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Closure to Discussion of "Voltage Stability Analysis: V-Q Power Flow Simulation vs. Dynamic Simulation"

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of each allele represents the number of blocks of fixed capacity that are being added to the existing circuit. The representation of other situations, such as replacing the existing circuit for another one with different technology, or different voltage, would require the use of more than one allele for the respective circuit (let call them as "sub-alleles") as well as the implementation of a rule that tells the GA to turn off the effect of one sub-allele to let the other take place. For instance, if one wants to analyze the expansion of a given circuit at two different voltage levels, say 230 kV and 500 kV, two sub-alleles should be set up: one representing the number of blocks of expansion at 230 kV and the other at 500 kV. The aforementioned rule should ask the GA to fix to zero either one of the sub-alleles to let the other influence in the chromosome's fitness. Even though we did not implement such an option, we believe that it can be successful.

Concerning the second issue, even though a GA for finding optimum dynamic expansion plans could be developed and implemented, it should be mentioned that considering the uncertainties, the amount of information that is no longer available for the public and the decentralization of decisions in a competitive market of electricity supply, the effort of implementing a GA-based, dynamic expansion model, would not be worthwhile. In our opinion, the dynamic of the expansion (dating of new installations) is defined by complementary studies such as stability and reliability assessment and short-circuit analysis. However, among the set methodologies, methods and programs for the expansion planning, a static integer transmission expansion model is necessary to pick up major interconnections and facilities that will be present in most of the scenarios. A short-run, market-driven expansion model will never foresee those large-scale projects.

Regarding the third issue, in a market based on physical bilateral contracts with short-term transactions, the long-term view about the problem should be replaced by a short-term view, whose emphasis is to manage congestion through prices. Nevertheless, if the interest is focused on the long-term analysis of the transmission expansion under such a market of contracts, a GA-based algorithm could be used, if multiple scenarios of load, dispatch and bilateral transactions are considered.

Discussion of "Voltage Stability Analysis: V–Q Power Flow Simulation Versus Dynamic Simulation"

William A. Mittelstadt

The authors are to be congratulated on their excellent and needed comparison of two methods of performing voltage stability analysis in the above paper.[1] These results emphasize the importance of using the best possible model in planning and operating decisions affecting the reliability and cost of the electric transmission system. The two-step process suggested of using V–Q or P–V analysis for screening, and using dynamic simulation for critical cases affecting operating limits or investment decisions, should be followed.

Those involved in applying these tools would benefit from further insight into the end-state differences between the two methods. It would be very helpful if the authors could present a comparison between the two methods for a marginal case that is stable in both methods of analysis. For example, are there differences between the resulting load magnitude or generator reactive output that could account for why the V–Q method is more conservative? Would the dynamic simulation also be unstable for the three test cases if the same model assumptions were used as in the V–Q analysis? Finally, I would be interested in knowing to what extent it would be practical to improve the accuracy of the V–Q screening method by including steady-state models of features used in the dynamic simulation such as OEL or load tap changers?

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[1]B. H. Chowdhury and C. W. Taylor, *IEEE Trans. Power Systems*, vol. 15, no. 4, pp. 1354–1359, November 2000.

Closure to Discussion of "Voltage Stability Analysis: V–Q Power Flow Simulation Versus Dynamic Simulation"

Badrul H. Chowdhury and Carson W. Taylor

We appreciate the comments and questions of Mr. Mittelstadt in the above paper.[1]

We do not necessarily advocate V–Q or P–V methods for contingency screening. Especially for on-line voltage security assessment, but also for off-line analysis, single power flow simulation per contingency may be more effective. From a current or projected operating point, contingencies are simulated. With power flow convergence, results can be evaluated for adequate voltage magnitudes and reactive power reserves. Sensitivity analysis can suggest preventive or corrective countermeasures to ensure security. For divergent cases, procedures such as reducing load or power transfers, or widening reactive power limits may be used to obtain solved cases, and to determine countermeasures. In many cases, a secure operating limit is desired, and binary search methods are most efficient [1], [2]. Dynamic simulation can then be used for verification or for more accurate assessment.

All three outages simulated for the paper were unstable by V–Q analysis and stable for dynamic simulation. Since there was no operating point for the unstable V–Q curve cases, results at the end of stable dynamic simulation could not be directly compared with the power flow results. Mr. Mittelstadt, suggests a comparison between the two methods for a case that is stable in both methods of analysis.

We added a 460 MVAr shunt capacitor bank at Keeler 500 kV substation in the pre-outage power flow case and ran a V–Q analysis as well as time domain simulations. The Big Eddy–Ostrander 500-kV line outage was simulated.

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[1]B. H. Chowdhury and C. W. Taylor, *IEEE Trans. Power Systems*, vol. 15, no. 4, pp. 1354–1359, November 2000.

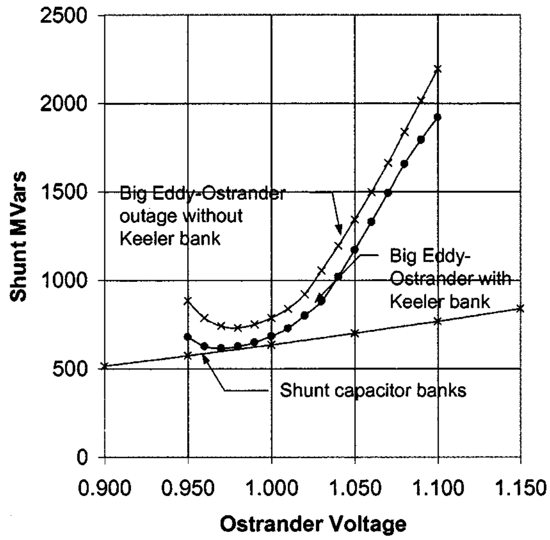

Fig. A1. V–Q curve at Ostrander with a 460 Mvar shunt capacitor added at Keeler substation.

