Preventive Actions For Power System Stability Preservation

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Abstract - As deregulation occurs, power quality will be more important to electric utilities' customers. Power quality problems are mainly devoted to maintaining the supply voltage within certain limits. We have developed a new approach to maintain a given voltage value in the load nodes and increase the region of existence of solution to power flow equations by optimal selection of contingency arming schemes actions. The actions include estimation of the minimum value of generator tripping and load shedding, determination of the necessary level of static VAR compensation, and choice of minimum values of admittance increase in controlled lines using FACTS.

I. INTRODUCTION

The US electric utilities are facing dramatic changes as deregulation occurs. This process requires development of various services; for example, ancillary services, [1]. It also causes numerous problems that have yet to be solved. Solution of these problems, known as "outstanding open problems" [2], will be a basis for a new generation of methods and software for fast, effective and accurate application to power industry. A detailed list of technical "open outstanding problems" is given in [3].

A real time voltage stability analysis of interconnected power systems has been recognized as an important technical problem. The existing methods, [4, 5, 6], for prediction of voltage collapse may be classified as steady-state methods and dynamic methods. Steady state methods employ a steady-state model, such as a power flow model, or a steady-state model linearized about the steady-state operation. The dynamic methods incorporate models which are described by linearized or nonlinear differential and algebraic equations. Currently, it is the steady-state methodology that is mainly being developed.

This methodology consists of the following two approaches:

- Load flow feasibility methods, [7 - 13]

  These methods relate to existence of the real solutions to the power flow equations, i.e. network/load equations, or existence of an acceptable voltage profile across the network. Determination of this region is essential for proper selection of preventive actions. Currently, the region is analytically defined only for the simplified one generator - load power system.

- Steady-state stability methods, [14 - 17]

  The methods test for the existence of a stable equilibrium point, i.e. regime coordinates, of a power system.

Our company has developed analytical techniques to select preventive actions for voltage control, steady-state stability and transient stability preservation. In this paper, preventive actions are analytically selected for voltage control and steady-state stability preservation. Preventive actions for transient stability preservation include generator tripping, fast turbine valving, dynamic braking, e.t.c. These actions have been considered in [18].

II. CHOICE OF PREVENTIVE ACTIONS FOR VOLTAGE CONTROL

Proper prediction of power system behavior is vital for choice of preventive action to guarantee voltage stability, [3]. Power system behavior can be mathematically described by a set of differential and algebraic equations. For practical purposes, generator nodes are defined by differential equations (swing equation model), and load nodes are defined by algebraic equations for active and reactive power balance. These equations are nonlinear,

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they are large in number, and they are coupled. A set of algebraic equations does not always have real solutions. The region of existence of solutions to the network/load equations defines the values of generator angles for which load voltages and angles can be determined. These voltages and angles satisfy algebraic equations.

The size of the region of existence of solutions to the network/load equations may be used to predict power system behavior and select preventive actions.

The region of existence of solutions to network/load equations may be considered a tool for determination of critical values of parameters; for example, limit values of voltages in the load nodes. Prediction of critical values of parameters allows one to avoid emergency conditions and guarantee power quality.

As an illustrative example, let us consider a four-node scheme shown in Fig. 1. It consists of generator nodes 1 and 2, load node 3, and infinite bus 4.

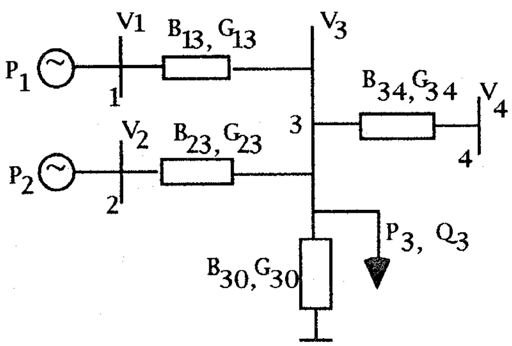

Fig. 1 Four node power system.

