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Estimation of Bifurcation Point in Multi-Bus System Using Generator Reactive Power Limit Approach

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Abstract: This study proposes an approach for estimating bifurcation point in multi-bus systems. The approach assumes that the generators would violate their Q-limits before the bifurcation point is reached. The result of this assumption clearly raises the voltages along the PV curve which consequently yield an infinitesimal error. Therefore, the final estimated point can be obtained after a number of load flow solutions depending on the complexity of the system and the loading pattern among others. Finally, computer simulations of two system networks are carried out to calculate the bifurcation point at the selected minimum voltage which estimates the bus that violates its Q-limit at a certain load.

Key words: Bifurcation point, PV curves, Q-limit, load flow, large power system, Nigeria

INTRODUCTION

The estimation of the bifurcation point gives a platform for calculating the power margin or extreme loading condition before voltage collapse occurs in a power system at its operating point. This, of course requires the initialization of the load flow as a basic unit in static and dynamic analysis of the system. The load flow solution can produce the trajectory of the PV curves to a point just before the bifurcation point where the solution starts to diverge. The final estimated point can be obtained after a number of load flow solutions depending on many factors such as system's complexity, the loading pattern, the size of the load step and the required accuracy (Hassan, 1995).

Various approaches have been adopted and applied to large power systems aiming at estimating the bifurcation points and improving the voltage stabilities of these systems. Semlyen *et al*. (1991) in the view, discussed the use of the basic nodal equation to obtain the bifurcation point of a large power system. The active and reactive powers of each bus are expressed in terms of its load admittance and voltage.

And the secant method is applied to find the zero crossing of the differential of both powers on the admittance-load factor plane.

Semlyen (1991) presents a simple numerical example to show how a proximity index can be calculated from the Jacobian and also depict the relation between the static and dynamic bifurcation using algebraic differential model. Suzuki *et al*. (1992) have used the curve fitting technique after obtaining a good number of lower and upper solutions on the PV curves to estimate the static bifurcation point. However, the difficulty appears to be in obtaining the lower solution for large systems and the appropriate load increment for a weak system without passing the bifurcation point.

The other controversial issue is the suitability of curve fitting techniques close to the bifurcation point when generators Q-limits are considered which tend to give staircase type curves.

Another approach called the Continuation technique which offers a unique approach of obtaining the full trace of nose curves was documented. This formed the basis of Ajjaraju and Christy (1992)'s research. The same technique has also been used by Canizares and Alvarado (1993) for large AC/DC system.

The optimization technique (Obadina and Berg, 1998) was one of the early methods of obtaining the exact bifurcation point. An objective function which is a function of the increase in active and reactive power demand together with the load flow equations are used to develop a Lagrange function. A stability margin having a value between 0 and 1 was also defined to serve as a measure of the voltage security of power systems. The same technique was also applied to the Belgian system (Custem, 1991).

However in this study, the focus is on the application of the generator reactive power limit technique to systems in order to determine their bifurcation points.

The concept of generator reactive power limit: When the system is complex the computational time can be very long and a technique for fast estimation of the bifurcation point is needed. Generators reactive power limit technique is one of the techniques used in fast estimation of the bifurcation point. Only reactive power limits of generators buses can lead to saddle limit induced bifurcation points that associated to a maximum loading condition. It has a direct influence on the voltage profile of electric systems. It limits the computation time and averts the dynamic simulation of many inaccessible parameters in real time. The algorithm of the generators reactive limit technique is as follows (Lof and Reeve, 1993):

Step 1: Set $k = 0$.

Step 2: Run load flow to obtain base case results or initial state, P_0, Q_0, V_0, θ_0 for each bus.

Step 3: Select a loading and generation scenario.

Step 4: For simplicity assume a uniform load increase of 2% ($d\alpha = 0.02$) on all buses.

Step 5: Obtain another system state using the load flow.

Step 6: Increment k.

Step 7: Evaluate $dQ/d\alpha$ for each generator bus and $dV/d\alpha$ and $d\theta/d\alpha$ for each bus.

