodology [5]. It has a compatible accuracy with that of N-R method. For the sake of brevity, FDPF is an extension of N-R method formulated in polar coordinates with certain approximation which results in algorithm for power flow solution.

It has been stated by Ekwue et al [11] that power Systems are generally nonlinear in nature and some primary elements such as generator, branch outage etc contribute to the severity of the nonlinearity. So considering the merits of FDPF aforementioned, we intend to look at the line flows, losses in the line, voltage violation constraints and the performance indices which were found missing in the work of the various authors reviewed above using the fast decoupled power flow algorithm.

III. The Network Under Study And Data

A single line diagram of the 330Kv Nigerian Power grid used in the study is shown in figure 1. It comprises nine generator buses, eighteen load buses, twenty nine transmission lines of the Nigerian 330kV transmission system.

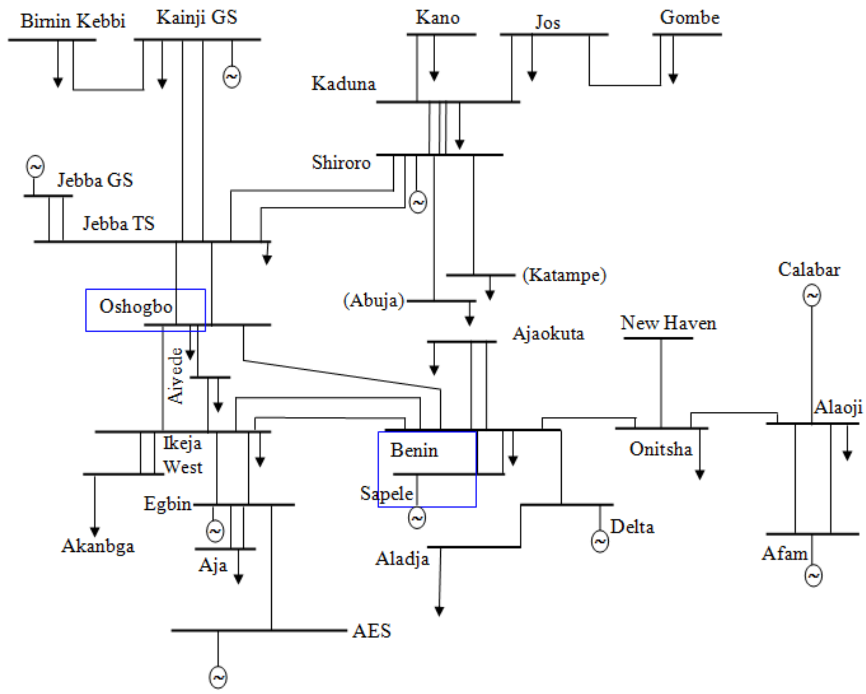

Figure 1: One line diagram of Nigerian 330kV transmission grid [2]

Tables 1, 2 and 3 show generator data, load data and line data respectively that are used for the simulations

Table 1: Generator Data

S/No.	Bus name	PG(MW) Rated
1	Kainji GS	756
2	Shiroro	413
3	Jebba GS	339
4	Sapele	70
5	Egbin	967
6	Afam	316
7	Delta GS	498
8	AES	235
9	Calabar	0

Source: [2]

Table 2: Load Data

S/No.	Bus Name	Active Power(MW)	Reactive Power (MVAR)
10	Birin-kebbi	89	55
11	Kano	226	140
12	Jos	114	90
13	Gombe	130	80
14	Kaduna	260	161
15	Jebba TS	7.44	3.79
16	Katampe	236	146
17	Oshogbo	194	120
18	Ajaokua	72	45
19	New Haven	182	112
20	Aiyede	210	130
21	Ikeja-west	484	300
22	Benin	136	84
23	Onitsha	146	77
24	Alaoji	248	153
25	Akangba	389	241
26	Aja	200	124
27	Aladja	47.997	24.589

Source: [2]