The region of existence of solutions to the network/load equations for this four node scheme is given in Fig. 2. It is shown in the plane (δ_1, δ_2), where δ_1 and δ_2 are the phase angles of generators 1 and 2 respectively. The lines of equal level of the voltage V_3 are shown inside this region. The region of existence of solutions to the network/load equations is constructed for polynomial load model. The plane (δ_1, δ_2) is covered completely. This is a proper load modeling.

Fig. 3 illustrates prediction of power system behavior for a limit (i.e. critical) voltage value in the load node. The critical value in the load node 3 is $V_c = 0.68$. The region of existence of solutions for power flow equations is close to zero.

Such prediction of power system behavior is determined without solving power flow equations. For any $V_c < 0.68$, the solution of power flow equations does not exist.

In reality, the value V_3 should be higher than 0.68 to guarantee necessary level of the stability margin. This value may be determined for a given stability margin.

Fig. 4 illustrates load shedding as a preventive action to maintain a given voltage value in the load node 3. For example, it is necessary to switch active power in the load node from $P_3 = -3.75$ (see Fig. 3) to $P_3 = -1.75$ (see Fig. 4). Thus, the voltage will be increased from $V_3 = 0.703$ (see Fig. 3) to $V_3 = 0.928$ (see Fig. 4). The region of existence of solutions to power flow equations is significantly increased.

Fig. 5 illustrates static Voltage-Ampere (VAR) compensation and load shedding as preventive actions to maintain a given voltage value in the load node 3. For example, it is necessary to switch active power in the load node from $P_3 = -3.75$ (see Fig. 3) to $P_3 = -2.75$ (see Fig. 5), and increase reactive power from $Q_3 = -0.1$ (see Fig. 3) to $Q_3 = 0.2$ (see Fig. 5). Thus, the voltage will be increased from $V_3 = 0.703$ (see Fig. 3) to $V_3 = 0.928$ (see Fig. 5). The region of existence of solutions to power flow equations significantly increases.

III. CHOICE OF ACTIONS FOR STEADY-STATE STABILITY PRESERVATION

We have developed a new approach to guarantee steady-state stability after any disturbance in a power system, [17]. It allows us to select the following control actions:

- Determination of limit values of both power flow and power in the nodes
- Estimation of the minimum value of generator tripping and load shedding
- Choice of minimal values of admittance increase in the controlled lines using Flexible AC Transmission Systems (FACTS)

These actions also maintain a given voltage value in the load node and increase the region of existence of solutions to power flow equations.

We apply the proposed approach to selection of preventive actions in a 24-node IEEE test system, Fig. 6.