Step 8: Calculate the new load increase $\Delta\alpha_k$ that will cause the first generator, say i to reach its Q-limit, $Q_{imax} = Q_{ik-1} + \Delta\alpha_k(dV_i/d\alpha)$.

Step 9: If all generators have violated their Q-limits calculate the new load increase $\Delta\alpha$ that will cause the first bus say i, to reach its critical voltage: $V_{icritical} = V_{ik-1} + \Delta\alpha_k (dV_i/d\alpha)$.

Step 10: Assuming that linearity is maintained, obtain a set of voltages and angles for each bus I: $V_{ik} = V_{ik-1} + \Delta\alpha (dV_i/d\alpha)$; $\theta_{ik} = \theta_{ik-1} + \Delta\alpha_k (d\theta_i/d\alpha)$.

Step 11: Update the Jacobian using the above values and find the new solution:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_k \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix}$$

Step 12: Check if the bifurcation point has been passed i.e., if $dV/dQ<0$ or $dV/dP<0$.

Step 13: Go to step 4. If the solution is unstable then use the binary or dichotomic search method until the increment $\Delta\alpha_k$ is within a specified tolerance.

Step 14: Calculate the margin $= \sum_k \Delta\alpha_k$.

Description of the test systems: Two systems have been selected for the application of generator reactive power limit technique. These systems are 9-bus system and IEEE 14-bus system (Pecas Lopes *et al*., 1993) as shown in Fig. 1 and 2. The line and bus data of these systems are given in Appendixes A1 and A2.

Simulations: The simulations are carried out with Power System Analysis Toolbox (PSAT). The calculation of the bifurcation point depends on the minimum voltage selected. The calculated step according to the initial slopes will estimate the bus that violates its Q-limit at a certain load.

