Power system security analysis under transmission line outage condition

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Abstract: The power system becomes more severe under contingency conditions. In general, the contingencies may be outage of transmission lines or generators. To identify the effect of outages on system security, the contingency analysis is one of the analytical tools. The congestion on a system must be manages using generation rescheduling and with the proper control of the compensation equipments. The transmission line outage sometime increases the total power system losses, cascading outage of transmission lines, etc. Finally, the system leads to collapse condition. To avoid this type of uncontrolled condition, the power system security needs to be analyzed under transmission line outage condition. In this paper, the most critical transmission lines are identified using line collapse proximity index values and the system severity is analyzed in terms of transmission line loadings, bus voltage magnitude variations are tested on standard IEEE-14 bus test system and the analytical results are presented in numerically and as well as graphically.

Keywords: Power system security, contingency analysis, transmission line outages, line collapse proximity index.

I. INTRODUCTION

Now a day, because of the restructuring and deregulation of the power system network, the operation, control and management of the system becomes one of the most challenging tasks. To avoid uncontrolled operation of power system, it is necessary to analyse the severity of system under contingency conditions. There are different types of contingency conditions that lead the system to collapse condition.

In contingency analysis, outage of transmission lines and ranking processes are performed to determine the most severe line outage contingencies considering line overloads and bus voltage limit violations through performance index. An important issue of transmission system congestion management in a pool electricity market environment with the consideration of voltage stability as loadability limit is present in [1]. In this, the optimal generators rescheduling has been obtained for three block bid structure submitted to the ISO in a day-a-head market.

In [2], an attempt on congestion management by considering the impact of constant current, impedance, and power (ZIP) load model along with the load variation pattern in a day-a-head hybrid electricity market. In [3], methods to the relieve congestion by generation rescheduling and/or load shedding under sever congestion are presented. A contingency analysis is performed in [4] to detect and rank the faulted contingencies on the basis of their severity in electrical energy transmission systems. Minimization of the average loadability on all energy transmission lines minimizes the active power losses under pre-contingency conditions.

In [5], they proposed a stochastic programming framework for congestion management considering the power system uncertainties comprising outage of transmission branches

and generating units. In [6], the potential benefits provided by demand-side management programs applied in power system congested areas to improve voltage security are investigated in this congested areas are indicated by expanded modal analysis technique from a new perspective of active power variations.

From the careful review of the literature, it is identified that transmission line outage condition is the most severe contingency condition in power system. Hence, it is necessary to analyse the severity of the system under this contingency condition. In this paper, the most critical transmission lines in a given system are identified using line collapse proximity index (LCPI) values .The complete methodology of identifying system severity in terms of transmission line loadings and bus voltage magnitude violations are tested on standard IEEE-14 bus system with supporting numerical and as well as graphical results.

II. CONTINGENCY ANALYSIS

The system severity should be evaluated for one of the severe conditions such as contingency condition. The result of this analysis allows the system to be operated securely. Now a day, because of the modernization of the power system with the help of computers, it is possible to identify the most critical transmission lines [7] that causes the system to be operates in an uncontrolled manner and leads cascading outages and failures. From this, it is necessary to perform a contingency analysis to predetermine the system effectiveness before they arise. As the present power system is an interconnected network, when transmission lines are lost, due to which some of the transmission lines get overloaded [8]. From this discussion, it is necessary an operational person should know the information regarding the severity of the

transmission lines and the possibilities of the generator outages to maintain the system secure. In common practice, contingency analysis is performed on a given system with single outage events (one transmission line outage or one generator outage) or multiple outage events (two/more transmission lines outage or two/more generators outage or combinations thereof) are analyzed. For each of the events, the limit violations of power flows in transmission lines and voltage magnitude deviations at buses are identified. Finally, the event which has highest severity is identified and the respective precautions are suggested to improve the system security for safer operation.

III. POWER SYSTEM SECURITY

In general, the main aim of power system operation and control is to meet the demand continuously without any failures. While, in this operation, sometimes, outage of generator due to failure of the auxiliary equipment or removal of a transmission line for maintenance purpose or due to storm and other effects may happens. Due to which, the system frequency may drops and leads to load shedding or uncontrolled operation and sometimes leads to system collapse condition [9]. This happens mainly due to the overloading of the transmission lines, voltage deviation at the load buses and lack of reactive power support at the load buses.