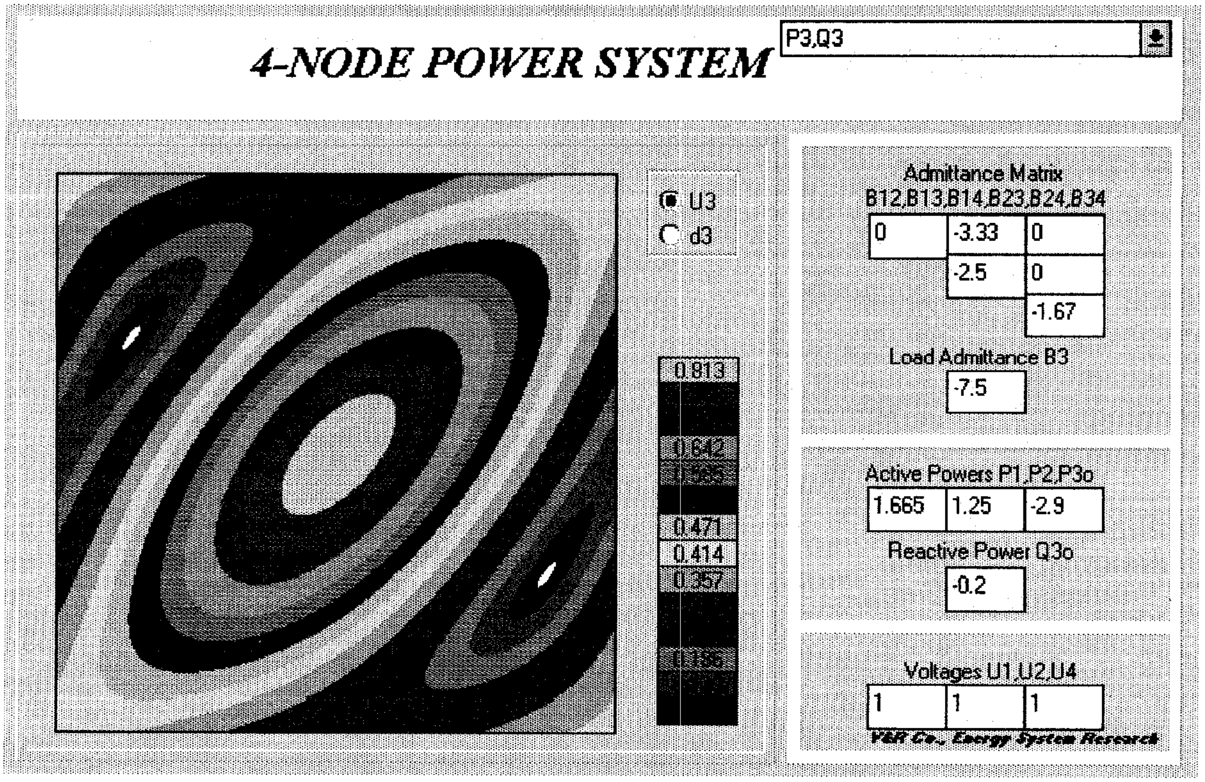

Fig. 2 The region of existence of solutions, P_3 polynomial model

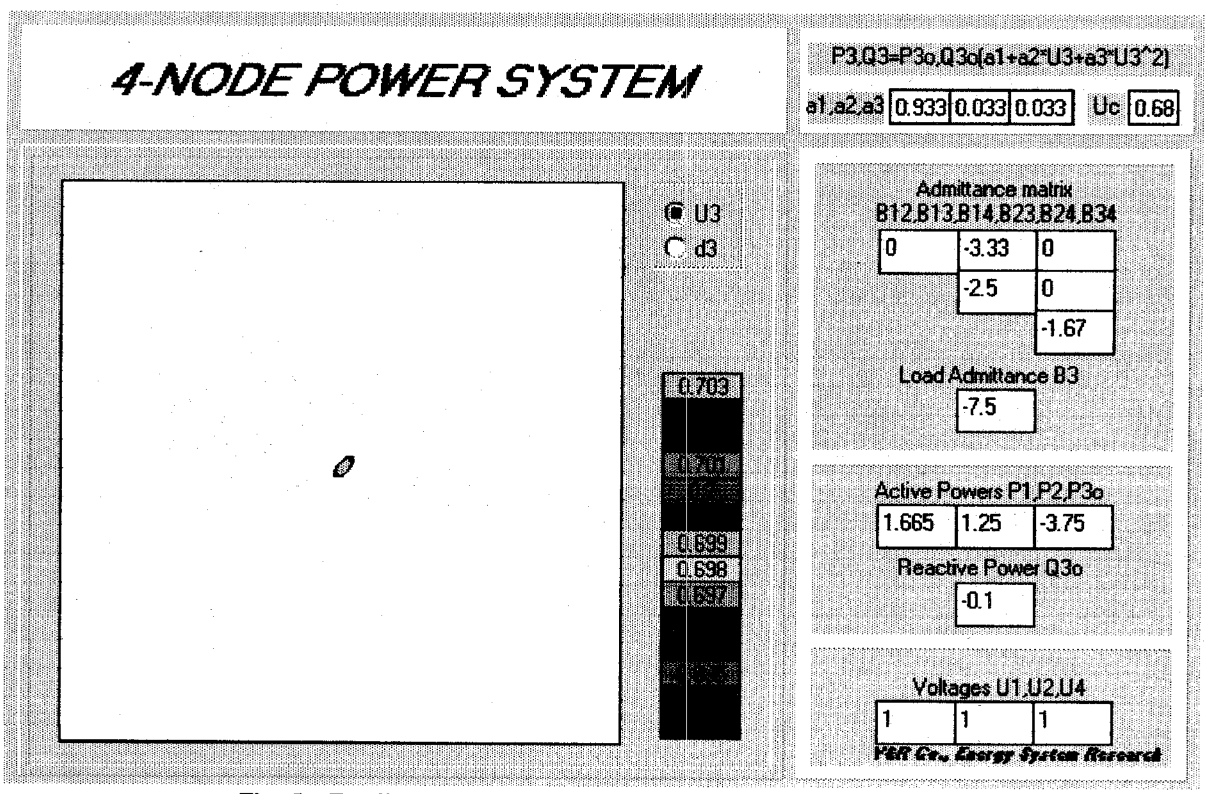

Fig. 3 Prediction of power