Power System Security Improvement by a Linear Approximation Method

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Abstract

This paper presents a linear approximation method for calculating risk-based index of low voltage security. MATLAB source codes using the concept of risk that considers both the probability of occurrence and the severity of the contingency were used to analyze the low voltage security. Sensitivities of voltage with respect to active power and reactive power, the mean/variance of the load uncertainty were used to achieve the Probability distribution. Continuous severity function was adopted to quantify the severity because it uniformly quantifies the severity of the contingencies. The Nigerian 330KV transmission grid was used to illustrate the proposed method and the risk indices were evaluated after a contingency was simulated. The calculated risk indices reflect a quantitative measure of the system low voltage security levels. They are efficient means of quickly indentifying and investigating situations that cause high risk to the system.

Keywords: *Power system security, risk-based index, severity function*

I. INTRODUCTION

The Nigerian power system that the government has regulated heavily, is now undergoing deregulation and the competitive/uncertain market environment has resulted to operating the power system in highly stressed and unpredictable conditions. Hence, the network has become more vulnerable and the need to monitor the system's security level had increased. This is frequently driving operators to make complex decisions whether or not to take action, which actions to take and to what extent. In order to address the decisions making problem, security analysis must be carry out on the power system. Power system security is the ability of the power system to withstand one or more component outages with minimal disruption of service or its quality [1].

The determination of security level for a given operating condition has been done traditionally using deterministic criteria. Under deterministic criteria, an operating condition is secure if it can withstand the effect of each, and every contingency in a pre-specified contingency set [2, 3, 4]. However, with industry's emphasis on economic competition and with the associated increased network vulnerability, there is a growing alternative approach based on the concept of

risk, within the context of operational decisions making [2]. This method considers both probability and impact of the contingency [5]. The impact can be measured in terms of the voltage and current violations, Energy Not Served (ENS), and/or cost.

The purpose of this paper is to contribute to the improvement of the Nigeria power system security using the promising risk-based method.

II. RISK-BASED SECURITY ASSESSMENT (RBSA)

The RBSA techniques are explicitly based on the concept of risk and they evaluate security margins beyond the deterministic method (credibility and severity) by taking into account the likelihood (probabilistic) nature of many uncertain events. The authors of references [2, 6, 7, 8, 9,] discussed different models of risk based security assessment and some of the methods discussed include independent single element outage model, multiple element outage model, risk based optimal power flow, sensitivity based methods, weighted multi-criteria decisions making, and methods based on evidential theory.

The techniques worked out a single risk index after considering the likelihood and severity of each contingency. The risk index quantifies the degree of risk of the current operating conditions when the system experiences a contingency(s) [10, 11]. In simplified terms, risk index is the product of contingency likelihood and its severity. In mathematical terms;

Risk Index = Probability x Impact   (1)

A. *Probability*

In the context of power system security, probability is the likelihood that a contingency can cause security violations and the simplest way of obtaining probability for a contingency is based on the system operator's experience [11]. However, modern probabilistic and statistic techniques for deriving contingency probability distribution through the collection and analysis of historical data produce results that are more reliable. Contingencies are modeled to be Poisson distributed since they are rare events [11] and a widely used expression for Poisson distribution is,

$$P_r(x) = 1 - e^{-\lambda} \qquad (2)$$

Where, x: is the number of occurrence. λ: is the mean number of events during a given unit of time.

B. Impact

Severity provides a quantitative evaluation of what would happen to the power system in the specified condition in terms of impact, consequence, or cost [7]. Severity functions are used to uniformly quantify the severity of network condition in terms of performance indicators and they should reflect the consequences of the contingency and loading conditions in terms of network parameters that are understandable to system operators. In general, there are three types of severity functions: discrete, continuous and percentage of violation severity function [7].

III. METHODOLOGY

In this paper, we adopt linear approximation model of evaluating the risk indices of low voltage security based on sensitivity method of probabilistic contingency analysis, because sensitivity techniques are quick and easy ways of computing any possible violations of operating limits. In addition, when applied to linear systems they are efficient even when the systems are very large.

A. The Linear Approximation Method of Risk-Based Low Voltage Security Assessment (RBVSA)

The linear approximation method requires the probability of voltage distribution, probability of contingency and the severity function to evaluate the risk indices of low voltage security.

