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Assessment of Critical Loads Instigating Voltage Instability in Transmission Network using Novel Load Tracing Capable Index LQP_LT and PSS/E Tools Validation

Existing power systems are significantly susceptible to voltage instability problem since such systems are stressed with the huge power transfers across the grids. Various power tracing techniques have been developed but are limited to the application of transmission service pricing in a deregulated environment. This paper presents a novel approach which adopts the power tracing theory for voltage stability improvement via the development of reactive power tracing capable index, named as LQP_LT. The index is tested in IEEE 14 Test Bus System in various contingency states and comparison were made using the results obtained from the industrial graded software PSS/E in evaluating the critical transmission lines in severe contingencies. The LQP_LT index is found to be effective in determining the weak load buses in a transmission system which ultimately responsible to cause stressed lines and overall voltage instability in a system.

Keywords: Voltage instability; reactive power tracing; power system simulation for engineers (PSS/E).

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1. Introduction

The non- linear nature of power system flow has caused the task of determining the power transfer from generators to loads or lines to be complex. Approximate models and tracing algorithms have been introduced in order to trace the power transfers between loads, generators and lines, with the real power tracing being the main commodity [1-2].

However, reactive power in a system too, plays a vital role to maintain the system stability and reliability. System operator need to make appropriate decision to implement the corrective and preventive actions during multi-contingency situations which can lead to voltage collapse occurrence [3-5]. Identification of the best location to perform load shedding in a critical power network is crucial since this will affect the system performance after improvement being done. The implementation of power tracing approach so far has been limited to the field of transmission service pricing [7-9]. Due to the limited research done for load fraction contribution on reactive power flow in transmission lines of power system stability study [6-11], this paper presents a new reactive power tracing algorithm and index known as LQP_LT, for the purpose of finding the appropriate locations in a power system network for any preventive and corrective actions.

The study system comprises of IEEE 14 Test Bus system and system stability study is performed using industrial graded powerful power system simulator software known as Power System Simulator for Engineers, PSS/E [12]. Violations caused by given contingencies are obtained and violation alleviation process is implemented. The

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contingency results demonstrated that low voltage profile and flow violations can be relieved by appropriate load reduction. The similar contingency analysis is carried out using power flow in Matlab environment, and the LQP_LT index algorithm is simulated for all the contingency analysis. The objective of the LQP_LT index algorithm is to classify the weak load buses according to its priority rank for any future preventive and corrective actions especially for the implementation of under voltage load shedding.

2. Notation

The notation used throughout the paper is stated below.

Indexes:

PSS/E	Power System Simulation for Engineers
ACCC	AC Contingency Calculation
A1	Area 1
A2	Area 1
PV	Transmitted Power P (P) and receiving end voltage (V)
QV	Reactive power injection (Q) and receiving end voltage (V)
p.u.	Per unit
LQP_LT	Reactive power tracing due to load index

Constants:

Q_{lm}	Reactive power flow on line *l-m*
n	Number of loads
x^{i}_{lm}	Power fraction of load *i* in line *l-m*

3. Description of the System Study via PSS/E

The power flow model analysis for the system is performed using PSS/E software. The PSS/E software is a leading tool in the power industry for electric transmission system analysis and planning. It is used by transmission planners, operations planners, consultants, and many others in over 115 countries worldwide due to its powerful performance, customizable and full featured.

3.1. Model System in PSS/E

The transmission network studied consists of 14 buses with 5 PV buses and 11 PQ buses.

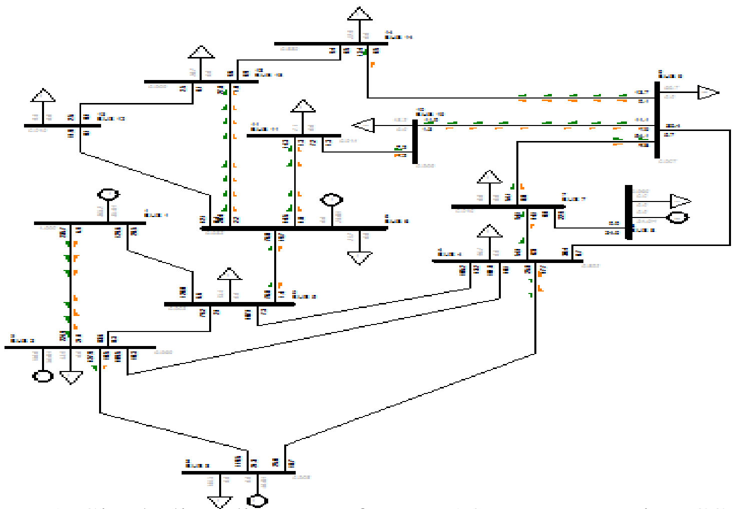

Figure 1: Single line diagram of IEEE 14 Bus system in PSS/E

The bus data, branch data and generation data is prepared accordingly into the data entry file while the single line diagram is developed in the graphical file. Figure 1 shows the single line diagram of the 14 bus system.

3.2. Power Flow Analysis Development in PSS/E

Three types of analysis were performed in PSS/E software namely, AC contingency calculation, PV transfer analysis and QV analysis. All the analysis is performed by stressing the system with overall load increment as well as N-1 or single line contingency and N-2 or double line contingency. Several important files and system description were defined in order to perform the analysis in PSS/E.

- Saved case file (*.sav): This file contains all the information about the buses, generators, loads, branches and etc.
- Subsystem description data file (*.sub): This file defines a new subsystem. It defines all the buses and subsystems of ‘Source’ and ‘Sink’ that are to be included in the new subsystem.
- Monitored element data file (*.mon): The network elements such as buses, branches and others to be monitored and recorded in the analysis are specified in this file. For the study, all buses in the area studied with voltages from 1.05p.u to 0.6 p.u is monitored and recorded. Besides, branches with flow rating larger than 100% of Rate A is monitored and recorded too.
- Contingency description file (*.con): All contingencies to be tested in the AC contingency analysis are listed in this file.

