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ContingencyModellingandAnalysisofPowerSystemUsing LoadFlowSolution:ACaseStudyofMakurdi33kVDistribution Network

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ABTRACT: *This paper presents the contingency analysis of Makurdi 33 kV distribution network which investigates and evaluates the impact of a single distribution line outage on its operational condition. Newton Raphson's load flow method was used to carry out the analysis in order to determine the voltage violation at various buses and to calculate the performance indices of lines. The research used ETAP software as a tool for design, simulation and analysis of generation, transmission, distribution and industrial power systems. Load flow analysis was carried out to determine the steady state solution of the network. The analysis shows bus voltages outside their specified limits of 95% - 105%. A shunt capacitive compensation was applied to the network and improved results were recorded. Analysis for pre and post contingency event was carried out and the result shows that the system does not have enough redundancy to withstand any distribution line outage. Each line outage harms the steady state condition of the network. Performance indices were determined so as to inform system operators and planners the lines to be given priority for redundancy expansion of the network. The research recommends double circuit lines in place of lines 2 and 7. Shunt capacitor or FACTs devices can also be introduced to boost the network robustness and reduce cases of system vulnerability as demonstrated in this study.*

KEYWORDS: *contingency analysis, Performance Index, Optimal Capacitor Placement, line outage*

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I. INTRODUCTION

An electric power system is made up of various components, which include alternators, transformers, transmission lines, buses, circuit breakers, etc. The stability and security of these equipments are very important to the operation of the power system. Hence, there is need to check the state of the system for possible outage of any of the components. Power system engineers and operators use contingency analysis (CA) to evaluate the system for future outage. The evaluation is used to plan ahead in case of contingencies and to suggest possible ways to remedy the problem if it occurs. According to [1] CA is a key function of security assessment which involves predicting and mitigating potential failures in distribution networks. Typical contingencies on a distribution network can occur in the form of single or multiple outages, such as eventual loss of generators or distribution feeders.CA is performed using load flow solution for list of potential failures in power system equipment.

II. LITERATUREREVIEW

[2] carried out CA to study the impact of forced or planned outages on Iraqi, Al_Amereah 11 kV network which is a part of Baghdad city distribution network employing load flow analysis (Backward/Forward sweep algorithm) and the power restoration analysis. The results show that full power restoration under contingency conditions after fault isolation without violating constraints was achieved in three steps: optimal switching, addition of a feeder, and optimal capacitor placement. [3] Presented a distribution network contingency analysis and contingency detection with the consideration of load models. The distribution network contingency analysis under different contingency levels was performed and detailed analysis results were given. [4] Proposed optimal allocation and contingency analysis studies of Embedded Generation (EG) in distributionsystems.Thepaperusedrealcodegeneticalgorithmtechniquetoallocatethelocationandthesize

of EG in distribution system. The allocation method and contingency analysis study were demonstrated using 24-bus and IEEE 69-bus radial distribution systems. The result of the study shows that the installations of EG gives better results in term of voltage profile and losses improvements compared to base case with or without contingency. The relevance of power system security using contingency analysis for distributed network has been studied by Singh [5]. The study was implemented using a 66 kV, 12-bus simplified distribution network using conventional load flow analysis method in ETAP software (Version 11). The results of the study show that initial events and possible cascading chains may be identified, ranked and visualized. CA of Enugu 132/33 kV electricity distribution network was treated by [6] using Fast Decoupled Load Flow (FDLF) method. The simulation result shows that some of the buses have voltage violations and some transmission lines have high severity index. [7] Proposed a coordinated approach to contingency analysis on UK power distribution network. The proposition here was an on-going project by the KENT ACTIVE SYSTEM MANAGEMENT. Resilience of electric power distribution networks to N-1 contingencies have been treated by [8] on Sekondi-Takoradi Metropolis in Ghana. The authors employed N-R load flow method on Power World Simulator (PWS) version 19 GSO. Simulations were done after modelling the electric power distribution network with forty-buses and ninety-two feeders considering 120 $mm^2$and 150 mm^2conductor sizes. The result indicates that the present use of 120 $mm^2$and 150 mm^2conductor sizes results in voltage violations giving an indication that the electric power distribution network is vulnerable to N-1 contingencies. It was recommended that the network will be more secured and reliable when all existing 120 mm^2 aluminium conductors are replaced with 150 mm^2aluminium conductors. [9] Focuses on analysis of steady state stability of 33 kV power grid using load flow, contingency analysis and voltage stability (P-V Curve). Contingency ranking is an essential task in CA. Contingency ranking using PI is a method of line outages in a power network, where the contingencies are sorted in descending manner reflecting their severity. [10] Presented contingency ranking of IEEE 30-bus test system using Performance Indices (PI). N-R method was used to rank the active and reactive PI. It was shown that the outage of some lines overload other branches in the network. The author did not bring to light the voltage instability of the network; similarly [11] who worked on IEEE 25-bus and 35-line test system using N-R method to rank the real and reactive power index also fail to consider voltageinstability.