I.) Probability of Voltage Distribution: The standard deviation calculation from variance – covariance matrix and sensitivities of voltage with respect to active (P) and reactive (Q) power are required to evaluate the probability of voltage distribution. The sensitivities can be obtained from the Jacobian matrix (J) of the basic load flow problem, by simply inverting the Jacobian matrix using special techniques. Newton Raphson load flow algorithm was used due to its inherent advantages of accuracy and fast convergence. However, only the stressed buses sensitivities are evaluated and they are located at the particular stress row of J^{-1}. Assuming that the stressed voltage bus is i^{th} bus, then the probability distribution of V_i will be;

$$P_r(V_i) = \frac{1}{\sigma V_i \sqrt{2\pi}} e^{\frac{-(V_i - \mu V_i)^2}{2\sigma^2 V_i}} \qquad (3)$$

Where;

$P_r(V_i) = $ the probability distribution of V_i

$\sigma V_i = $ the standard deviation of V_i

$\mu V_i = $ the mean deviation of V_i

II) Probability of Contingency: The events of contingency (E_i) are modeled to be Poisson distributed since they are rare events [11]. The formula for Poisson distribution is,

$$P_r E_i = \sum_{x=1}^{\infty} P_r(x) = 1 - P_r(x = 0) = 1 - e^{-\lambda_i} \quad (4)$$

Where

λ_i is the occurrence rate of contingency per time interval and E_i is the ith contingency.

III) Low Voltage Severity Function: We adopt continuous severity function because it measures the extent of the violation and it can be compose easily. The continuous severity evaluates to 1.0 for each bus at the deterministic limits (0.95 pu) and increases linearly as voltage magnitude fall below limits. Figure 1 shows an illustration of continuous severity function.
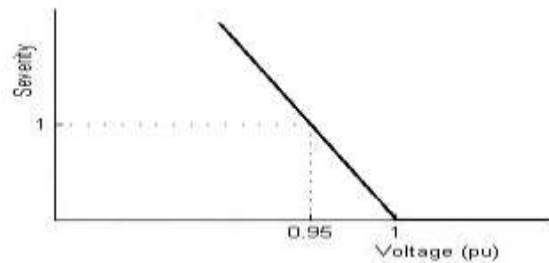

Figure 1: Continuous severity functions for low voltage.

B. Risk Evaluation

From equation (1) can be modification as follows in order to evaluate the low voltage risk of a real power system [12]:

$$Risk(X_{t,f}) = \sum_i P_r(E_i) \sum_i [\int_{-\infty}^{\infty} P_r(V_i/E_i X_{t,f}) \times Sev(E_i V_i) dV_i] \qquad (5)$$

Where
$X_{t,f}$ is forecast uncertain loading conditions at time t.

$P_r(V_i/E_i X_{t,f})$: is the probability of the stressed voltage of ith bus for i^{th} contingency and forecast uncertain loading condition.

$P_r(E_i)$: is the probability of ith contingency.

$Sev(E_i, V_i)$: is the severity function that quantifies the impact of the ith contingency with variation of the bus voltage.

This modified equation (5) is used to evaluate the total low voltage risk for all probable contingencies.

IV. SIMULATION

The Nigerian 330kV transmission grid has been used as a case study system to evaluate the performance of the proposed method. The study system single line diagram is shown in figure 2. [13] and the line data and bus data are shown in tables I and II respectively. A line outage was simulated to evaluate the system risk indices and the simulation was done by simply removing the line information from the line data. The load mean values were assumed to be the same as the base case forecast values and 2% load standard deviation was assumed and MATLAB software was used for the simulation.
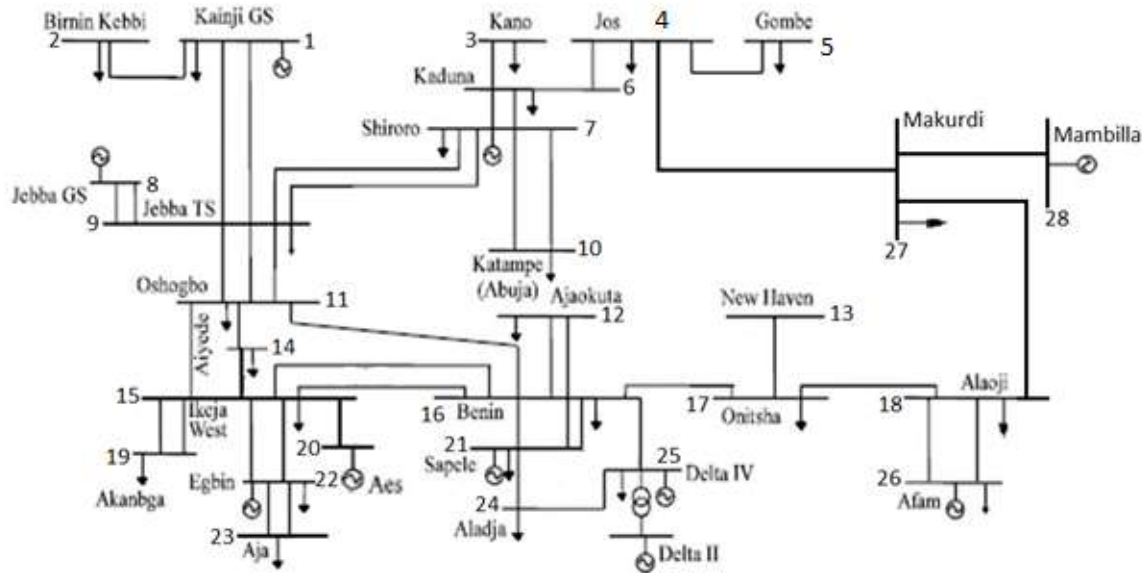