With the above system description files, the ACCC analysis, PV and QV analysis curves were obtained through a series of load flow solutions.

3.3 ACCC Report Generation

The contingency, monitor and subsystem files are utilized by the ACCC features to perform an analysis of the 14 bus power system. Figure 2 shows the analysis of ACCC.

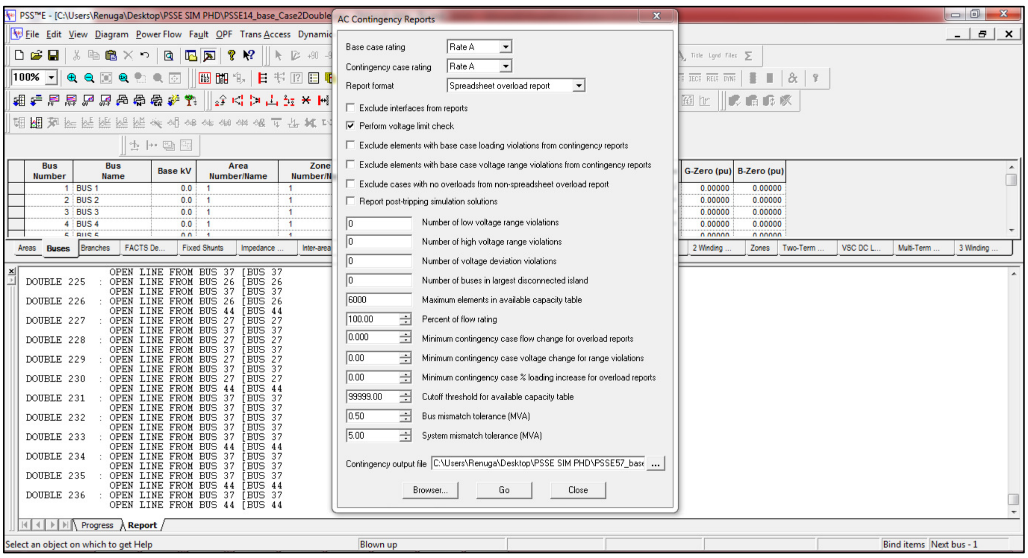

Figure 2: PSS/E system for ACCC Analysis

3.4 PV Analysis and QV Analysis

The PV curve is a representation of voltage change as a result of increased power transfer between two systems while QV curve is a representation of reactive power demand by a bus or buses as voltage level changes. These analysis methods are used to determine the loading limits imposed by voltage stability under steady- state conditions.

4. Reactive Power Tracing Concept and Formulation for Novel LQP_LT Index

Load tracing is defined as a task to trace the power contributed by an individual load.

4.1 Formulation of LQP_LT index

A transmission line can be either absorbing or generating reactive power. The transmission element's contribution to the reactive power flows depends of its π equivalent circuit and the voltage magnitude at its terminals. In order to make the complexity of reactive power tracing accurate, a generalized π equivalent model were developed by considering all possible reactive power flow directions, which are either generations or absorptions, at both terminals of sending and receiving, as well as inside the series impedance of the network elements of the 14 bus system. Utilizing [13-15], with appropriate modification performed for the purpose of reactive power flow derivation, the flow Q_{lm} on line l-m can be expressed as a summation of load components as in equation (1), where n is the total number of loads in the network.

$$Q_{lm} = Q_{lm}^{L1} + Q_{lm}^{L2} + Q_{lm}^{L3} + \cdots + Q_{lm}^{Ln} \tag{1}$$

The component of load defined as Q_{Li} on line l-m is expressed as a fraction x_{lm}^{i} of load Q_{Li} and written as follows:

$$Q_{lm}^{Li} = x_{lm}^{i} \cdot Q_{Li} \tag{2}$$

thus, $$Q_{lm} = \sum_{i=1}^{Ln} x_{lm}^{i} \cdot Q_{Li} \tag{3}$$

Applying the above concept into LQP_LT of line *l-m* for summation of individual load components, gives equation (4):

$$LQP_{LT_{lm}} = LQP_{lm}^{L1} + LQP_{lm}^{L2} + LQP_{lm}^{L3} + \cdots + LQP_{lm}^{Ln} \tag{4}$$

or can be written also as:

$$LQP_{LT_{lm}} = 4\left(\frac{X}{V_s^2}\left[\sum_{i=1}^{Ln} Q_{r,lm}^{i}\right] + \frac{XP_s^2}{V_s^2}\right) \tag{5}$$

The algorithm is developed in MATLAB environment to automate the reactive tracing in the system study and the power fraction contribution computation for LQP_LT index is formulated accurately for contingency analysis computation.

4.2. Computerization of Reactive Power Tracing and LQP_LT index for System Study

Figure 3 shows the flow chart development for the automation of LQP_LT index computation in MATLAB environment. The algorithm developed in MATLAB is found to fast, effective and robust in generating the output and it can be implemented for any large size of power test system.