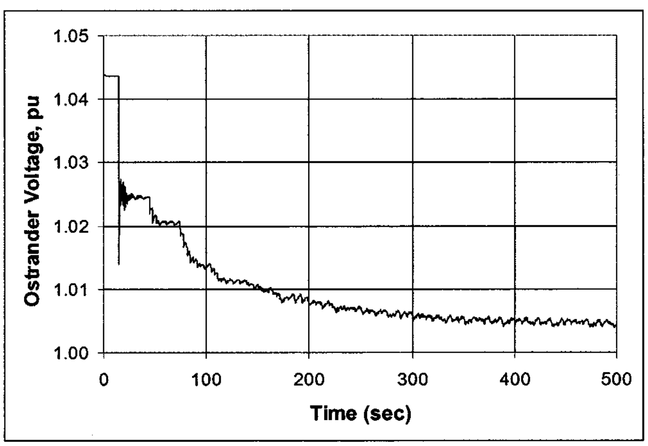

Fig. A2. Bus voltage at Ostrander obtained from time domain simulation with a 460 Mvar shunt capacitor added at Keeler substation.

The V–Q curve power flow analysis shows approximately zero MVAr margin at the Ostrander 500-kV bus, as shown in Fig. A1. Hence the outage case could be considered as marginally stable. For comparison with time domain simulation, we will assume an operating point at the 0.98 pu voltage solution point.

Time domain simulation shows a stable system with Ostrander voltage reaching about 1.0 pu in the steady state—about 5% below the pre-disturbance value. The time evolution of the Ostrander bus voltage magnitude is shown in Fig. A2. All loads are restored to pre-disturbance power levels as found from load voltage levels. Some of the most sensitive generators in the Portland area have remaining reactive power reserves as shown on Table A1. Other smaller generators affecting the Portland area also are within the reactive power limits. Also shown on Table A1 are the reactive power reserves found from the V–Q analysis. The differences in reactive reserves could be due to the difference in stable operating points obtained from the two analyzes.

TABLE A1
COMPARISON OF REACTIVE POWER RESERVE

Plant	*V–Q* Analysis	Dynamic Simulation
Centralia	25 Mvar	10 Mvar
John Day	133 Mvar	127 Mvar
Hermistn 1	160 Mvar	170 Mvar
Hermistn 2	79 Mvar	84 Mvar

Finally, Mr. Mittelstadt asks about improving the accuracy of the V–Q method. Overexcitation limiter operation is normally represented in power flow simulation by generator reactive power limits, but more detailed generator representation is possible [1]–[3]. While simple reactive power limits may be appropriate, it's essential to realize the consequences of field current/reactive power limiting. With limiting, the generator terminal voltage is no longer controlled and the terminal voltage will drop for severe network conditions. Armature current limits may thus be encountered, requiring either severe reduction in field current/reactive power or reduction in active power [4]. Armature current limiting is also critical if generators operate above rated active power (i.e., because of a turbine uprate). Armature limiting may be enforced by operators in response to alarms, or protection may trip the generator—either action may ensure voltage collapse. Digital AVR's may include armature current limiters that reduce field current [5]. It's thus vital to monitor armature current in both power flow and dynamic simulation [1].

In power flow simulation, it's also possible to represent loads in more detail (e.g., voltage sensitive static load), with distribution voltage control by bulk power delivery LTC transformers with tap limits. Numerical problems or inaccurate solutions may result, however, in power flow simulation of hundreds of LTC transformers plus other voltage/time controlled devices such as OEL's and switched reactive power compensation.

Thus we believe that relatively simple power flow simulation followed by dynamic simulation of critical cases is the best approach. As argued in the many papers by Dr. Van Cutsem, the fast time domain approach is a good compromise between speed and accuracy for the slow time frame voltage stability problems studied in our paper.

REFERENCES

[1] T. Van Cutsem, C. Moisse, and R. Mailhot, "Determination of secure operating limits with respect to voltage collapse," *IEEE Trans. Power Systems*, vol. 14, no. 1, pp. 327–335, Feb. 1999.
[2] T. Van Cutsem, F. Capitanescu, C. Moors, D. Lefebvre, and V. Sermanson, "An advanced tool for preventive voltage security assessment," in *VII Symposium of Specialists in Electrical Operational and Expansion Planning (VII SEPOPE)*, Curitiba, Brazil, May 2000, pp. 21–26.
[3] P.-A. Löf, G. Andersson, and D. J. Hill, "Voltage dependent reactive power limits for voltage stability studies," *IEEE Trans. Power Systems*, vol. 10, no. 1, pp. 220–228, Feb. 1995.
[4] S. G. Johansson, "Mitigation of voltage collapse caused by armature current protection," *IEEE Trans. Power Systems*, vol. 14, no. 2, pp. 591–599, May 1999.
[5] A. Murdoch, G. E. Boukarim, B. E. Gott, M. J. D'Antonio, and R. A. Lawson, "Generator overexcitation capability and excitation system limiters," in *Special Technical Session on Maximizing Benefits of Temporary Generator Overexcited Capability, Proceedings of IEEE/PES 2001 Winter Meeting*, Columbus, OH, Jan. 28–Feb. 1, 2001.