Table 3: Line Data

Branch No.	From	To	R(pu)	X(pu)	B(PU)
1	10	1	0.02676	0.06576	1.178
2	8	5	0.00300	0.02100	0.300
3	9	24	0.00216	0.00530	0.2570
4	1	15	0.00699	0.01718	0.308
5	3	15	0.00069	0.0017	0.033
6	15	17	0.01355	0.0333	0.597
7	17	21	0.02167	0.05324	0.521
8	17	20	0.00993	0.02439	0.437
9	20	21	0.01183	0.02906	0.521
10	21	25	0.00147	0.0361	0.065
11	21	5	0.00535	0.01315	0.257
12	5	26	0.00138	0.00339	0.257
13	21	22	0.02417	0.05939	1.162
14	22	4	0.00432	0.01061	0.208
15	4	27	0.00544	0.01336	0.239
16	7	27	0.00276	0.00679	0.239
17	7	22	0.00924	0.0227	0.239
18	18	22	0.0145	0.03564	0.208
19	17	22	0.02167	0.05324	0.954
20	2	15	0.02106	0.05176	0.927
21	2	16	0.01243	0.03055	0.308
22	14	2	0.00829	0.02036	0.364
23	11	14	0.01985	0.04879	0.874
24	12	14	0.01692	0.04158	0.927
25	12	13	0.002279	0.056	1.01
26	22	23	0.01183	0.02906	0.521
27	19	23	0.00829	0.02036	0.365
28	23	24	0.01191	0.02927	0.524
29	24	6	0.00216	0.0053	0.104

Source: [2]

IV. Methodology

The power flow study of the 330kV line was carried out comparatively, using various techniques such as Gauss-Seidel, Newton Raphson and Fast Decoupled Load Flow. However, Gauss-Seidel could not converge after 0.93seconds and 1000 iterations. Newton Raphson Converged in 0.15seconds and 6 Iterations but as a matter of fact, Fast Decoupled load flow converged in 0.01seconds and 28 Iterations. Hence, because of its time for numerical iteration and its capacity to hold as many data as possible, we utilized the FDLF for the research work. To compute the performance indices, one of the lines was removed and the load flow analysis was carried out in order to see the effect on the network. This was done by calculating the performance indices and ranking them based on highest severity and thus, the operation continued until no severe contingencies are found. The performance indices are given by

$$\Psi = A_{ip} + R_{ip} \qquad (1)$$

Moreover, the A_{ip} has got to do with the violation of the line active power flow and it is given by:

$$A_{iP} = \sum_{i=1}^{N} \left(\frac{A_{pi}}{A_{pi}^{max}}\right)^{2x} \qquad (2)$$

Where, A_{ip} = Active power performance index

A_{ip} =Active power flow in line i

A_{pi}^{max} = Maximum active power flow in line i

N = The total number of transmission lines in the system.

x = the specific exponent where x is assumed to be unity.

And the maximum power flow in each line is given by $A_{pi}^{max} = \frac{(V_j \times V_k)}{Z}$ (3)

Where, V_j = voltage at bus j got from FDLF solution, V_K = Voltage at bus k obtained from FDLF solution. And Z = impedance of the line connecting bus j and k.

However, $$R_{ip} = \sum_{j=1}^{Nb} \left[\frac{2(V_K - V_A)}{V_{Kmax} - V_{Kmin}}\right]^2 \qquad (4)$$

$$V_A = \frac{(V_{Kmax} - V_{Kmin})}{Z} \qquad (5)$$

Figure 2 shows a bar chart that represents voltage drops at various branches when Kainji- generating station was not committed**.** The result shows that the following buses are experiencing low voltages. They are: Kano, Jos, Gombe, Kaduna, Katampe, Oshogbo, Ajaokuta, New Haven, Aiyede, Ikeja-West, Onitsha and Akangba.

V. Simulation, Results And Discussion

The input data for the case to be simulated are specified in a set of data matrices packaged as the fields of a Matlab struct, referred to as a "Matpower case" and denoted by the variable mpc. The struct is typically defined in a case file called M-file whose return value is mpc struct. The solver was invoked by calling the simulation function "runpf" and passing in a case file name as the first argument. So the FDLF was ran by typing runpf('case27') . By default, the results of the simulation are pretty to the screen, displaying a system summary, bus data, branch data and, for the power flow, binding constraint information. The bus data comprises the voltage, angle, total generation and load at each bus. The branch data shows the power flows and power losses in each branch. Then the performance indices were computed using equations 1,2,3,4 and 5. The voltage drops and the power losses are respectively shown in figure 2 and figure 3.