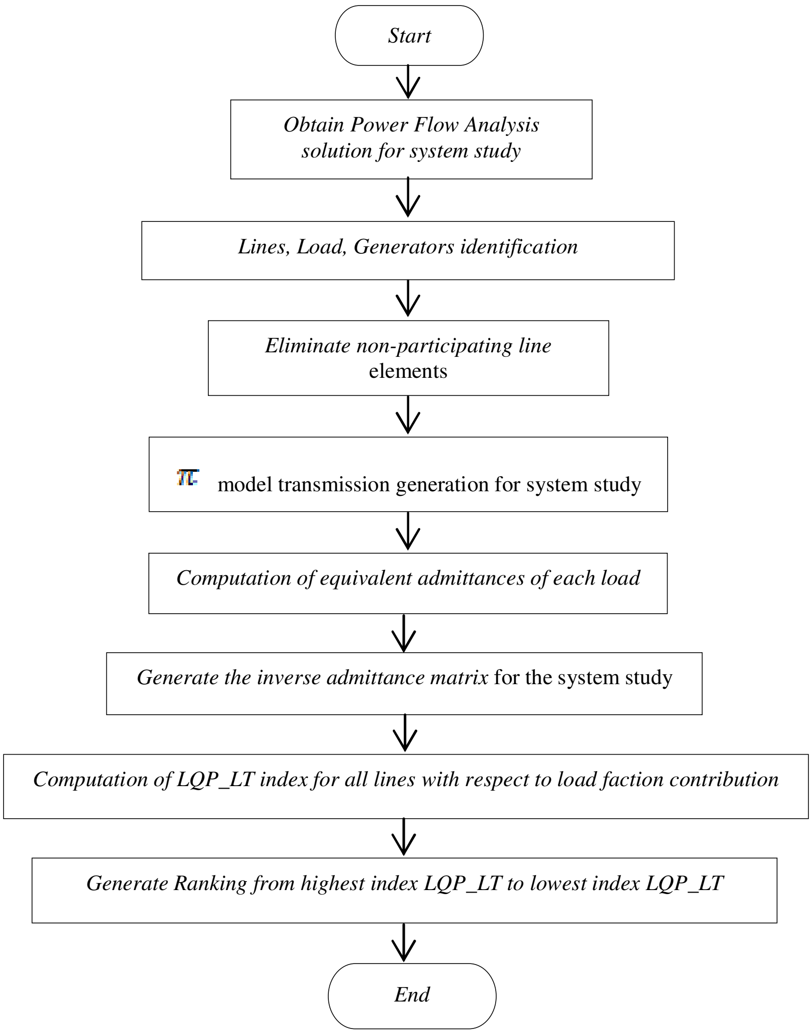

Figure 3: Flow Chart for LQP_LT Automation in MATLAB

5.0. Case Study and Results via PSS/E

The simulations performed via PSS/E is explained in the following sections.

5.1. AC Contingency Analysis for Single Line Outage

The AC contingency analysis was carried out for single line contingency for the overall system study and Table 1 shows part of the single line contingency events simulated in the analysis. The ranked result is extracted and shown in Table 2. The results revealed that bus 14 followed by bus 9, bus 10, bus 11, bus 13 and bus 12 are having the most vulnerable voltages that can lead to system voltage collapse. The single line diagram captured for the lowest voltage value of 0.67245 p.u. when line outage occurred at line connecting bus 7 to 9 is shown in Figure 4.

Table 1: Contingency Legends

LABEL	EVENTS
SINGLE 4	OPEN LINE FROM BUS 2 [BUS 2] TO BUS 4 [BUS 4]
SINGLE 5	OPEN LINE FROM BUS 2 [BUS 2] TO BUS 5 [BUS 5]
SINGLE 6	OPEN LINE FROM BUS 3 [BUS 3] TO BUS 4 [BUS 4]
SINGLE 7	OPEN LINE FROM BUS 4 [BUS 4] TO BUS 5 [BUS 5]
SINGLE 13	OPEN LINE FROM BUS 6 [BUS 6] TO BUS 13 [BUS 13]
SINGLE 14	OPEN LINE FROM BUS 7 [BUS 7] TO BUS 8 [BUS 8]
SINGLE 15	OPEN LINE FROM BUS 7 [BUS 7] TO BUS 9 [BUS 9]
SINGLE 16	OPEN LINE FROM BUS 9 [BUS 9] TO BUS 10 [BUS 10]
SINGLE 17	OPEN LINE FROM BUS 9 [BUS 9] TO BUS 14 [BUS 14]
SINGLE 18	OPEN LINE FROM BUS 10 [BUS 10] TO BUS 11 [BUS 11]
SINGLE 19	OPEN LINE FROM BUS 12 [BUS 12] TO BUS 13 [BUS 13]
SINGLE 20	OPEN LINE FROM BUS 13 [BUS 13] TO BUS 14 [BUS 14]

Table 2: AC Contingency Report

SYSTEM	CONTINGENCY	BUSES	V-CONT	V-INIT
'CASEA '	RANGE SINGLE 15	BUS 14	0.67245	0.88871
'CASEA '	DEVIATION SINGLE 15	BUS 14	0.67245	0.88871
'CASEA '	RANGE SINGLE 15	BUS 9	0.67787	0.9074
'CASEA '	DEVIATION SINGLE 15	BUS 9	0.67787	0.9074
'CASEA '	RANGE SINGLE 15	BUS 10	0.68168	0.90456
'CASEA '	DEVIATION SINGLE 15	BUS 10	0.68168	0.90456
'CASEA '	RANGE SINGLE 15	11 BUS 11	0.71596	0.91368
'CASEA '	DEVIATION SINGLE 15	11 BUS 11	0.71596	0.91368
'CASEA '	RANGE SINGLE 15	13 BUS 13	0.73026	0.90945
'CASEA '	DEVIATION SINGLE 15	13 BUS 13	0.73026	0.90945

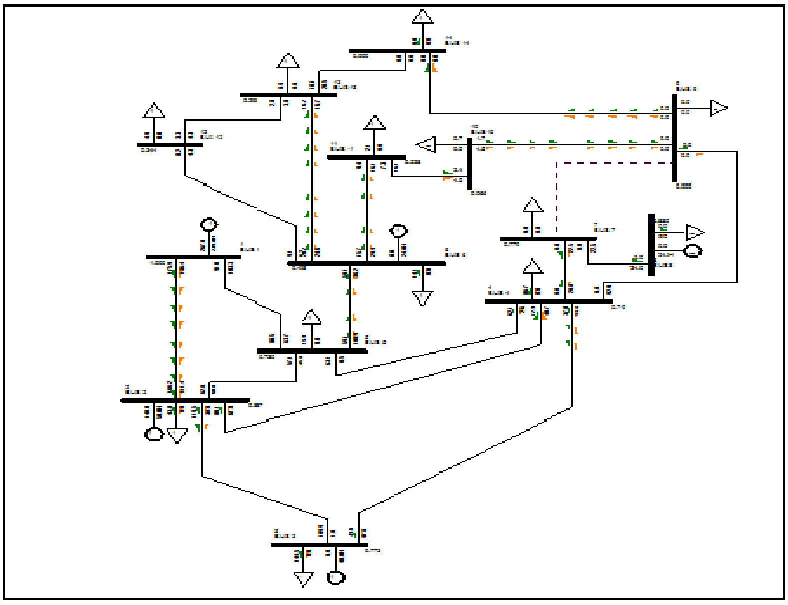

Figure 4: Single line contingency at Bus 7 to Bus 9.