system behavior: the limit voltage value

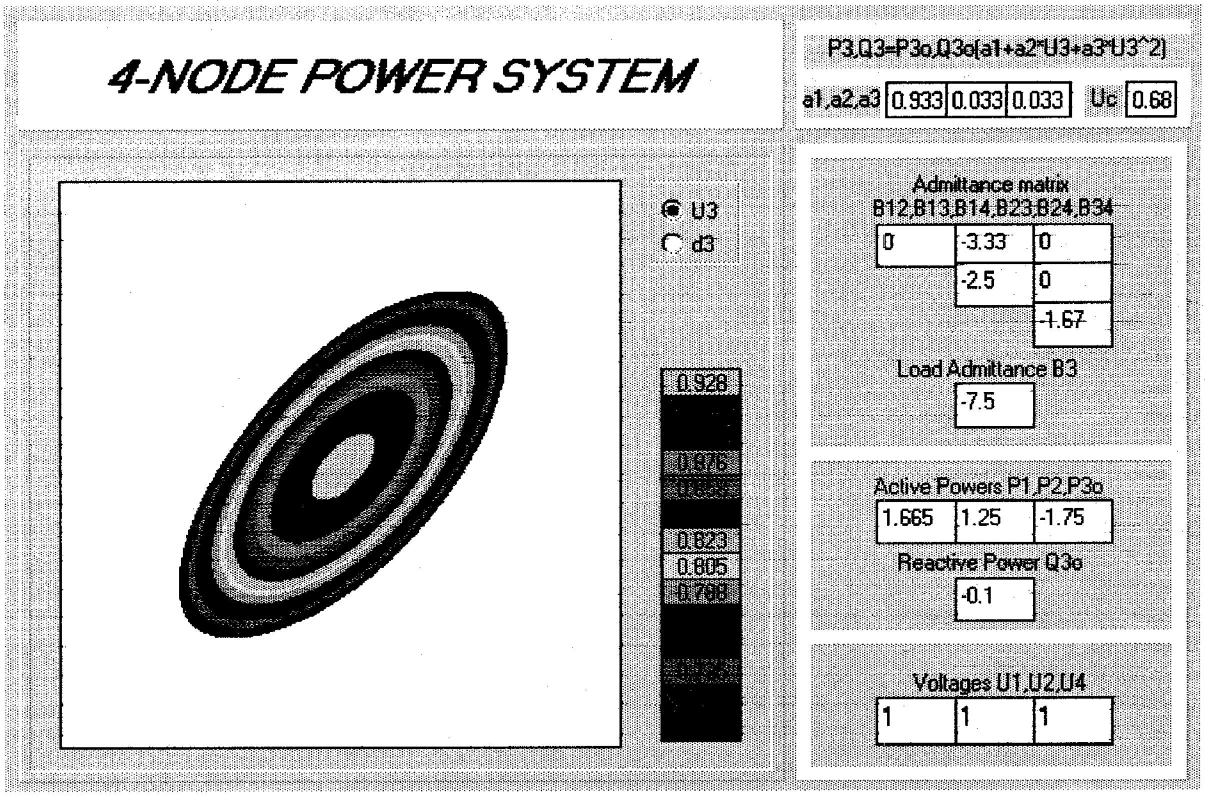

Fig. 4 Preventive action: load shedding

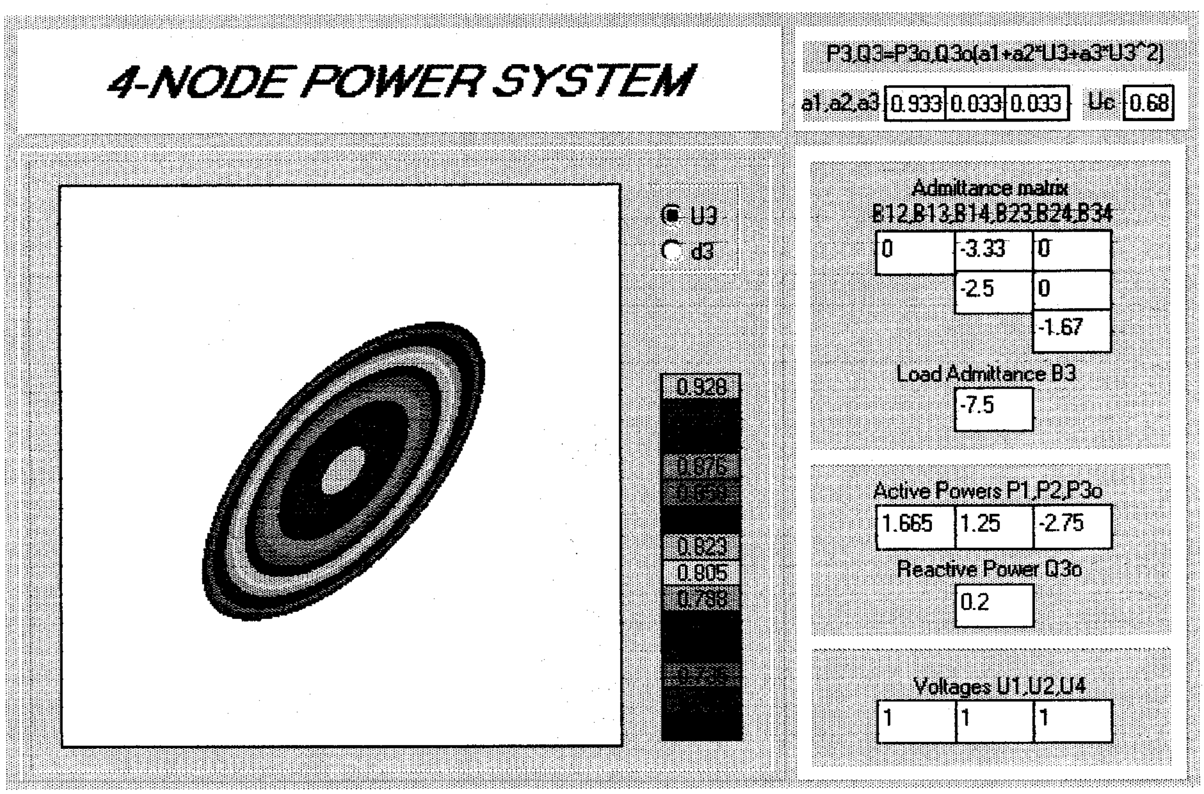

Fig. 5 Preventive actions: Static VAR Compensation ~~and load shedding~~

Results of synthesis when active and reactive powers in load nodes are the functions of the voltage are shown in Table 1.