A. Line collapse proximity index

From the literature, it is identified that, there are variety of indices to identify the most severe lines in a given system. Due to the difficulties reported in the literature for the available indices, a new index based on the effect of power flow in transmission lines, line charging reactance and the direction of reactive power flow with respect of the direction of active power flow known as "Line collapse proximity index" (LCPI) is proposed [10]. The modeling of this index is based on the exact pi-model of the transmission lines using ABCD-parameters.

Conventionally, the relation between system parameters for a transmission line connected between buses 's' and 'r' can be expressed as follows

$$\begin{bmatrix} \overline{V}_s \\ \overline{I}_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \overline{V}_r \\ \overline{I}_r \end{bmatrix} \qquad (1)$$

Here, A, B, C and D are the transmission line parameters related to two-port network and can be expressed as

$A = \left(1 + \frac{ZY}{2}\right)$-Open circuit reverse voltage transfer ratio

$B = Z$ -Short circuit reverse transfer impedance

$C = Y\left(1 + \frac{ZY}{4}\right)$-Open circuit reverse transfer admittance

$D = A$ -Short circuit reverse current transfer ratio

Here, Z and Y are the transmission line impedance and line charging admittance respectively. $\overline{V}_s, \overline{V}_r$ and $\overline{I}_s, \overline{I}_r$ are the voltage and current vectors at the respective buses. The current at the receiving end of the transmission line can be calculated as

$$\overline{S}_r = \overline{V}_r \left(\overline{I}_r\right)^* \qquad (2)$$

$$\overline{I}_r = \frac{\left(\overline{S}_r\right)^*}{\left(\overline{V}_r\right)^*} = \frac{P_r - jQ_r}{\left(\overline{V}_r\right)^*} = \frac{P_r - jQ_r}{V_r \angle -\delta_r} \qquad (3)$$

Where, P_r, Q_r are the active and reactive powers and V_r, δ_r are the voltage magnitude and voltage angles at the receiving end respectively.

From Eqn (1), the sending end voltage of the transmission line can be expressed as

$$V_s \angle \delta_s = A \angle \alpha V_r \angle \delta_r + B \angle \beta I_r \angle 0^0 \qquad (4)$$

Here, A and B are magnitudes and α, β are the phase angles of parameters of A, B respectively.

After solving Eqn (4) using Eqn (3), we get

$$V_s \angle \delta_s = A \angle \alpha V_r \angle \delta_r + B \angle \beta \left(\frac{P_r - jQ_r}{V_r \angle -\delta_r}\right) \qquad (5)$$

Rearranging Eqn (5), results

$$V_s V_r \angle (\delta_s - \delta_r) = A \angle \alpha V_r^2 + B \angle \beta (P_r - jQ_r) \qquad (6)$$

Let us define $\delta = \delta_s - \delta_r$ and solve for Eqn (6), we get

$$V_s V_r \cos \delta + j V_s V_r \sin \delta = A V_r^2 \cos \alpha + j A V_r^2 \sin \alpha + B \left(P_r \cos \beta + Q_r \sin \beta\right) - jB \left(Q_r \cos \beta - P_r \sin \beta\right) \qquad (7)$$

The real part of Eqn (7) can be written as

$$V_s V_r \cos \delta = A V_r^2 \cos \delta + B \left(P_r \cos \beta + Q_r \sin \beta\right) \qquad (8)$$

Eqn (8) seems to be the quadratic equation and the roots of this equation results the receiving end voltage, this can be derived as

$$V_r = \frac{-V_s \cos \delta \pm \sqrt{(V_s \cos \delta)^2 - 4A \cos \alpha (P_r B \cos \beta + Q_r B \sin \beta)}}{2A \cos \alpha} \qquad (9)$$

The real and non-zeros values of the Eqn (9) can be obtained by equating determinant of Eqn (9) to greater than zero, i.e.

$$\left(V_s \cos \delta\right)^2 - 4A \cos \alpha \left(P_r B \cos \beta + Q_r B \sin \beta\right) > 0 \qquad (10)$$

Based on this, the condition that should satisfy to operate power system securely to avoid voltage collapse condition can be expressed as

$$\frac{4A \cos \alpha (P_r B \cos \beta + Q_r B \sin \beta)}{(V_s \cos \delta)^2} < 1 \qquad (11)$$

From this, the line collapse proximity index for each of the transmission lines can be calculated using

$$LCPI = \frac{4A \cos \alpha (P_r B \cos \beta + Q_r B \sin \beta)}{(V_s \cos \delta)^2} \qquad (12)$$

For secured operation, the value of LCPI must be less than 1(one).