Figure 2: Single line diagram of Nigerian 330KV transmission grid

Table I Line data

S/N	BUS NAME		R	X	½ B
	FROM	TO	(p. u)	(p. u)	(p. u)
1	1	2	0.0111	0.942	1.178
2	1	9	0.0022	0.0246	0.308
3	4	5	0.0095	0.081	1.01
4	4	27	0.0029	0.0246	0
5	4	6	0.007	0.0599	0.748
6	6	3	0.0082	0.0899	0.874
7	7	6	0.0034	0.0292	0.364
8	7	6	0.0034	0.0292	0.364
9	9	8	0.003	0.0022	0.033
10	9	8	0.003	0.0022	0.033
11	9	7	0.0087	0.0742	0.927
12	9	7	0.0087	0.0742	0.927
13	9	1	0.0022	0.0246	0.308
14	10	7	0.0038	0.0284	0.189
15	10	7	0.0038	0.0284	0.189
16	11	9	0.0056	0.477	0.597
17	11	9	0.0056	0.477	0.597
18	11	9	0.0056	0.477	0.597
19	11	16	0.0089	0.0763	0.954
20	11	15	0.0049	0.0341	0.521
21	14	11	0.0041	0.0349	0.437
22	14	15	0.0049	0.0416	0.521
23	15	22	0.0022	0.0172	0.257
24	15	22	0.0022	0.0172	0.257
25	15	16	0.0101	0.0799	1.162
26	15	16	0.0101	0.0799	1.162
27	16	25	0.0022	0.019	0.239
28	16	12	0.007	0.056	0.745
29	16	12	0.007	0.056	0.745
30	16	21	0.0018	0.0139	0.208
31	16	21	0.0018	0.0139	0.208
32	16	21	0.0018	0.0139	0.208
33	16	17	0.0049	0.0416	0.521
34	17	13	0.0034	0.0292	0.0355
35	17	18	0.0049	0.0419	0.524
36	18	26	0.009	0.007	0.104
37	18	26	0.009	0.007	0.104

38	19	15	0.0006	0.0051	0.065
39	19	15	0.0006	0.0051	0.065
40	20	15	0.0016	0.0118	0.093
41	21	24	0.0023	0.019	0.239
42	22	23	0.0022	0.0172	0.257

43	22	23	0.0022	0.0172	0.257
44	25	24	0.0011	0.0088	0.171
45	27	18	0.0071	0.0532	0.380
46	27	28	0.0079	0.0591	0.390

Source : [13, 14]