Load flow is a very vital tool for analysis of power systems applications particularly in distribution automation and optimization in power systems requiring repeated load flow solutions. [12] considered the load flow solution for three phase unbalanced radial distribution feeder using MATLAB/Simulink software on IEEE 13 and 34 node test feeder using N-R method for load flow analysis. A further comparison was made between Simulink load flow analysis and solution provided by IEEE distribution system analysis subcommittee for various configurations. The comparison of voltage magnitude and angles at various buses for different phases was done. The result shows that the Simulink model takes less iteration for load flow convergence and minimum losses at the load buses. Also [13] proposed the analysis of 33/11 kV Rivers State University (RSU) injection substation for improved performance with distributed generation units. The 33/11 kV RSU injection substation is one of the injection substations connected from the Port Harcourt town (zone 4, sub-transmission network). The method employed was N-R load flow techniques for the simulation in ETAP 7.

Distribution networks are characterized by low voltages due to their radial nature. Makurdi metropolitan distribution network is experiencing several outages primarily due to load shedding, voltage instability, etc. With proper monitoring and security checks, the issue can be addressed and the reliability of the network will be enhanced for continuity of supply. It is against this backdrop that this work is carried out to check and create awareness on the state of the Makurdi 33 kV distribution network. CA using load flow solution has been proven to be a valuable method for tackling the aforementioned issue. The main objectives of this studyis to perform a CA of the network using N-R load flow method for a single line outage, to determine the voltage violation at the buses, to introduce capacitive compensation to the network and observe whether voltage stability is attained and to calculate the Performance Index (PI) of thelines.

I. MATERIALS ANDMETHOD

The data for the paper was retrieved from Energy Trading Unit (ETU), Jos Electricity Distribution Plc, Makurdi Business Unit. Single line diagram of the network, Base-case model of the feeder network; Type of conductor in used is Aluminium; Size of the conductor is 150 mm^2, overhead horizontal formation and vertical formation; Length of conductors shown in Table 1; Transformers of various rating; The input load data is shown in Table 2.Acpower flow using N-R technique under ETAP 16.0.0 was applied to obtain load flow solution of the network.

A. Single line diagram of the case study

Figure 1 shows the single line diagram of the 18-bus radial network of Makurdi distribution network in which ten are 33 kV buses, seven are 11 kV buses and one is 132 kV bus. The 330 kV incoming high voltage is

stepped down to 132 kV and further to 33 kV in the switch yard. This is later stepped down to 11/0.415 kV for distribution to consumers.
In the given single line diagram of the power system shown in Figure 1, bus 1 is taken to be the Slack or Swing Bus in computing the load flow solution of the network.