IV. ALGORITHM FOR SECURITY ANALYSIS UNDER TRANSMISSION LINE OUTAGE CONDITION

It is necessary to predetermine the most severe transmission lines in a system to analyze the system security. To suggest and to take the protective corrections against contingency conditions, it is necessary to analyze the system severity under contingency conditions. For this purpose, in this paper, 15% of the transmission line outages are considered to form contingency condition.

To identify the severity of transmission line outages on system security, the steps needs to be followed are:

Step 1: Read the system line and bus data.

Step 2: Perform load flow analysis using Newton-Raphson method.

Step 3: Obtain voltage magnitudes at all load buses and voltage angles at all buses except slack bus.

Step 4: Calculate power flows in each of the transmission lines.

Step 5: Calculate line collapse proximity index (LCPI) values for each of the transmission lines.

Step 6: Rank the lines based on their LCPI values.

Step 7: Remove the top 15% severe lines from a given system to create contingency condition.

Step 8: Repeat steps from 2 to 4 and identify the over loaded lines and voltage violated buses to analyze the system security.

V. RESULTS AND ANALYSIS

IEEE-14 bus system with twenty transmission lines, five generators, three tap-changing transformers and one shunt compensator is considered. The proposed methodology is tested for the following condition.

➢ Identifying critical lines using LCPI values and outage of top 15% LCPI valued lines to create transmission line contingency condition.

For this system, by following the procedure given in section-3, LCPI value for each of the transmission lines is calculated. Here, LCPI values are not calculated for five lines i.e. line-1 connected between buses 1 and 2 is double circuit line, lines 8, 9, 10 are transformer connected lines and line-14 isolates the generator from system. Hence, for this system LCPI values for fifteen transmission lines out of twenty are calculated and tabulated in Table.1. Based on these LCPI values, respective ranks are assigned to each of the lines. From Table.1, it is observed that, line-6 connected between buses 3 and 4 is assigned as rank-1 and line-17 connected between buses 9 and 14 is assigned as rank-2. To analyze the system security under transmission line outage condition, the procedure given in section 4 is followed. For this, the top 15% of the critical lines i.e. lines which are ranked 1 and 2 are removed from the system to create contingency condition. The Variation of LCPI values is shown in Fig.1.

TABLE.1 LCPI VALUES FOR IEEE-14 BUS SYSTEM

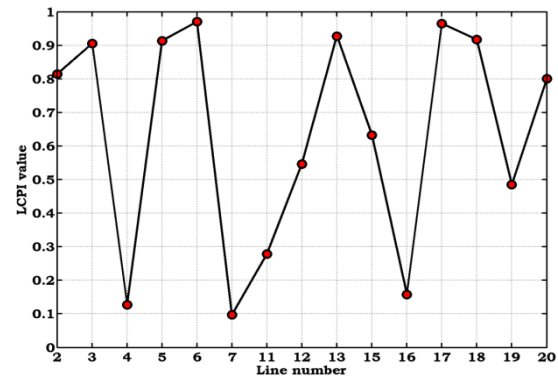| S. No	Line No	From bus -To bus	LCPI value	Rank
1	2	1-5	0.8147	7
2	3	2-3	0.9058	6
3	4	2-4	0.1270	14
4	5	2-5	0.9134	5
5	6	3-4	0.9706	1
6	7	4-5	0.0975	15
7	11	6-11	0.2785	12
8	12	6-12	0.5469	10
9	13	6-13	0.9275	3
10	15	7-9	0.6324	9
11	16	9-10	0.1576	13
12	17	9-14	0.9649	2
13	18	10-11	0.9172	4
14	19	12-13	0.4854	11
15	20	13-14	0.8003	8

Fig.1. Variation of LCPI values

To show the effect of transmission line contingencies, the apparent power flow in lines under single and multi-line contingencies are tabulated in Table.2. From this table, it is identified that, line-15 is overloaded under the outage of first critical line i.e. line-6, this is because of the connection of line-15 is nearer to line-6. It is also identified that, lines 13 and 20 are overloaded under the outage of second critical line i.e. line-17, this is because of the connection of these lines is nearer to line-17. Finally, it is observed that, lines 13 and 20 are overloaded under the outage of lines 6 and 17; this is because of the nearer connection to the critical lines. The respective variation of power flow in lines is shown in Fig. 2.