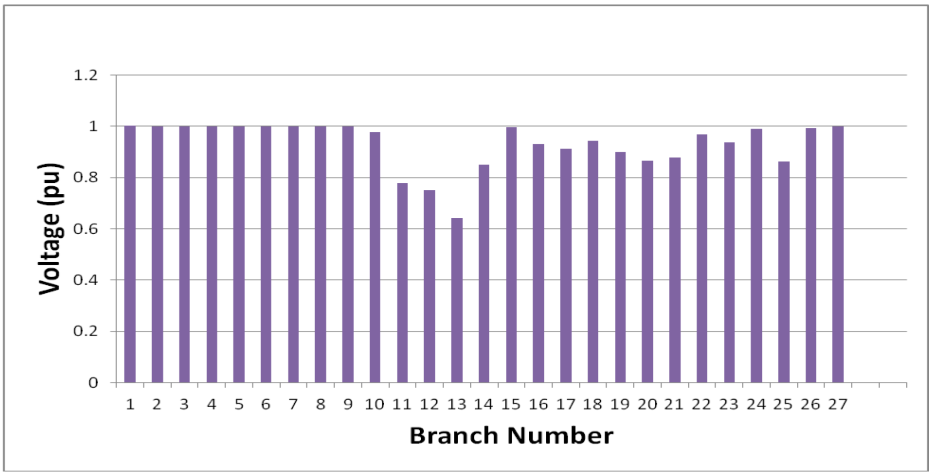

Figure 2: Voltage drop at the outage of kainji GS

At the outage of Kainji GS, the following branches experienced power losses. They are: Ikeja-West to Egbin, Ikeja-West to Benin, Oshogbo to Benin, Kaduna to Shiroro, Kano to Kaduna, Jos to Kaduna and Jos to Gombe.

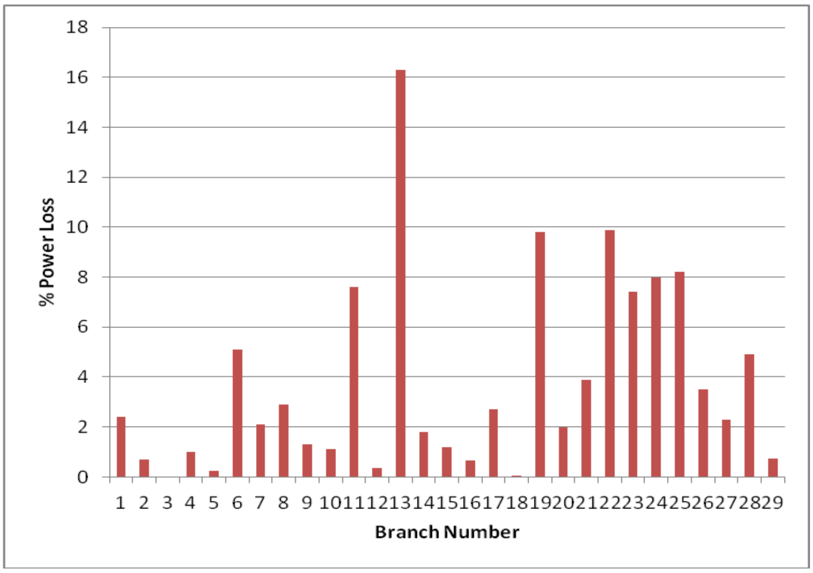

Figure 3: Power loss at the various branches when kainji- generating station was not committed.

Power losses greater than 5% were observed at Ikeja-West to Egbin, Ikeja-West to Benin, Oshogbo to Benin, Kaduna to Shiroro, Kano to Kaduna, Jos to Kaduna and Jos to Gombe transmission lines.

VI. Computing The Performance Indices

The calculation of the performance indices was done using equation 1. The simulation results provided the requisite parameters such as those given in equations 2, 3, 4 and 5.The results are tabulated in Table 4.

Table 4: Performance indices of the various lines of the network and the ranking based on the severity of the lines