5.2. AC Contingency Analysis for Double Line Outage

Similarly, the double line contingency was performed and Table 3 shows the contingency events simulated while Table 4 shows the ranked results from the AC contingency report. The results revealed that bus 14 followed by bus 12, bus 11, bus 9, bus 10 and bus 13 are having the most vulnerable voltages that can cause system voltage collapse. The single line diagram captured for the lowest voltage value of 0.37246 p.u. when line outage occurred at line connecting from bus 6 to 13 and bus 9 to 14 is shown in Figure 5.

Table 3: Contingency Legends

LABEL	EVENTS
DOUBLE 165	OPEN LINE FROM BUS 6 [BUS 6] TO BUS 13 [BUS 13]
	OPEN LINE FROM BUS 9 [BUS 9] TO BUS 10 [BUS 10]
DOUBLE 166	OPEN LINE FROM BUS 6 [BUS 6] TO BUS 13 [BUS 13]
	OPEN LINE FROM BUS 9 [BUS 9] TO BUS 14 [BUS 14]
DOUBLE 167	OPEN LINE FROM BUS 6 [BUS 6] TO BUS 13 [BUS 13]
	OPEN LINE FROM BUS 10 [BUS 10] TO BUS 11 [BUS 11]
DOUBLE 168	OPEN LINE FROM BUS 6 [BUS 6] TO BUS 13 [BUS 13]
	OPEN LINE FROM BUS 12 [BUS 12] TO BUS 13 [BUS 13]
DOUBLE 169	OPEN LINE FROM BUS 6 [BUS 6] TO BUS 13 [BUS 13]
	OPEN LINE FROM BUS 13 [BUS 13] TO BUS 14 [BUS 14]

Table 4: AC Contingency Report

SYSTEM	CONTINGENCY	BUSES	V-CONT	V-INIT
'CASEA '	RANGE DOUBLE 166	14 BUS 14	0.37246	0.88871
'CASEA '	DEVIATION DOUBLE 166	14 BUS 14	0.37246	0.88871
'CASEA '	RANGE DOUBLE 58	14 BUS 14	0.40553	0.88871
'CASEA '	DEVIATION DOUBLE 58	14 BUS 14	0.40553	0.88871
'CASEA '	RANGE DOUBLE 155	12 BUS 12	0.41371	0.91544
'CASEA '	DEVIATION DOUBLE 155	12 BUS 12	0.41371	0.91544
'CASEA '	RANGE DOUBLE 65	14 BUS 14	0.42072	0.88871
'CASEA '	DEVIATION DOUBLE 65	14 BUS 14	0.42072	0.88871
'CASEA '	RANGE DOUBLE 149	11 BUS 11	0.42095	0.91368
'CASEA '	DEVIATION DOUBLE 149	11 BUS 11	0.42095	0.91368
'CASEA '	RANGE DOUBLE 65	9 BUS 9	0.4236	0.9074
'CASEA '	DEVIATION DOUBLE 65	9 BUS 9	0.4236	0.9074

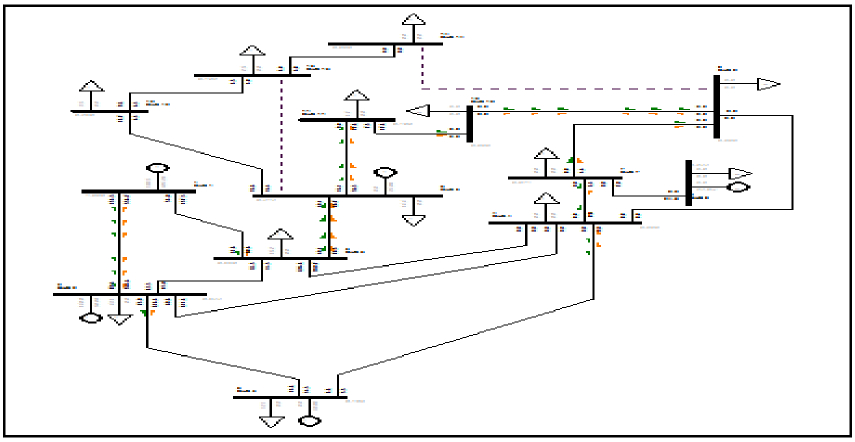

Figure 5: Double line contingency at Bus 6 to 13 and Bus 9 to 14.

5.3. PV Analysis and QV Transfer for Single Line Contingency and Double Line Contingency

The PV transfer and QV analysis were performed from the subsystems created for the AC contingency analysis. Table 5 shows the bus categorization for the power transfer to take place from the source subsystem to sink subsystem. Figure 6 shows the PV curve obtained at the weakest bus, which is bus 14 with a minimum voltage value of 0.586 taken for maximum load transfer when single line outage occurred at line connecting from bus 13 to bus 14. Figure 7 shows the QV curve obtained at the same weak bus scenario which at bus 14.