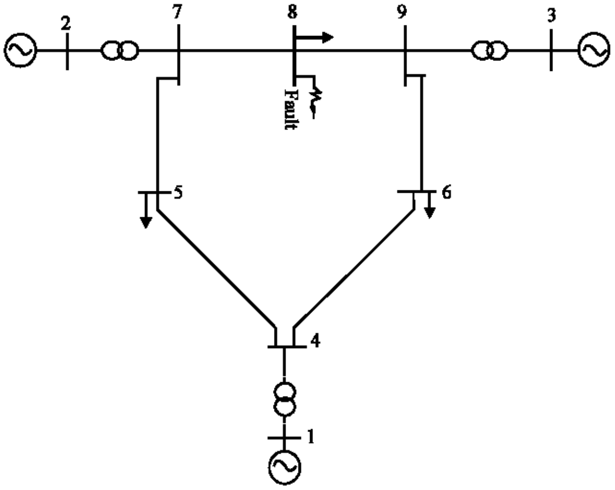

Fig. 1: Continue

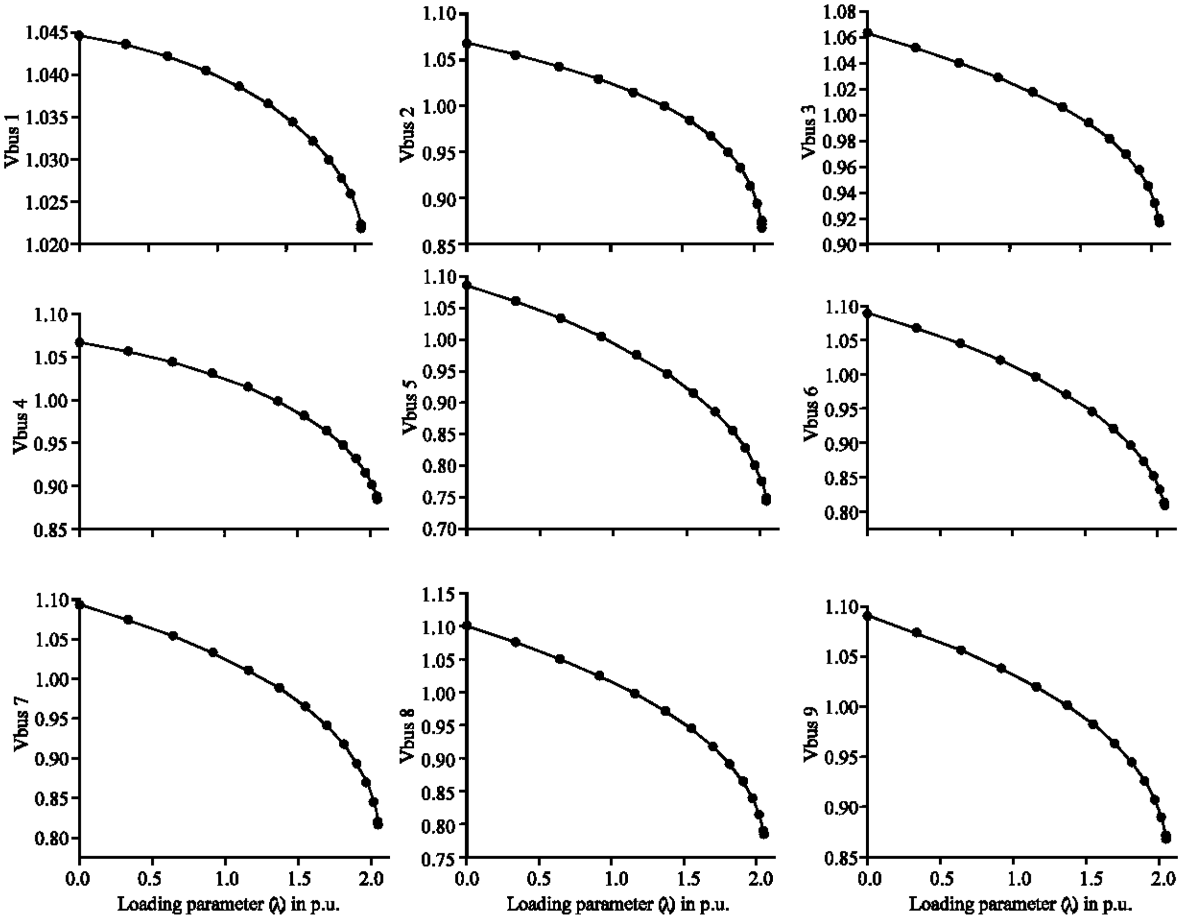

Fig. 1: 3-machine 9-bus system

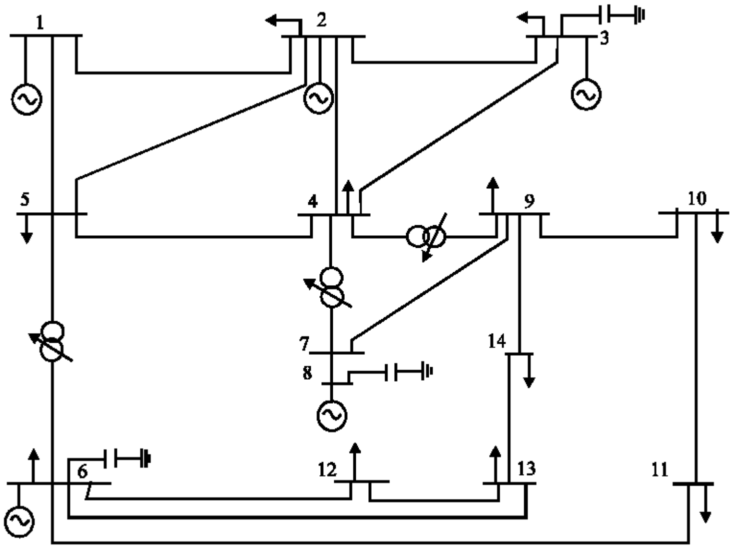

Fig. 2: Continue

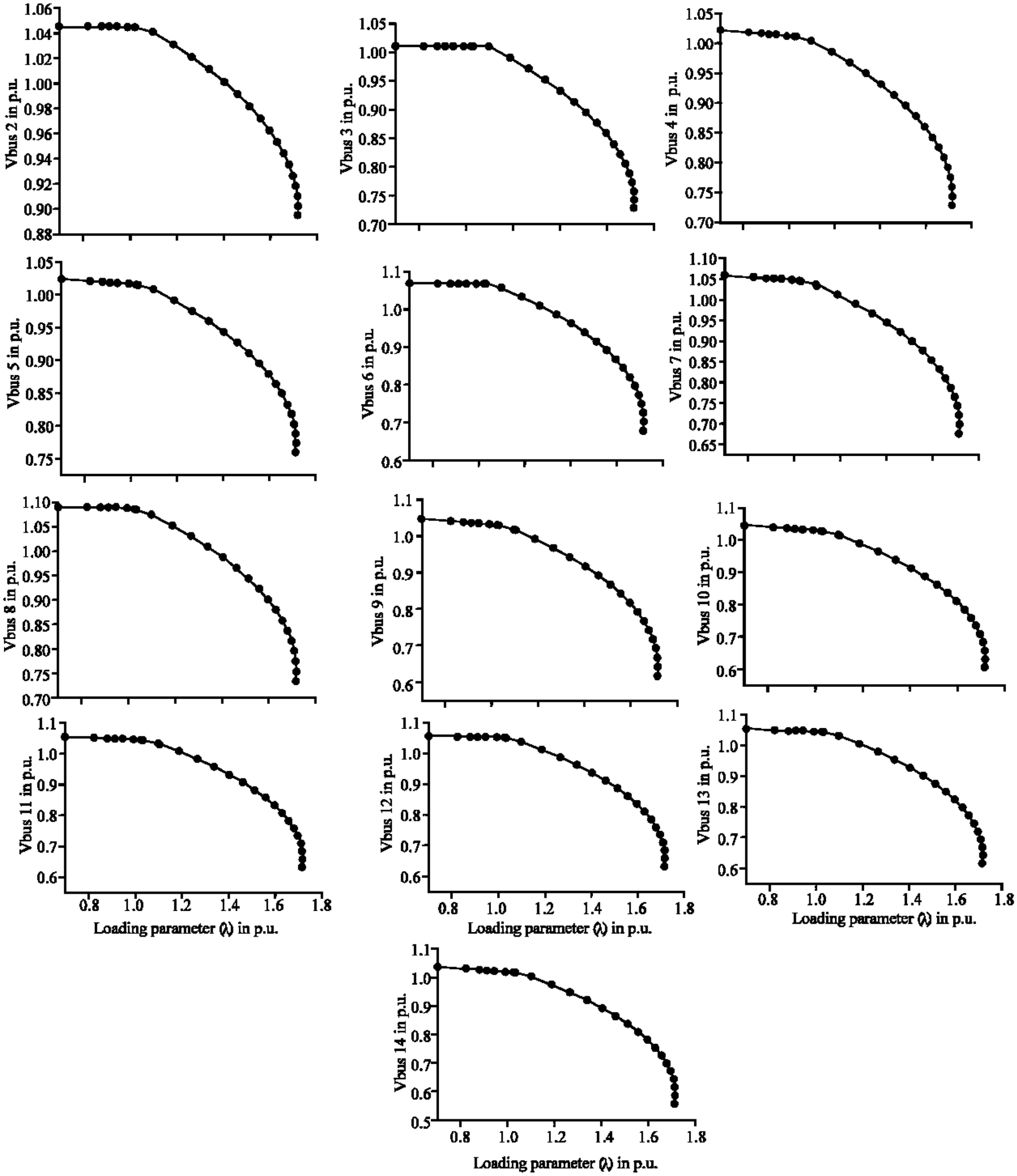

Fig. 2: IEEE 14-bus system

CONCLUSION

This study has proposed a technique for estimating the bifurcation point of power systems. It is hoped that the study would give an insight of the fast approach to estimate bifurcation point for voltage stability of any power network as IEEE 14-bus system has been considered a benchmark for comparative study in the proposed technique. Finally, computer simulations of these system networks are carried out to calculate the bifurcation point which subsequently, evolved pragmatic results that validate the proposed technique.

