Weak Bus Identification in Power System Using Contingency Ranking

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Abstract: ***One of the essential aspects of modern power system security assessment is the consideration of any contingencies arises due to planned or unplanned line outages leading to system overloads or abnormal system voltages. Several techniques have been developed in the past few years to address this problem but computation time has been identified as the constraint making the process inefficient. This paper presents a new algorithm for automatic contingency analysis and ranking caused by line outage in a power transmission system. All steps in the algorithms, including the load flow analysis; removal and reinsertion of line and overall ranking process were accommodated in one compete Programme making it a complete and effective solution for contingency analysis and ranking. A pre-developed line- based voltage stability index is used as a tool in determining the severity of the contingencies. Results from experiments showed that this technique is much faster than the existing technique while reducing human error constraint.***

Keywords: Contingency analysis, Ranking, LMN method, Weak Bus Identification.

I. INTRODUCTION

Contingency analysis, ranking and selection are acceptably considered as crucial activities in power security assessment and normally conducted in line with the voltage stability analysis. Most of contingency analysis algorithms are meant to perform the contingency selection in order to identify and filter out worst contingency cases for further detailed analysis once the preventive and corrective measures have been identified [I]. Complex system mainly caused by the economic and environmental pressures in continuing interconnections of bulk power systems has caused the system to operate close *to* its limit of stability. This situation becomes worst when contingencies occur in the stressed power network. Contingencies caused by line, generator and transformer outages are identified as the most common contingencies that could violate the voltage stability condition of the entire system Previous researches have shown that contingency analysis can be time consuming particularly for a bulk power system [2]. Human factor has been identified as one of main factors that made contingency process a tedious task with the increasing execution time. Approach to reduce computation burden traditional load flow solution to reach its nonconvergence point. Beyond this point, the ordinary load flow solution does not converge, which in turn forces the system to reach the voltage stability limit prior to bifurcation in the system. The margin measured from the base case solution to the maximum convergence point in the load flow computation determines the maximum loadability at a particular bus in the system. Solvability of load flow can only be achieved before a power system network reaches its bifurcation point. P.W.Sauer, R.J.Evans and M.A.Pai [1], determined maximum loadability through two basic forms, i.e., the equality and inequality constraints. The equality constraint dealt with the Kirchoff's circuit laws, while the second one reflects physical limits such as thermal overload, critical voltage drop and steady-state stability. A.C.G.Melo [2], I.A.Hiskens [3] and Y.H.Moon [4] agreed that maximum loadability depends on the solvability margin of load flow when the Jacobian matrix becomes singular.

In this paper, maximum loadability is estimated through voltage stability analysis. Voltage stability analysis is conducted using line stability index indicated by LMN to indicate the stressfulness of a line in a transmission system. The reactive power at a particular bus is increased until it reaches the instability point. At the instability point, the connected load at the particular bus is determined as the maximum loadability. The maximum loadability for each load bus will be sorted in ascending order with the smallest value being ranked highest. The highest rank implies the weak bus in the system that has the lowest sustainable load. This technique is tested on the IEEE test system and results show that it is able to estimate the maximum loadability in a system. The proposed technique in determining critical line in the system. The critical line means the line which is close to its voltage stability limit.

II. INDEX FORMULATION

The voltage stability index or proximity is the device used to indicate the voltage stability condition formulated based on a line or a bus. The maximum threshold is set at unity as the maximum value beyond which this limit system bifurcation will be experienced.

A. Proposed LMN Formulation

The LMN is derived from the voltage quadratic equation at the receiving bus on a two-bus system. The general two-bus representation is illustrated in Figure 1.