Table 5: Source and Sink buses

Source Area 1 (A1)	Sink Area 2 (A2)
Bus 1	Bus 8
Bus 2	Bus 9
Bus 3	Bus 10
Bus 4	Bus 11
Bus 5	Bus 12
Bus 6	Bus 13
Bus 7	Bus 14

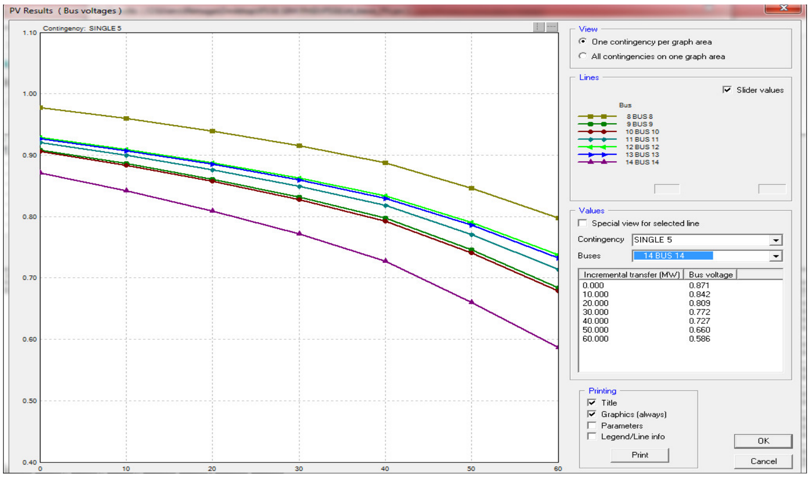

Figure 5: PV Analysis for the worst case with single line contingency

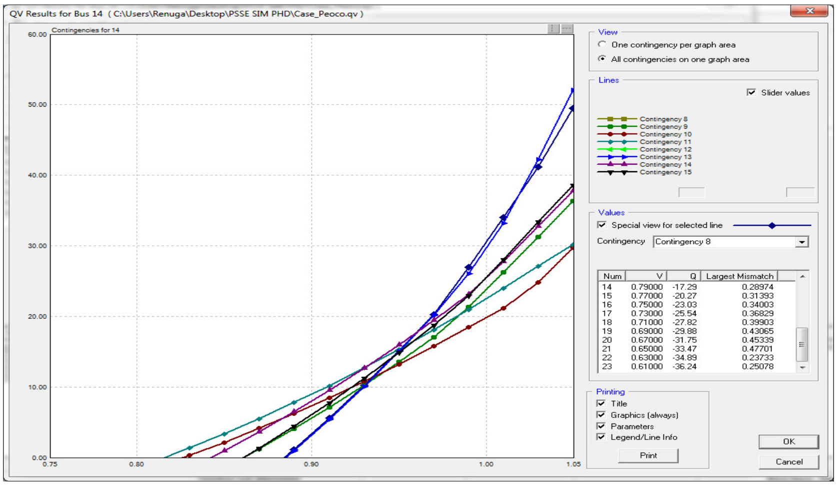

Figure 6: QV Analysis for the worst case with single line contingency

Similarly, the PV analysis and QV analysis with double line contingency were performed for the subsystem. Figure 7 and Figure 8 shows the PV analysis and QV analysis obtained at the worst case. Bus 14 is found to have the most insufficient reactive power margin to sustain the voltage stable range of the study system.