APPENDIX

A1: Study system data (9-bus system)

Line data

		Values are in per unit and base on 100 MVA			
Element no.	From bus	To bus	R	X	Half line charge
1	7	8	0.0085	0.0720	0.0745
2	8	9	0.0119	0.1008	0.1045
3	7	5	0.0320	0.1610	0.1530
4	9	6	0.0390	0.1700	0.1790
5	5	4	0.0100	0.0850	0.0880
6	4	6	0.0170	0.0920	0.0790
7	2	7	0.0000	0.0625	1.0000
8	9	3	0.0000	0.0586	1.0000

Bus data

		All power values are in MW and MVAR						
Bus no.	Bus type	V	Pg	Qg	Pl	Ql	Q_{min}	Q_{max}
1	2	1.040	-	0	0	0	0	0
2	2	1.025	163	0	0	0	-100	130
3	2	1.025	85	0	0	0	-70	50
4	1	1	0	0	0	0	-	-
5	1	1	0	0	125	50	-	-
6	1	1	0	0	90	30	-	-
7	1	1	0	0	0	0	-	-
8	1	1	0	0	0	0	-	-
9	1	1	0	0	0	0	-	-

Machine and exciter parameters

	Values are in per unit and sec			
Parameters	Machine1	Machine2	Machine3	Unit
x_d	0.146	0.8958	1.3125	p.u.
x'_d	0.0608	0.1198	0.1813	p.u.
x_q	0.0969	0.8645	1.2578	p.u.
x'_q	0.000969	0.1969	0.2500	p.u.
T'_{do}	8.96	6.0000	5.8900	sec
T_{qo}	0.1	0.5350	0.6000	sec
M	0.0507	0.0590	0.0125	p.u.
K_a	50	25.0000	175.0000	p.u.
T_a	0.06	0.2000	0.0500	sec
K_e	-0.08	-0.0500	-0.1700	p.u.
T_e	0.405	0.5685	0.9520	sec
K_f	0.0648	0.0910	0.0300	p.u.
T_f	1	0.3500	1.0000	sec

A2: IEEE-14-bus system

Line data

			Values are in per unit and base on 100 MVA			
Element no.	From bus	To bus	R	X	B/2	Transf. ratio
1	1	2	0.01938	0.05917	-	0.0264
2	2	3	0.04699	0.19797	-	0.0219
3	2	4	0.05811	0.17632	-	0.0187
4	1	5	0.05403	0.22304	-	0.0246
5	2	5	0.05695	0.17388	-	0.0170
6	3	4	0.06701	0.17103	-	0.0173
7	4	5	0.01335	0.04211	-	0.0064
8	5	6	0.00000	0.25202	0.932	-
9	4	7	0.00000	0.20912	0.978	-
10	7	8	0.00000	0.17615	0	-
11	4	9	0.00000	0.55618	0.969	-
12	7	9	0.00000	0.11001	0	-
13	9	10	0.03181	0.08450	-	0
14	6	11	0.09498	0.19890	-	0
15	6	12	0.12291	0.25581	-	0
16	6	13	0.06615	0.13027	-	0
17	9	14	0.12711	0.27038	0	-
18	10	11	0.08205	0.19207	0	-
19	12	13	0.22092	0.19988	0	-
20	13	14	0.17093	0.34802	0	-

Bus data

		All power values are in MW and MVAR						
Bus no.	Bus type	V	Pg	Qg	Pl	Ql	Q_{min}	Q_{max}
1	2	1.060	232.4	0	0.0	0.0	-	-
2	2	1.045	40.0	0	21.7	12.7	-40	50
3	2	1.010	0.0	0	94.2	19.0	0	40
4	1	1.000	0.0	0	47.8	-3.9	0	0
5	1	1.000	0.0	0	7.6	1.6	0	0
6	1	1.070	0.0	0	11.2	7.5	-6	24
7	1	1.000	0.0	0	0.0	0.0	0	0
8	1	1.090	0.0	0	0.0	0.0	-6	24
9	1	1.000	0.0	0	29.5	16.6	0	0
10	1	1.000	0.0	0	9.0	5.8	0	0
11	1	1.000	0.0	0	3.5	1.8	0	0
12	1	1.000	0.0	0	6.1	1.6	0	0
13	1	1.000	0.0	0	13.5	5.8	0	0
14	1	1.000	0.0	0	14.9	5.0	0	0

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