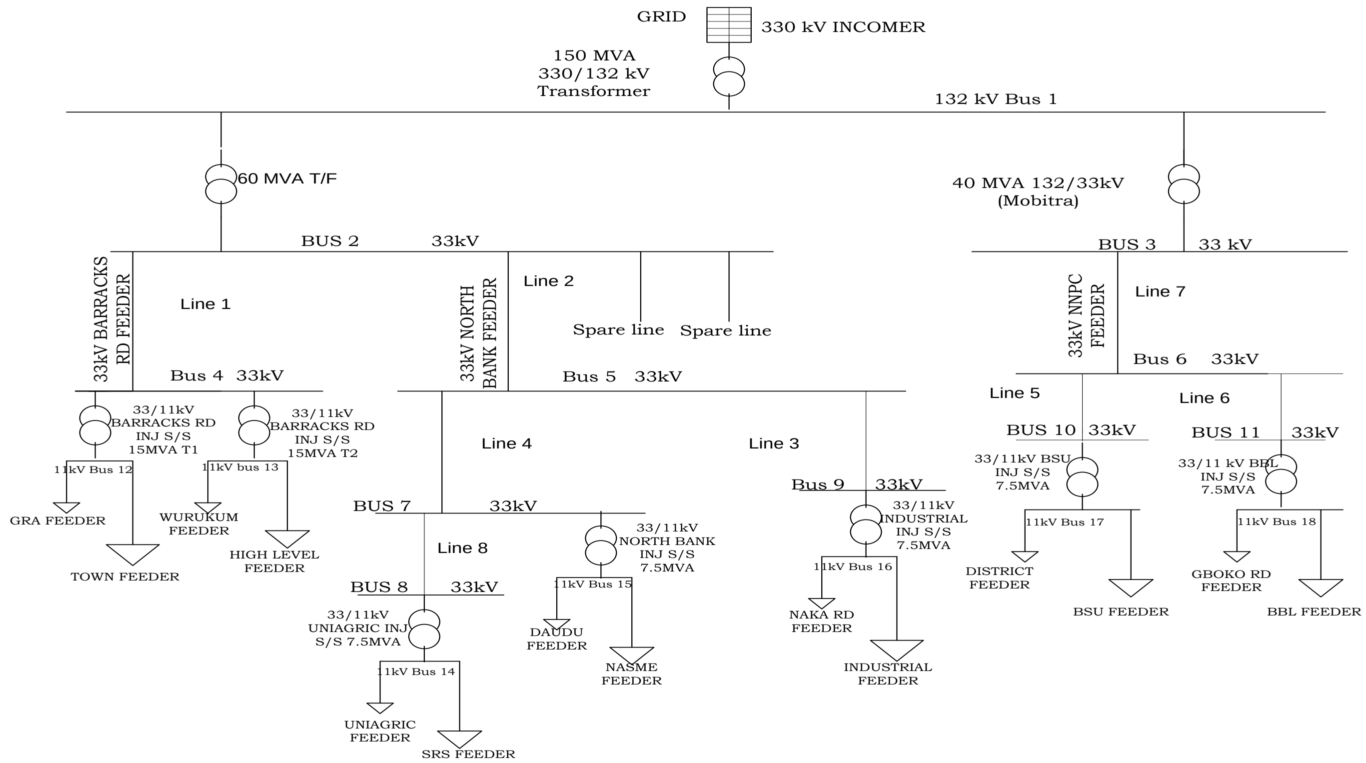


Figure 1: Single line diagram of Makurdi 33 kV radial distribution network (JED Plc, Makurdi Business Unit)

A. Transmission Line Modelling

The modelling was done based on the following parameters:
Type of conductor in use is Aluminium
Diameter of the conductor in use = 150 mm
Distance between the conductors = 2.44 m
Height between the conductor and ground = 10.97 m
Frequency of the distribution network is 50 Hz
The resistance R, of a conductor is given as [14]:

$$R = \frac{\rho l}{A} \quad (1)$$

$$L = 2 \times 10^{-7} ln \frac{GMD}{GMR} \quad H/m \quad (2)$$

The inductive reactance is given as

$$X_L = 2\pi f L \quad (3)$$

The line modelling was performed on ETAP software since it offers an exhaustive approach for the purpose of designing, analyzing and simulating of generation, transmission, distribution and industrial power system.
The resistance and inductive reactance of the lines per kilometer is given below