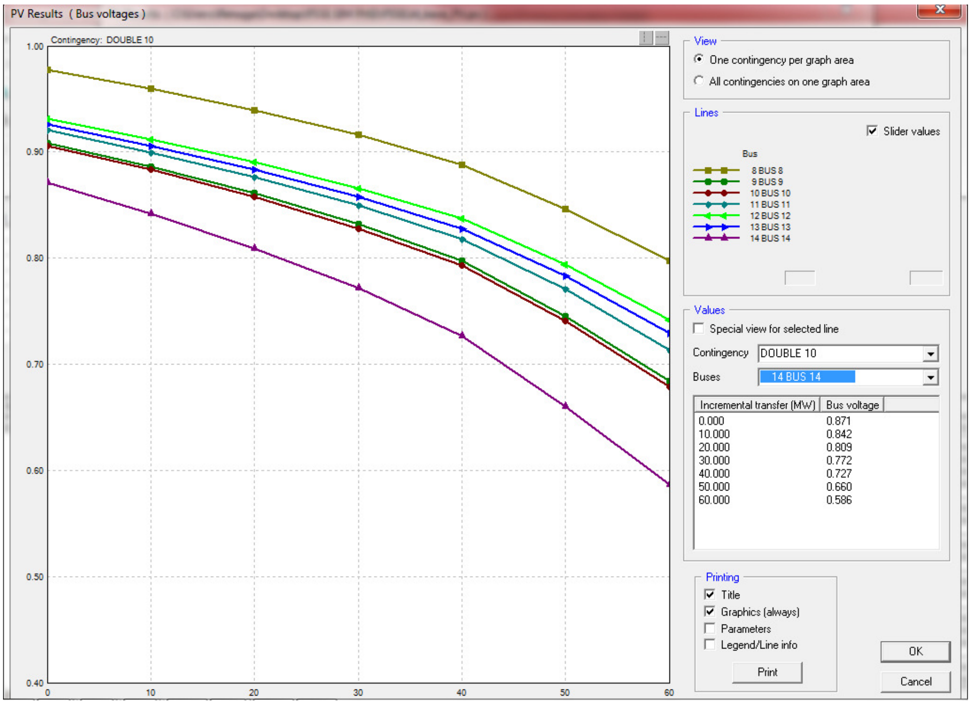

Figure 7: PV Analysis for the worst case with double line contingency

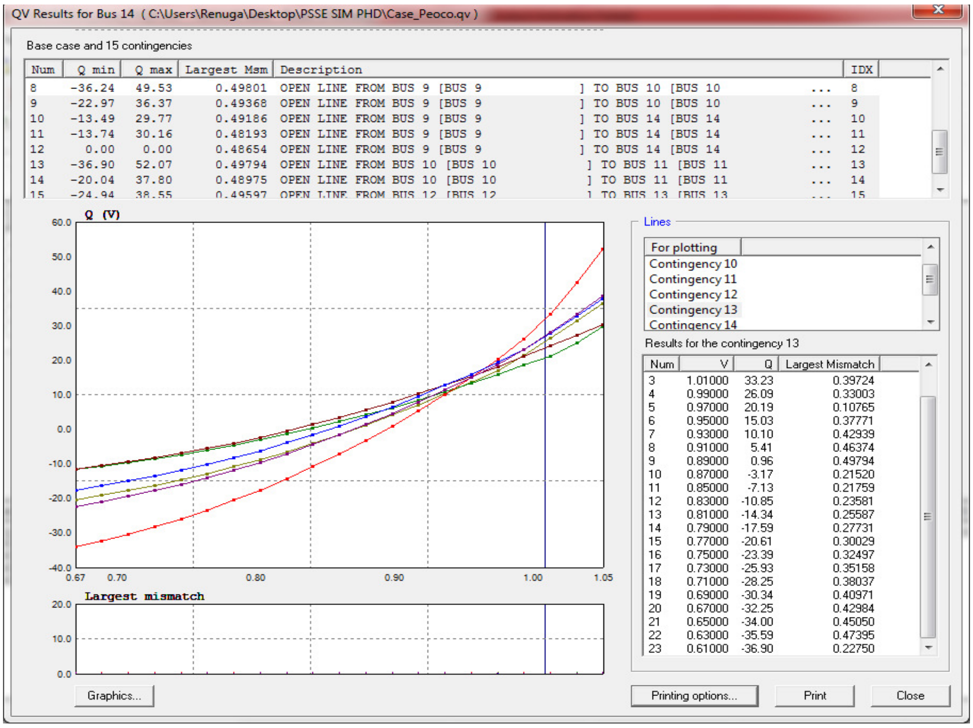

Figure 8: QV Analysis for the worst case with double line contingency

For both the cases it was found that the critical buses are ranked at bus 14 followed by bus 10, 9, 11, 13, 12 and finally bus 8. Any corrective or preventive actions must be performed by considering those weak buses for overall system voltage improvement.

6.0. Case Study and Results via LQP_LT index Computation

The LQP_LT index is computed for the single line and double line contingency analysis using developed reactive power tracing algorithm in Matlab. All power flow simulations were carried out using optimal power flow.

6.1. LQP_LT Computation for Single Line Contingency

The optimal load flow simulation for the single line contingency is performed in the same method carried out using PSS/E software. The load increments were performed in stages with constant power factor, and it was found that the system can have a maximum loading factor of 2.98 without any contingencies. When the line outage from bus 7 to bus 9 is carried out, the system could not reach a feasible solution. With the loading factor reduced to maximum value of 2.29, the system convergence is obtained. The LQP_LT resulted for this case is shown in the Table 6. Figure 9 shows the distribution of load buses towards the reactive power tracing via LQP_LT index for system lines. The individual load bus contribution to each transmission lines were obtained accurately and efficiently. The buses are ranked in priority order with bus 9 is at the highest rank followed by load bus 14, 10, 12, 11and 6. This indicates that the load bus at highest order of ranking should be given the priority for any corrective or preventive actions by the system operator. The weak load bus identification found in this case are identical with the ranking results obtained from the analysis in the PSS/E software.

Table 6: LQP_LT Computation for single line contingency

From Bus	To Bus	LQP_LT											Sum LQP_LT
		Load 2	Load 3	Load 4	Load 5	Load 6	Load 9	Load 10	Load 11	Load 12	Load 13	Load 14	
2	1	0.009	0.009	0.009	0.009	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.100
1	5	0.066	0.066	0.068	0.080	0.084	0.078	0.080	0.071	0.070	0.080	0.078	0.823
2	4	0.040	0.040	0.062	0.040	0.040	0.126	0.040	0.040	0.040	0.040	0.041	0.550
2	5	0.031	0.031	0.033	0.043	0.047	0.041	0.043	0.035	0.034	0.043	0.041	0.424
3	4	0.009	0.009	0.041	0.009	0.009	0.134	0.009	0.009	0.009	0.009	0.010	0.258
5	4	0.001	0.001	0.002	0.001	0.001	0.004	0.001	0.001	0.001	0.001	0.001	0.012
7	4	0.171	0.171	0.172	0.171	0.171	0.174	0.171	0.171	0.171	0.171	0.171	1.883
4	9	0.352	0.352	0.352	0.352	0.352	1.181	0.352	0.352	0.352	0.352	0.359	4.706
5	6	0.140	0.140	0.140	0.140	0.191	0.151	0.180	0.152	0.151	0.180	0.173	1.739
6	11	0.061	0.061	0.061	0.061	0.061	0.094	0.180	0.098	0.061	0.061	0.062	0.862
6	12	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.062	0.040	0.036	0.298
6	13	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.102	0.091	0.501
8	7	0.098	0.098	0.099	0.098	0.098	0.101	0.098	0.098	0.098	0.098	0.098	1.085
10	9	0.004	0.004	0.004	0.004	0.004	0.028	0.004	0.004	0.004	0.004	0.004	0.068
9	14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.008
11	10	0.062	0.062	0.062	0.062	0.062	0.104	0.216	0.062	0.062	0.062	0.062	0.876
12	13	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.020	0.017	0.059
13	14	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.345	1.667
Maximum		0.352	0.352	0.352	0.352	0.352	1.181	0.352	0.352	0.352	0.352	0.359	