Unstable regime is chosen after switching off lines shown in column 2. Power flow in the switched off line in the pre-fault regime is given in column 3. Values of active and reactive powers (P, Q) for generator tripping and load shedding for stability preservation are given in the columns 5, 7 and 8.

Letter "G" is shown in parenthesis, column 5, if switching off generator power (generator tripping) is necessary to preserve stability. Letter "L" is shown in parenthesis, column 7, if switching off load power (load shedding) is necessary to preserve stability.

We considered actions of FACTS necessary to guarantee a desirable power flow and steady-state stability preservation.

We have computed minimal values of admittance increase (column 10) in controlled lines (column 9) after switching off the lines shown in column 2.

Power flows in controlled lines in the pre-fault and the post-fault regimes are given in columns 11 and 12 respectively.

Positive sign means direct power flow from the beginning to the end of the line. Opposite direction of the power flow has a negative sign.

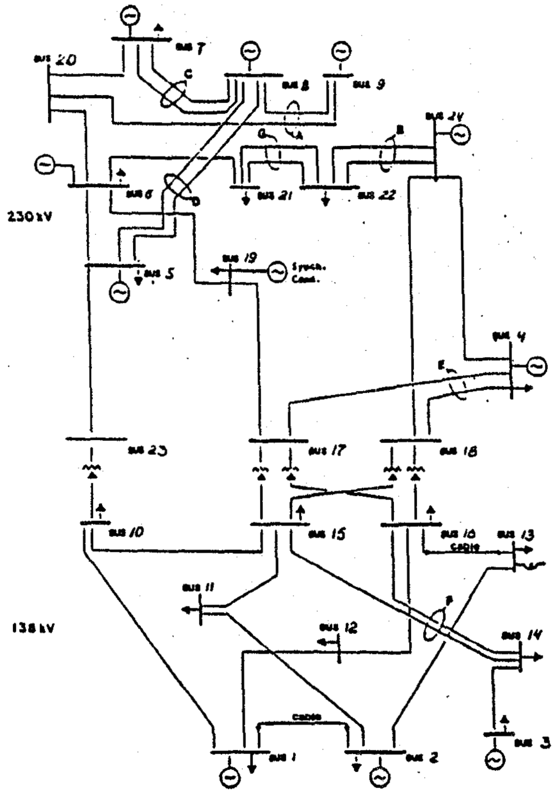

Fig. 6 Twenty Four Node IEEE Test System.

TABLE 1.
GENERATOR TRIPPING, LOAD SHEDDING AND FACTS
FOR STABILITY PRESERVATION ($P = P(V)$, $Q = Q(V)$)

No.	Line	Power Flow	Generator Tripping and Load Shedding					FACTS			
			Node No.	P (G)	Node No.	P (L)	Q	Line	$\lvert Y_{ij}\rvert$, %	Power Flow	
1	2	3	4	5	6	7	8	9	10	11	12
1	1-10	0.59	1	0.041	10	0.034	0.058	10-15	9.5	0.287	-0.459
2	1-12	2.55	1	0.014	12	0.013	0.003	12-16	3.0	0.440	-1.485
3	2-11	1.81	Stable					Stable			
4	2-13	1.96	2	0.325	13	0.285	0.015	13-16	7.0	-1.803	-2.894
5	5- 6	10.34	5	4.217	6	4.123	-	6-20	95.0	-11.560	-21.390
6	6-19	8.82	6	5.523	19	5.246	0.123	Controlled lines*			

* Lines: 4-17 (90%), 4-24 (18.5%), 5-23 (90%), 6-21 (87.5%)

IV. CONCLUSION

Novel analytical tools have been developed to select preventive actions for voltage control and steady-state stability preservation. Choice of preventive actions for voltage control is based on the size of the region of existence of solutions to the network/load equations. This region may be analytically determined for multimachine power systems. Remedial actions of generator tripping, load shedding and FACTS have been analytically selected to preserve steady-state stability. The technique does not utilize the iterative procedure which results in obtaining the uniform convergence after any contingency.

V. ACKNOWLEDGMENT

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