$$Resistance = 0.0015988\ \Omega/km$$

$$Reactance = 0.1898\ \Omega/km$$

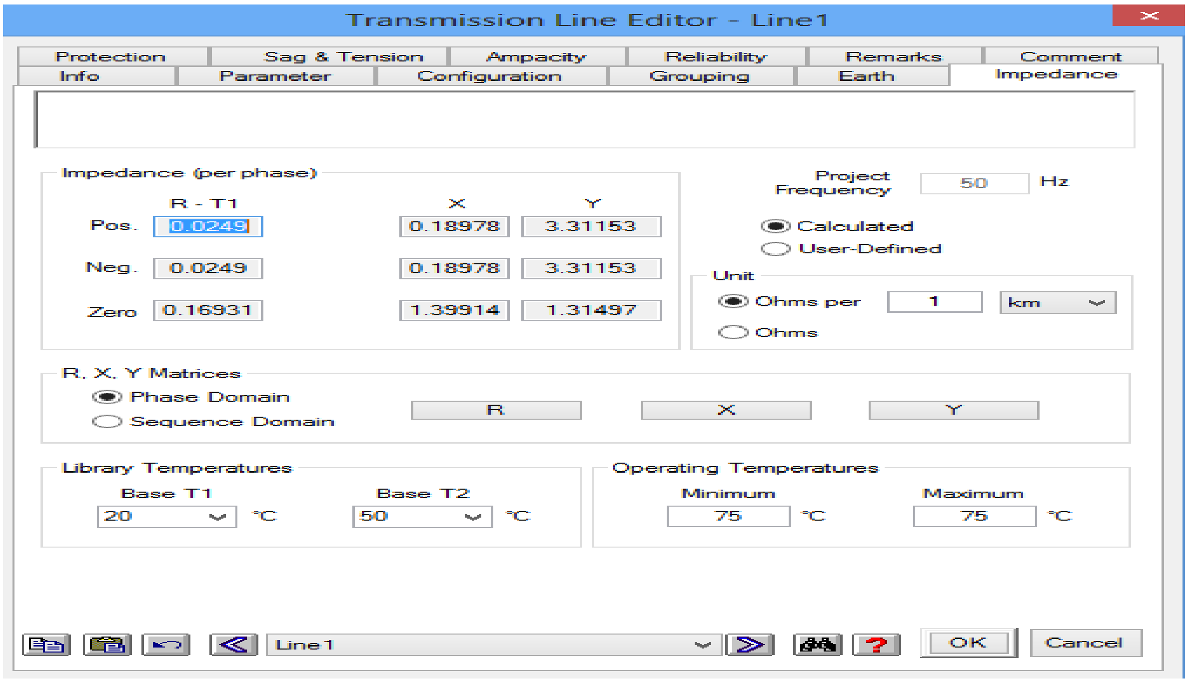


Figure 2: Transmission line editor with impedance tab selected (ETAPs)

A. Network Simulation

The load flow analysis was carried out using N-R method for the network in order to determine the steady state stability of the system. ETAP software uses Genetic Algorithm (GA) technique for Optimal Capacitor Placement (OCP). The OCP was performed to determine the optimal sizing and placement of capacitors on some buses in order to improve their voltage profile. A substantive contingency analysis was run for different outage conditions. For each outage condition, the pre- and post- contingency bus voltage violation and then the performance indices of the lines were determined.