Branch No.	$F_{bus} - T_{bus}$	A_{ip}	R_{ip}	ψ	R_{ψ}
1	1-10	40.41	0.900	41.31	11
2	8-5	24.85	0.410	25.26	17
3	9-24	6.68	0.40	7.08	24
4	1-15	8.56	0.52	9.08	22
5	3-15	0.16	0.32	0.48	29
6	15-17	4.65	0.88	5.53	25
7	17-21	138.59	0.87	139.46	6
8	17-20	116.43	0.44	116.84	7
9	20-21	85.40	0.01	85.41	8
10	21-25	4.19	16.45	20.64	18
11	21-5	1.08	0.64	1.74	27
12	5-26	1.64	1.08	2.72	26
13	21-22	18.75	20.38	39.13	12
14	22-4	9.37	66.08	75.45	9
15	4-27	13.61	14.30	27.91	13
16	7-27	13.27	12.98	26.25	16
17	7-22	164.42	14.81	179.23	3
18	18-22	9.68	17.80	27.49	14
19	17-22	159.11	18.08	177.19	5
20	2-15	1.34	25.10	26.44	15
21	2-16	60.51	1.02	61.53	10
22	14-2	214	6.52	220.52	1
23	11-14	0.75	0.24	0.99	28
24	12-14	175..62	2.14	177.76	4
25	12-13	9.62	4.34	13.96	20
26	22-23	10.21	2.32	12.53	21
27	19-23	12.41	3.25	15.66	19
28	23-24	6.24	1.22	7.46	23
29	24-6	196.42	4.56	200.98	2

6.2 Relationship Between Performance Indices And Outages

The relationship between the performance indices and outages is plotted in figure 5 below. It has been shown in Table 4 that contingency has been ranked by considering the line with the highest performance indices. Kaduna to Shiroro having the highest performance indices is ranked first and Jebba GS to Jebba TS having the least performance indices is ranked the last. However, the most severe contingency which is clearly shown in figure 4, should be given priority attention.

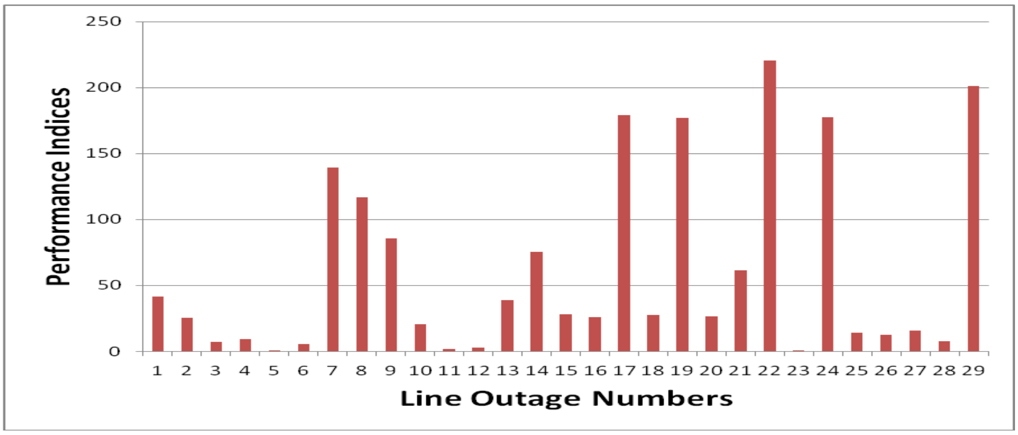

Figure 4: Performance indices plotted against line outage numbers.

VII. Conclusion

Considering the number of numerical iteration per time taken, Fast Decoupled load flow method has proven to be excellent in the load flow analysis of the 27-bus Nigerian 330kV transmission grid. Hence, owing to its time for numerical iteration, its capacity to hold as many data as possible and its merit of having a matrix alteration formula that can be incorporated and used to simulate problem of contingencies involving power system equipment outages without involving the inversion of the Jacobian matrix for all iteration, then FDLF is considered extensively in the research work. The load flow studies identified buses with low voltages. At the outage of Kainji generator bus, it was observed that Birnin-Kebbi, Jos, Gombe, Kaduna, Katampe, Oshogbo, Ajaokuta, New Haven, Aiyede, Ikeja-West, Onitsha and Akangba have voltages less than 0.95pu which was regarded as low voltages. Power losses greater than 5% were also observed at Jebba TS to Oshogbo, Ikeja-West to Egbin, Ikeja-West to Benin, Oshogbo to Benin, Kaduna to Shiroro, Kano to Kaduna, Jos to Kaduna and Jos to Gombe. At the outage of Sapele GS and Calabar GS, low voltages were noticed in the same buses given above and also power losses greater than 5% in the same line above. However, a single line contingency evaluation shows that a transmission line from Kaduna to Shiroro has the highest severity index and hence ranked number one (1). The ranking continued until the line with the least performance index. Furthermore, it can be seen that the outages of one or more generators give low voltages at the same bus and power losses at the same transmission lines. Hence, it becomes expedient to compensate the lines.

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