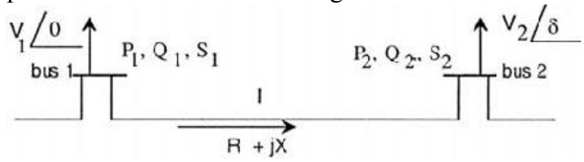

Fig. 1.Two-bus power system model

When From the figure, the voltage quadratic equation at the receiving bus is written as

$$V_2^{\,2} - \left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1V_2 + \left(X + \frac{R^2}{X}\right)Q_2 = 0$$

------------------------ (1)

Setting the discriminant of the equation to be greater than or equal to zero yields

$$\left[\left(\frac{R}{X}\sin\delta+\cos\delta\right)V_1\right]^2-4\left(X+\frac{R^2}{X}\right)Q_2\geq 0$$

---------------------- (2)

Rearranging (2), we obtain

$$\frac{4Z^2Q_2X}{(V_1)^2(R\sin\delta+X\cos\delta)^2}\leq 1$$

------------------------ (3)

Since δ is normally very small, then

δ=0, Rsinδ = 0 and Xcosδ=X. ------------- (4)

Taking the symbols 'i'as the sending bus and 'j' as the receiving bus, LMN can be defined by

$$L_{mn}=\frac{4Q_r\,x}{\left[|V_s|\sin(\theta-\delta)\right]^2}$$ ------(5)

Where Z is the line impedance, X is the line reactance, Q_j is the reactive power at the receiving end, and Vi is the sending end voltage.

The value of LMN that is evaluated close to 1.00 indicates that the particular line is closed to its instability point. Therefore, LMN has to be maintained less than 1.00 in order to maintain a stable system.

Test system

To validate the performance of the indicator, an IEEE30 bus reliability test system is used.

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This system has six generator buses and 24 load buses. In order to investigate the effectiveness of the LMN four load buses were selected in random. The reactive power at these buses increased gradually one at a time.

III. Procedure For Determining The Maximum Loadability

The following steps are implemented.

1. Run the load flow program using Newton-Raphson method for the base case.
2. Evaluate the LMN value for every line in the system.
3. Gradually increase the reactive power at chosen load bus until the load flow fails to give the results. Calculate LMN Values for every load variation.
4. Plot the graph of LMN versus Q.
5. Extract the line index that has the highest value; this line is called as the most critical line with respect to a bus.
6. Choose an other load bus repeat steps 1 to 5.
7. Plot a common graph obtained from step 5 for every test bus. This graph will be a plot of LMN curve referred to a bus versus reactive power loading.
8. Obtain the voltage at the maximum computable LMN prior to the divergence of the Load flow .It can be obtained from step 3.This determines the critical Voltage of a Particular bus.
9. Extract the maximum reactive power loading for the maximum computable LMN for every test bus. It can be obtained from step 5.The maximum Reactive Power loading is referred to as the maximum loadability of a Particular bus.
10. Sort the maximum loadability obtained from step 9 in ascending order. The Smallest maximum loadability is ranked the highest implying the Weakest bus in the system.

The proposed algorithm was implemented in MATLAB 7 and executed on Pentium 4 machine.

IV. Results And Discussion

A. Use *case 1: bus 3*

The reactive power is increased gradually at Bus No.3 under base load condition keeping the real power remain constant (2.4MW) calculated. The maximum computable value of LMN obtained is 0.9997 for the line connected between buses 1 and 3 i.e. L4.The value of LMN for the same line is 0.0051 initially when the reactive power loading is 1.2 Mvar.

The LMN (L4) value (0.9997) at this point is close to unity indicating that the system has reached its stability limit. At this point L4 is the most critical line with respect to bus 3. The critical voltage of particular bus is 0.7755 p.u. At the same time maximum reactive power loading for the maximum computable value of LMN **(**Bus No.3) is 286.4 Mvar (Qmax), beyond this limit violation will be experienced. The Figure 3 illustrates the corresponding LMN profile against load variation at bus 3.

B. *case 2: bus 14*

The reactive power is increased gradually at Bus No.14 under base load condition keeping the real power remain constant (6.2MW) calculated. The maximum computable value of FVSI obtained is 0.9998 for the line connected between buses 14 and 15 i.e. L20.The value of FVSI for the same line is 0.0112 initially when the reactive power loading is 1.6 Mvar.

The FVSI (L20) value (0.9998) at this point is close to unity indicating that the system has reached its stability limit. At this point L20 is the most critical line with respect to bus 14.The critical voltage of particular bus is 0.7784 p.u. At the same time maximum reactive power loading for the maximum computable value of LMN **(**Bus No.14) is 82.3 Mvar (Qmax), beyond this limit violation will be experienced. The Figure 4 illustrates the corresponding LMN profile against load variation at bus 14.