Table 1: Distribution Line Distance in Kilometers (JED Plc, Makurdi Business Unit)

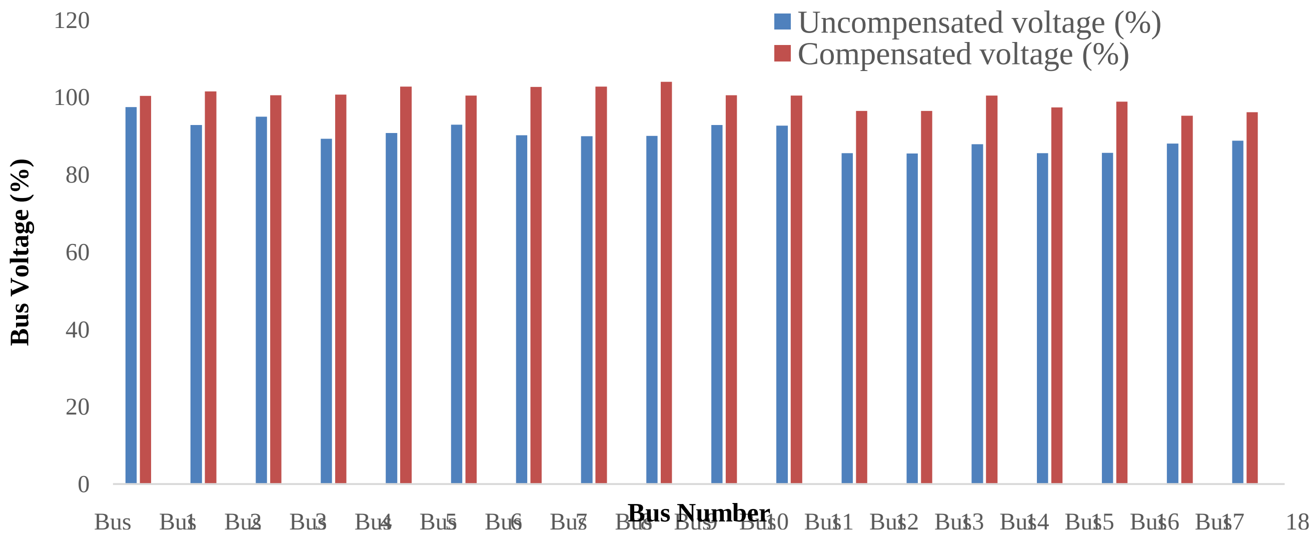
S/N	**Distance (km)**	**From Bus**	**To Bus**
1	15.6	2	4
2	11.4	2	5
3	5.4	5	7
4	9.2	5	9
5	7.35	7	8
6	13.8	3	6
7	1.4	6	10
8	4	6	11

Table 2: Load Current during Peak Load Condition (JED Plc, Makurdi Business Unit)

S/N	Feeders	Voltage (kV)	Peak Current Load (A)
1	GRA	11	264
2	TOWN	11	257
3	HIGH LEVEL	11	230
4	WURUKUM	11	297
5	NAKA ROAD	11	311
6	INDUSTRIAL	11	47
7	NASME	11	267
8	DAUDU	11	106
9	UAM	11	7.4
10	SRS	11	158
11	BSU	11	35
12	DISTRICT	11	344
13	BBL	11	6.1
14	GBOKO ROAD	11	299

Base Load = 100 MVA, Base Voltage = 11 kV

IV. RESULTS AND DISCUSSION



A. Base Case

Table 3 indicates the bus voltages before and after capacitor compensation of the network. The result of the analysis shows a total system collapse, i.e. all the buses fall outside the allowable voltage limits of ± 5 %. To surmount the under voltage at the feeder buses, a shunt capacitive compensation method was applied to the distribution network using the OCP module installed on ETAP software. This was done to determine the optimal sizing and placement of capacitors on the buses to improve the voltage profile of the network. The result of the OCP is detailed in Table 4. Capacitors were installed on buses 4, 7, 8, 9, 10 and 11. By placing the capacitors at the buses, voltage level at the buses were found to improve greatly as demonstrated in figure 3.