Table II Bus Data

BUS NO	GENERATOR				LOAD		V (p.u)	ANGLE (deg)	REMARKS
	P (MW)	Q (MVar)	Q_{min}	Q_{max}	P (MW)	Q (MVar)			
1	624.7	0.00	-1010	1010	7.00	5.20	1.05	0	Gen bus
2	0.00	0.00	0.00	0.00	114.5	85.9	1.00	0	Load bus
3	0.00	0.00	0.00	0.00	220.6	142.9	1.0	0	Load bus
4	0.00	0.00	0.00	0.00	70.30	52.70	1.0	0	Load bus
5	0.00	0.00	0.00	0.00	130.6	97.90	1.0	0	Load bus
6	0.00	0.00	0.00	0.00	193.0	144.70	1.0	0	Load bus
7	388.9	0.00	-1010	1010	70.30	36.10	1.05	0	Gen bus
8	495.0	0.00	-1050	1050	0.00	0.00	1.05	0	Gen bus
9	0.00	0.00	0.00	0.00	11.00	8.200	1.00	0	Load bus
10	0.00	0.00	0.00	0.00	110.0	89.00	1.00	0	Load bus
11	0.00	0.00	0.00	0.00	201.20	150.90	1.00	0	Load bus
12	0.00	0.00	0.00	0.00	13.80	10.30	1.00	0	Load bus
13	0.00	0.00	0.00	0.00	177.90	133.40	1.00	0	Load bus
14	0.00	0.00	0.00	0.00	275.80	206.8	1.00	0	Load bus
15	0.00	0.00	0.00	0.00	633.20	474.90	1.00	0	Load bus
16	0.00	0.00	0.00	0.00	383.30	287.50	1.00	0	Load bus
17	0.00	0.00	0.00	0.00	184.60	138.40	1.0	0	Load bus
18	0.00	0.00	0.00	0.00	427.00	320.20	1.00	0	Load bus
19	0.00	0.00	0.00	0.00	244.70	258.50	1.00	0	Load bus
20	750.0	0.00	-1010	1010	0.00	0.00	1.05	0	Gen bus
21	190.3	0.00	-1010	1010	20.60	15.40	1.05	0	Gen bus
22	0.00	0.00	-1006	1006	68.90	51.70	1.05	0	Slack bus
23	0.00	0.00	0.00	0.00	274.40	205.80	1.00	0	Load bus
24	0.00	0.00	0.00	0.00	96.50	72.40	1.00	0	Load bus
25	670.0	0.00	-1030	1000	0.00	0.00	1.05	0	Gen bus
26	431.0	0.00	-1000	1000	52.50	39.40	1.05	0	Gen bus
27	0.00	0.00	0.00	0.00	290.1	145.00	1.00	0	Load bus
28	750.0	0.00	-1010	1010	0.00	0.00	1.05	0	Gen bus

Source: [13, 14, 15]

V.   RESULTS

The results obtained after simulating a contingency on line 16- 17and assuming a standard deviation of 2% are recorded in table III. Table III shows the stressed buses (buses with voltages below 1.0 p.u.) and the low voltage risk indices of the stress buses. Figure 3 graphically represents the low voltage risk indices.

Table III Stressed buses and their risk indices

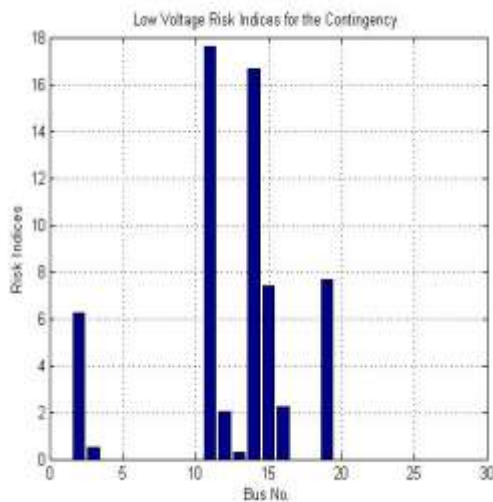| B US NO	VOLTAGE MAGNITUDE (PU)	RISK INDICES
2	0.689	6.2142
3	0.975	0.5017
11	0.120	17.6012
12	0.900	2.0045
13	0.986	0.2859
14	0.168	16.6396
15	0.630	7.4041
16	0.888	2.2353
19	0.618	7.6478
Total Risk Indices		**60.5342**

Figure 3: Graphical representation of the low voltage risk indices.

A.   *Discussion of Result*

The risk indices in table III reflect the quantitative measurement of security level hence, they facilitate decisions making in determining operating limits associated with static voltage problems. Ultimately, this involves selecting a risk level to delineate between acceptable and unacceptable operating regions. The threshold value selection can be based on experience, existing criteria, and/or optimization of cost. Furthermore, a decisions making algorithm can be used to select the threshold risk index level from these criteria and it is advantageous to the conservatism of the operational decision makers (ODM); the system operators, engineers and/or their managers.

The risk index is a leading indicator of security level in that the assessment provides a uniform security measurement for the near future operating condition based on the current information.

The results shown in table III enable the system operator/engineers to quickly identify and investigate high-risk scenarios. In addition, risk index gives useful information of insecurity beyond the threshold value and can be used in pricing power system security.

VI.   CONCLUSION

The competitive nature of electricity market has driven power systems into restructuring of their operating patterns and as a result, more stress conditions are encountered frequently. Therefore, there is the need for a quantitative measure that accurately reflects security level and can be used in control room economy decisions making. We believe that the use of the risk indices will improve power system security level and economy decisions making.

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