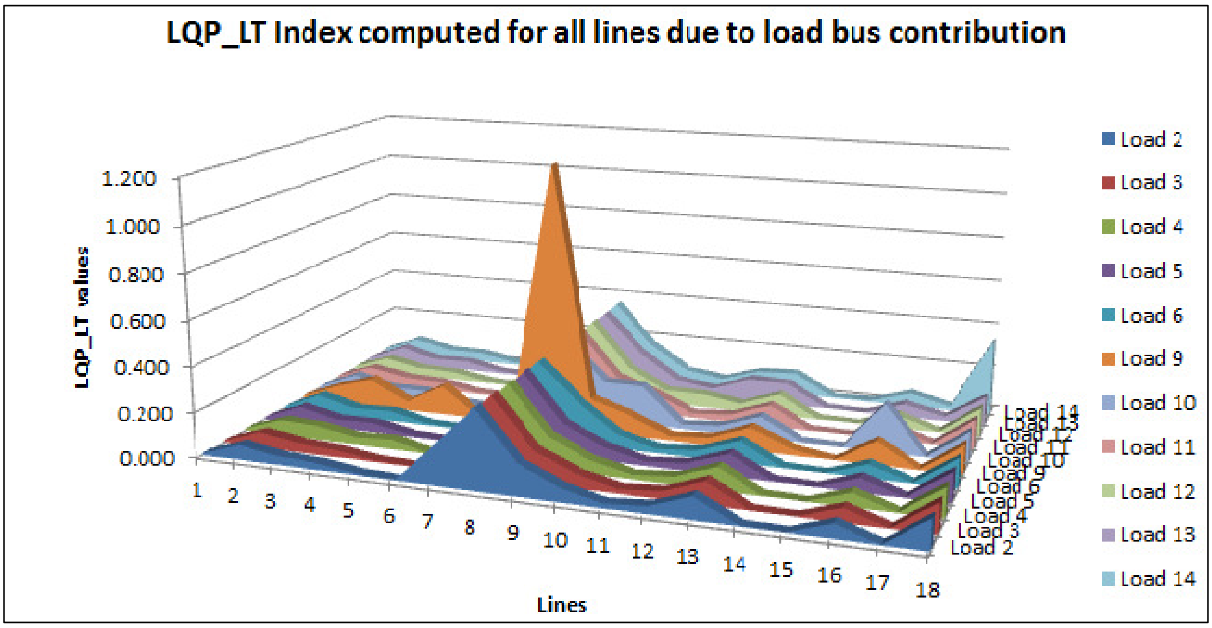

Figure 9: LQP_LT index for overall system due to load bus power fraction distribution.

6.2. LQP_LT Computation for Double Line Contingency

For the double line contingency simulation, the system maximum loading factor is further reduced to 1.35. Line outages were carried out for the lines connecting from bus 6 to 13 and bus 9 to 14. The selections of lines for the double line contingency were made in parallel with the worst double line contingency resulted from the PSS/E analysis. Table 7 shows the LQP_LT index computed for all transmission lines due to the load bus power fraction contribution. Figure 10 shows the distribution of load buses towards the reactive power tracing via LQP_LT index for the whole system lines. The buses are ranked in priority order with bus 14 is at the highest rank followed by load bus 13, 9, 10, 11 and 12. Similar to the single line contingency, the results indicate that the load bus at highest order of ranking should be given the priority for any corrective or preventive actions by the system operator for the overall system voltage enhancement. The weak load buses detection found in this case is identical with the ranking results attained from the PSS/E analysis.

Table 7: LQP_LT Computation for Double Line Contingency

From Bus	To Bus	LQP_LT											Sum LQP_LT
		Load 2	Load 3	Load 4	Load 5	Load 6	Load 9	Load 10	Load 11	Load 12	Load 13	Load 14	
2	1	0.021	0.021	0.021	0.022	0.022	0.021	0.021	0.021	0.021	0.021	0.021	0.233
1	5	0.069	0.069	0.069	0.074	0.072	0.069	0.071	0.070	0.070	0.072	0.071	0.777
2	4	0.025	0.025	0.030	0.026	0.025	0.028	0.025	0.025	0.025	0.025	0.025	0.284
2	5	0.015	0.015	0.015	0.019	0.018	0.015	0.016	0.015	0.015	0.017	0.017	0.176
3	4	0.001	0.001	0.020	0.005	0.004	0.014	0.004	0.002	0.002	0.003	0.003	0.057
4	5	0.001	0.001	0.001	0.003	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.021
7	4	0.001	0.001	0.013	0.003	0.002	0.009	0.002	0.001	0.001	0.002	0.002	0.036
4	9	0.014	0.014	0.014	0.014	0.014	0.091	0.020	0.014	0.014	0.014	0.014	0.240
5	6	0.050	0.050	0.050	0.050	0.064	0.050	0.059	0.053	0.053	0.061	0.059	0.598
6	11	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.017	0.000	0.000	0.000	0.062
6	12	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.104	0.156	0.146	1.079
8	7	0.014	0.014	0.024	0.015	0.015	0.139	0.023	0.014	0.014	0.015	0.014	0.300
7	9	0.008	0.008	0.008	0.008	0.008	0.084	0.013	0.008	0.008	0.008	0.008	0.167
9	10	0.001	0.001	0.001	0.001	0.001	0.001	0.006	0.001	0.001	0.001	0.001	0.011
11	10	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.045
12	13	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.140	0.129	0.820
13	14	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.280	1.219
Maximum		0.0939	0.0939	0.0939	0.0939	0.0939	0.1390	0.0939	0.0939	0.1039	0.1555	0.2128	