Table 3: Bus Voltages Before and After Compensation

Bus ID	Nominal Voltage (kV)	Uncompensated Voltage (%)	Compensated Voltage (%)	Voltage Deviation (%)
1	132	97.42	100.35	2.93
2	33	92.83	101.45	8.62
3	33	94.98	100.51	5.53
4	33	89.24	100.66	11.42
5	33	90.69	102.68	11.99
6	33	92.89	100.41	7.52
7	33	90.12	102.61	12.49
8	33	89.88	102.73	12.85
9	33	90	103.92	13.93
10	33	92.79	100.45	7.66
11	33	92.65	100.36	7.71
12	11	85.49	96.43	10.94
13	11	85.47	96.41	10.94
14	11	87.82	100.38	12.56
15	11	85.51	97.37	11.86
16	11	85.58	98.82	13.24
17	11	87.97	95.23	7.26
18	11	88.76	96.14	7.35

Table 4: Simulated Values from Optimal Capacitor Placement

Bus Number	Numbers of Banks	KVar	Amps	Rated kV
4	8	12000	209.9	33
7	2	3000	52.49	33
8	2	3000	52.49	33
9	8	12000	209.9	33
10	6	6000	105	33
11	2	3000	52.49	33

A. Contingency Case

Table 5 indicates voltages in the pre- and post-contingency state for transmission line outages. After the steady state condition of the network was determined, CA was run and the result of the simulation shows that the system does not have sufficient redundancy to withstand any transmission line outage. It is observed that each transmission line outage harms the steady state condition of the network.

Table 5: Contingency Violations of the Lines

Bus	**ID Condition**	**Rating/Limit (kV)**	**Pre-contingency (%)**	**Post-contingency (%)**	**Type**
Contingency Violations of Line 1					
4	Undervoltage	33	100.66	0	Critical
12	Undervoltage	11	96.43	0	Critical
13	Undervoltage	11	96.41	0	Critical
Contingency Violations of Line 2					
5	Undervoltage	33	100.68	0	Critical
7	Undervoltage	33	102.61	0	Critical
8	Undervoltage	33	102.73	0	Critical
9	Undervoltage	33	103.36	0	Critical
12	Undervoltage	11	96.43	94.67	Critical
13	Undervoltage	11	96.41	94.65	Critical
14	Undervoltage	11	100.38	0	Critical
16	Undervoltage	11	98.92	0	Critical
17	Undervoltage	11	95.23	94.79	Critical
Contingency Violations of Line 3					
9	Undervoltage	33	103.36	0	Critical
12	Undervoltage	11	96.43	94.42	Critical
13	Undervoltage	11	96.41	94.40	Critical
15	Undervoltage	11	97.37	93.98	Critical
16	Undervoltage	11	98.92	0	Critical
17	Undervoltage	11	95.23	94.69	Critical
Contingency Violations of Line 4					
7	Undervoltage	33	102.61	0	Critical
8	Undervoltage	33	102.73	0	Critical
14	Undervoltage	11	100.38	0	Critical
15	Undervoltage	11	97.37	0	Critical
Contingency Violations of Line 5					
10	Undervoltage	33	100.45	0	Critical
17	Undervoltage	11	95.23	0	Critical
Contingency Violations of Line 6					
11	Undervoltage	33	100.36	0	Critical
18	Undervoltage	11	96.14	0	Critical
Contingency Violations of Line 7					
6	Undervoltage	33	100.41	0	Critical
10	Undervoltage	33	100.45	0	Critical
11	Undervoltage	33	100.36	0	Critical
17	Undervoltage	11	95.23	0	Critical
18	Undervoltage	11	96.14	0	Critical
Contingency Violations of Line 8					
8	Undervoltage	33	102.73	0	Critical
11	Undervoltage	33	100.36	0	Critical

B. Performance Index

PI is the measure of stress imposes on a line and the ranking gives detail information to network operators and planners on which line is to be considered for the first phase of expansion of the network. The bus voltage security, real power flow change and reactive power flow change of line 1, 2, 4 and 7 are high indicating that more attention should be given to the lines. Figure 4 shows lines with high PI.