TABLE.2. POWER FLOWS UNDER TRANSMISSION LINE(S) OUTAGE CONDITION

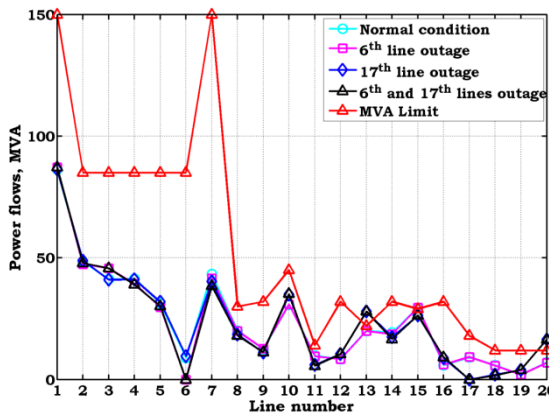| Line No	Power flows (MVA)				MVA limit
	Normal condition	Outage condition			
		Line-6	Line-17	Lines 6&17	
1	86.27	87.18	86.28	87.22	150
2	48.43	47.40	48.87	47.80	85
3	41.25	45.67	41.06	45.67	85
4	41.42	39.34	41.12	38.99	85
5	31.37	29.76	31.89	30.22	85
6	8.80	-	9.52	-	85
7	43.39	41.57	40.21	38.50	150
8	20.10	19.89	18.44	18.08	30
9	12.53	12.63	11.11	11.16	32
10	30.69	30.94	34.90	35.19	45
11	9.81	9.62	5.93	5.62	14
12	8.38	8.35	10.44	10.44	32
13	20.01	19.90	27.94	27.94	22
14	19.29	18.60	17.40	16.59	32
15	29.45	29.58	26.24	26.34	29
16	5.88	6.15	8.81	9.12	32
17	9.14	9.28	-	-	18
18	5.82	5.68	1.96	1.64	12
19	1.96	1.93	3.96	3.96	12
20	7.01	6.90	16.41	16.41	12

Fig.2. Variation of power flows under transmission line(s) outage condition

Voltage magnitude at buses under single and multi line contingencies are tabulated in Table.3. From this table, it is identified that, outage of multiple lines has more effect than that of single transmission line outage. The variation of voltage magnitude at buses under contingency conditions is shown in Fig.3.

TABLE.3. VOLTAGE MAGNITUDE AT BUSES UNDER TRANSMISSION LINE(S) OUTAGE CONDITION

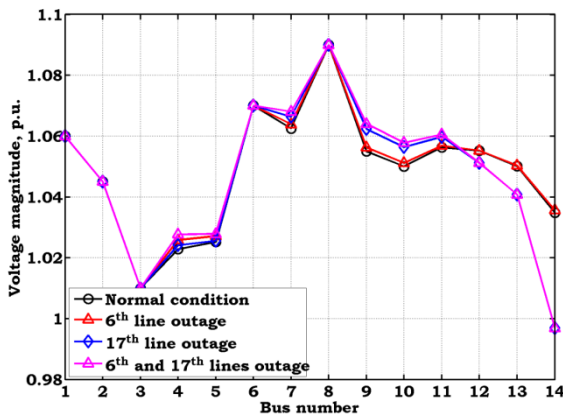| Bus. No	Voltage magnitude (p.u.)			
	Normal Condition	Outage of Line-6	Outage of Line-17	Outage of Lines 6 & 17
1	1.060	1.060	1.060	1.060
2	1.045	1.045	1.045	1.045
3	1.010	1.010	1.010	1.010
4	1.023	1.026	1.024	1.028
5	1.025	1.027	1.026	1.028
6	1.070	1.070	1.070	1.070
7	1.063	1.064	1.066	1.068
8	1.090	1.090	1.090	1.090
9	1.055	1.056	1.062	1.064
10	1.050	1.051	1.056	1.058
11	1.056	1.057	1.060	1.061
12	1.055	1.055	1.051	1.051
13	1.050	1.050	1.041	1.041
14	1.035	1.036	0.997	0.997

Fig.3. Variation of voltage magnitude at buses under transmission line(s) outage condition

VI. CONCLUSION

In this paper, the power system security has been analyzed under transmission line(s) outage condition. The most critical lines in a given system have been identified using line collapse proximity index values, and these lines are removed from the system to create contingency condition. The severity of this congestion has been analyzed in terms of transmission line loadings and bus voltage magnitude violations. From the analysis, it has been identified that, outage of two transmission lines has more effect on power flows when compared to outage of one of the transmission lines. The proposed methodology has been tested on standard IEEE-14 bus systems with supporting numerical and as well as graphical results.

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BIOGRAPHIES

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