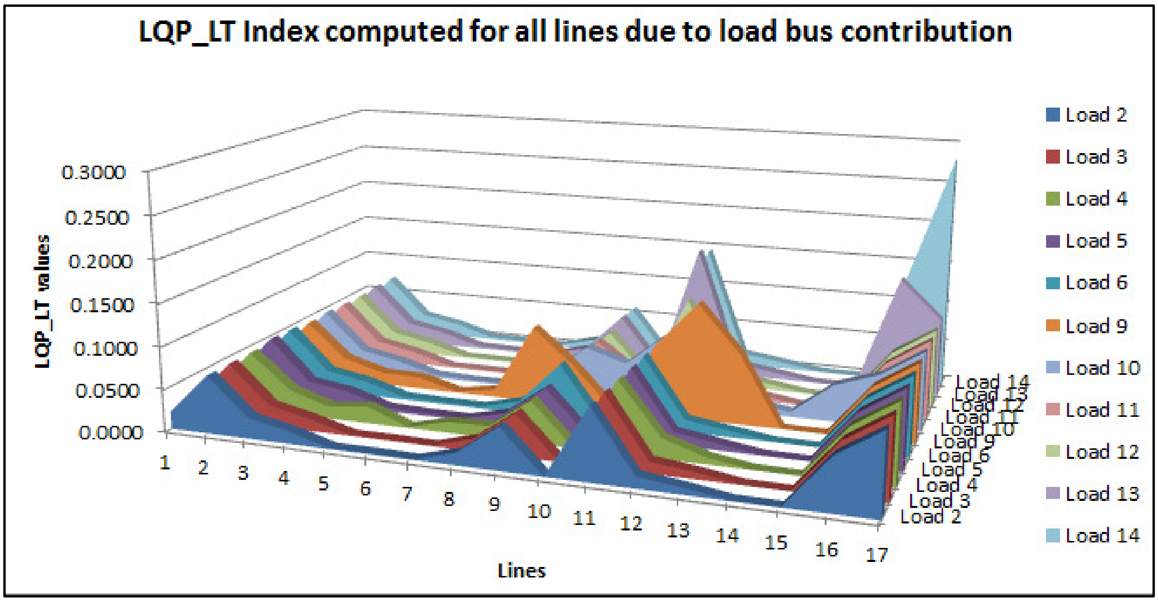

Figure 10: LQP_LT index for overall system due to load bus power fraction distribution.

7. Conclusions

To summarize, a new approach for weak load bus detection has been recommended. The method implements novel line stability factor, LQP_LT which has the ability to trace the stressed lines contributed by an individual load in a system. Enabling the priority ranking list based on the traced LQP_LT, system operator can perform an accurate selection of critical load bus prior to performing any corrective action against voltage instability condition. Based on the results obtained, it can be validated that LQP_LT index is robust, efficient and reliable in identifying the weak load points in any contingency conditions. The LQP_LT index capability to trace the weak load buses in a system study is in a strong agreement with the evidence of results obtained via AC contingency analysis using the powerful industrial graded PSS/E software. Thus, the proposed reactive power tracing index, LQP_LT is suitable to be applied and implemented in the actual power system industry.

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References

[1] T. Amraee, A. M. Ranjbar & R. Feuillet, Adaptive under voltage load shedding scheme using model predictive control, *Electrical Power System Research*, 81, 507–13, 2011.

[2] R. Verayiah, A. Mohamed, H. Shareef & I. H. Z. Abidin, Multi- level optimization strategy for load shedding with tracing capability index, *IEEE International Conference on Control System, Computing and Engineering (ICCSCE 2015)*, 558-562, 2015.

[3] S. J. Huang & C. C. Huang, Adaptive approach to load shedding including pumped storage units during underfrequency conditions, *IEEE Proceedings Generation, Transmission and Distribution*, 148, 165-171, 2001.

[4] V. N. Chuvychin, N. S. Gurov, S. S. Venkata & R. E. Brown, Adaptive approach to load shedding and spinning reserve control during underfrequency conditions, *IEEE Transaction On Power Systems*, 11, 1805-1810, 1996.

[5] J. Bialek, Tracing the flow of electricity, *IEEE Proceedings Generation Transmission & Distribution*, 143(4), 313-320, 1996.

[6] F. F Wu, Y. Ni & P. Wei, Power transfer allocation for open access using graph theory - fundamentals and applications in systems without loop flows, *IEEE Transactions on Power Systems*, 15(3), 923-929, 2000.

[7] D. Kirschen, R. Allan, & G. Strbac, Contributions of individual generators to loads and flows, *IEEE Transactions on Power Systems*, 12(1), 52-60, 1997.

[8] F. Gubina, D. Grgic & I. Banic, A method of determining the generators' share in a consumer load, *IEEE Transactions on Power Systems*,15(4), 1376-1381, 2000.

[9] D. Kirschen & G. Strbac, Tracing active and reactive power between generators and loads using real and imaginary currents, *IEEE Transactions on Power Systems*, 14(4), 1312-1319, 1999.

[10] Z. G. Wu, Y. Zhang, X. H. Chen, Z. B. Du & H. W. Ngan, A flexible current tracing algorithm in load tracing in bulk power systems, *International Conference on Power System Technology*, 4, 2135-2139, 2002.

[11] PSS/E User Manual, Siemens Power Transmission & Distribution, Inc., Dec 2007.

[12] R. Verayiah & I. Z. Abidin, A Study on static voltage collapse proximity indicators*, Proceedings of IEEE 2nd International Power and Energy Conference*, 531-536, 2008.

[13] A. R. Abhyankar, S. A. Soman & S. A. Khaparde, Optimization approach to real power tracing: an application to transmission fixed cost allocation, *IEEE Transactions on Power System*, 21, 1350–1361, 2006.

[14] A. Mohamed, G. B. Jasmon & S. Yusoff, A static voltage collapse indicator using line stability factors, *Journal of Industrial Technology*, 7(1), 73-85, 1989.

[15] I. Musirin & T. K. A. Rahman, Novel fast voltage stability index (FVSI) for voltage stability analysis in power transmission system, *Proceedings Student Conference on Research and Development*, 265-268, 2002.

[16] Z. A. Hamid, I. Musirin, M. M. Othman & N. A. Rahim, Efficient power scheduling via stability index based tracing technique and blended crossover continuous ant colony optimization, *Australian Journal of Basic and Applied Sciences*, 9, 1335-1347, 2011.

[17] Z. A. Hamid & I. Musirin, Optimal fuzzy inference system incorporated with stability index tracing: An application for effective load shedding, *Expert Systems with Applications*, 4(1), 1095-1103, 2014.

[18] J. Kennedy & R. Eberhart, Particle swarm optimization, *Proceedings of IEEE International Conference on Neural Networks IV*, 1942–1948, 1995.

[19] PSS®E: Industry Leader - siemens.com. http://w3.siemens.com/smartgrid.