Table 6: Line Performance Index

S/N	ID	V/V_{SP}	ΔP	ΔQ	S/S_{SP}	Combined	Rank
1	Line 1	63.37	0.19	0.18	0.02	0.64	4
2	Line 2	147.59	0.41	0.53	0.13	1.49	1
3	Line 3	42.44	0.13	0.34	0.18	0.43	6
4	Line 4	84.41	0.25	0.23	0.19	0.85	3
5	Line 5	42.30	0.15	0.39	0.20	0.43	7
6	Line 6	42.30	0.13	0.17	0.22	0.43	8
7	Line 7	105.42	0.34	0.33	0.17	1.06	2
8	Line 8	42.32	0.12	1.00	0.24	0.44	5

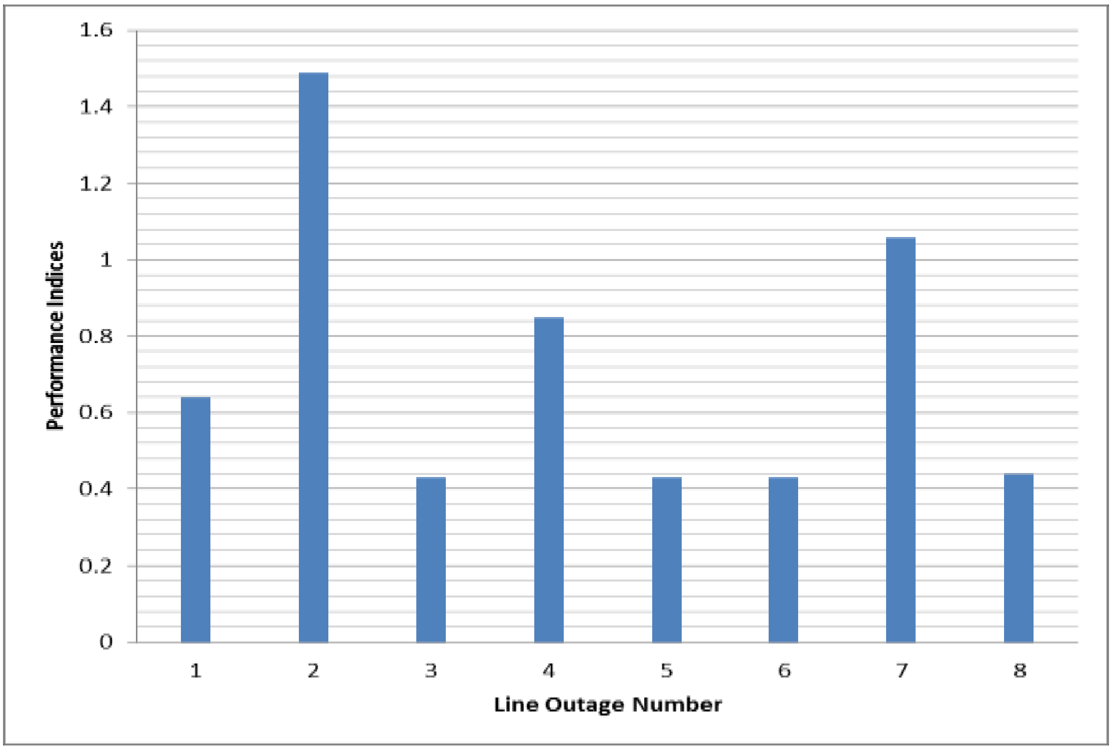


Figure 4: The bar chart plot of line outage numbers against performance index.

IV. CONCLUSION

The analysis of contingencies in power system, particularly line outages is essential to network operators in both operation and planning. If the potential outage of a distribution line would result in voltage violations at the buses or overload of another line, then the system is said to be weak, a condition which should be quickly identified for possible remedial scheme, or for network redesign. The analysis was done using N-R load flow method and the method has proven to be excellent. Simulation results revealed the distribution line with high PI and line outages that lead to critical violation of voltage outside the statutory limits of ± 5 %at the buses. It is recommended that feeders should be designed and constructed as double circuit lines so that in case of contingency the other line can serve especially line 2 and 7. Shunt capacitor or FACTs devices can also be introduced to boost the network and reduce cases of system vulnerability as demonstrated in this study.

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