C. *case 3: bus 15*

The values of LMN when the reactive power is increased gradually at Bus No.15 under base load condition keeping the real power remain constant (8.2MW) are calculated. The maximum computable value of LMN obtained is 0.9998 for the line connected between buses 12 and 15 i.e. L18.The value of LMN for the same line is 0.0408 initially when the reactive power loading is 2.5 Mvar.

The LMN (L18) value (0.9998) at this point is close to unity indicating that the system has reached its stability limit. At this point L18 is the most critical line with respect to bus 15. The critical voltage of particular bus is 0.6747 p.u. At the same time maximum reactive power loading for the maximum computable value of LMN (Bus No.15) is 149.7 Mvar (Qmax), beyond this limit violation will be experienced. The Figure 5 illustrates the corresponding FVSI profile against load variation at bus 15.

D. case 4: bus 30

The values of LMN when the reactive power is increased gradually at Bus No.30 under base load condition keeping the real power remain constant (10.6MW) are calculated. The maximum computable value of LMN obtained is 0.9962 for the line connected between buses 27 and 30 i.e. L38.The value of LMN for the same line is 0.0488 initially when the reactive power loading is 1.9 Mvar.

The LMN (L38) value (0.9962) at this point is close to unity indicating that the system has reached its stability limit. At this point L38 is the most critical line with respect to bus 30.The critical voltage of particular bus is 0.6597 p.u. At the same time maximum reactive power loading for the maximum computable value of LMN (Bus No.30) is 31.1Mvar (Qmax), beyond this limit violation will be experienced. The Figure 6 illustrates the corresponding LMN profile against load variation at bus 30.

TABLE 1. BUS RANKING (MAXIMUM LOADABILITY USING LMN)

V. Weak Bus Identification

The result for bus ranking based on maximum loadability. using FVSI is tabulated in Table. 1. The bus ranking could be performed by sorting the maximum loadability in ascending order.

Rank	Bus	Q max.(p.u)	Voltage	Line No	LMN
1	30	0.311	0.6597	38	0.9962
				39	0.5747
2	14	0.823	0.7784	17	0.8295
				20	0.9998
3	15	1.497	0.6747	18	0.9998
				20	0.7462
				22	0.4663
				30	0.4147
4	3	2.864	0.7755	2	0.5239
				4	0.9997

The smallest maximum loadability will be ranked the highest implying the weakest bus in the system.

Bus No.30 is ranked the highest with maximum loadability (Qmax) 0.311p.u.indicating weakest bus in the system, that this bus sustains the lowest load. Practically, proper monitoring should be conducted on this bus so that the load connected to the respective bus will not exceed the maximum allowable load to maintain a stable system the other hand, bus 3 is ranked the lowest since it has the highest Qmax value(2.864p.u), making it the most secure bus in the system.

The Figure 7 illustrates the response for LMN (referred to a bus) versus 'Q'.

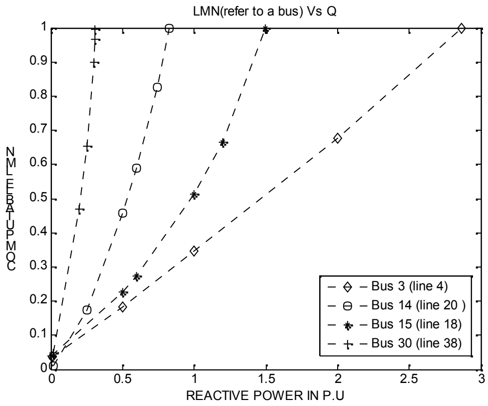

Fig. 7. LMN Vs Reactive load variation (Q)

VI. Conclusion

A rigorous investigation was carried out to see the effectiveness of reactive load variation on the line stability index. The LMN determines the maximum load that is possible to be connected to a bus in order to maintain stability before the system reaches its bifurcation point. This point is determined as the maximum loadability of a particular bus which beyond this limit system violation will be experienced.

The individual maximum loadability obtained from the load buses will be sorted in ascending order. The highest rank implies the weak bus in the system with low sustainable load and the bus which ranked highest may sustain higher load with broader stability margin.

From this information, proper monitoring of a weak node can be conducted in maintaining a secure electric utility so that the load connected to the respective bus will not exceed the maximum allowable load to maintain a stable system.

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