



Risk Assessment of Constraint Relaxation Practices

Final Project Report

M-34

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



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Project Team

Kory W. Hedman, Project Leader
Arizona State University

Vijay Vittal
Arizona State University

James McCalley
Iowa State University

Graduate Students

Ahmed Salloum
Jonghwan Kwon
Yousef M. Al-Abdullah
Arizona State University

Xian Guo
Iowa State University

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For information about this project, contact

Kory W. Hedman
Arizona State University
School of Electrical, Computer, and Energy Engineering
P.O. BOX 875706
Tempe, AZ 85287-5706
Phone: 480 965-1276
Fax: 480 965-0745
Email: kory.hedman@asu.edu

Power Systems Engineering Research Center

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For additional information, contact:

Power Systems Engineering Research Center
Arizona State University
527 Engineering Research Center
Tempe, Arizona 85287-5706
Phone: 480-965-1643
Fax: 480-727-2052

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Executive Summary

Today, system operators employ constraint relaxations practices, which allow certain constraints to be relaxed for penalty prices, in their market models. The prior research, PSERC project M-29, investigated the impacts of constraint relaxations on market solutions, reliability, and stability of the system while acknowledging the presence of the out-of-market correction phase that corrects constraint relaxations that occur within dispatch models. This research extends the prior work based on confirmation from industry advisors that these constraint relaxations can and do occur in real-time (i.e., actual) operations. The primary goal of this research is to analyze the impacts of constraint relaxations that propagate into actual operations. The analysis will include reliability analysis, stability analysis, risk-based analysis, as well as market economic analysis.

The report is presented in two parts.

Part I: Analyzing the Impacts of Constraint Relaxations in Real-Time Operations

Part I of the final report on PSERC project M-34 focuses on following concerns raised by industry advisors: 1) treatment of pre-contingency relaxations versus post-contingency relaxations; 2) the impact of constraint relaxations when accounting for probabilities of contingencies; 3) thermal transmission constraint relaxation staircase curve that considers the impact of the duration and magnitude of these relaxations; 4) the effect of operating reserve relaxations on system $N-1$ security. The research shows that:

- Constraint relaxations do occur in real-time operations.
- Relaxations in energy market models have negative effects on real-time system performance in general.
- Pre-contingency (base-case) relaxations encountered voltage violations caused by the limited availability of reactive power as a result of committing fewer generating units in the relaxed cases.
- Post-contingency constraint relaxations are much less likely to appear in the realtime system as line flow violations compared to base-case relaxations.
- Allowing base-case and post-contingency constraint relaxations simultaneously had the largest impact on real-time system performance.
- A risk-based penalty price determination approach that avoids (or limits) relaxing high-risk lines, based on outage frequency and the impact on system operational security, resulted in decreased total relaxations magnitude and reduced voltage violations.
- An online penalty price determination model provides staircase penalty prices for thermal constraint relaxations while accounting for the magnitude and duration of the relaxations simultaneously; the numerical analysis shows that the proposed approach can help system operators to reduce or eliminate the operator's manual intervention to cope with model infeasibility or possible risk on the transmission assets. This also helps reduce the discretionary changes imposed by market operators and provides added transparency for market participants.

- There was no trend or statistical significance in how much the reserve relaxations on system $N-1$ security costs; market solutions with reserve relaxations can have $N-1$ violations not only due to a lack of reserves, but also the approximate nature of the reserve requirement.

Part II: Risked-based Predictive Constraint Relaxation

Volume II of the final report on PSERC project M-34 reviews and investigates insights of industry-based constraint relaxation (CR) practice aligning with security constrained economic dispatch (SCED); it proposes and illustrates the methodology of risk-based predictive constraint relaxation to solve infeasibilities. Volume II summarizes the state of art of industry-based CR practice and statistics of the CR practice, which lays the foundation of this research.

A central concept developed in this volume is that, under conditions of CR, significant system maneuverability is gained through estimation of conductor temperature as flows vary from one market interval to another. This maneuverability occurs as a result of the increased line capacity obtained via the delay in conductor temperature change as flows change; it is safe because the temperature calculations are conservatively computed. The ability to conservatively compute temperature as a function of loading and time is built into the formulation of predictive risk-based constraint relaxation (P-RBCR). P-RBCR minimizes risk and cost during situations when one or more flows are approaching or exceeding what is considered to be their flow limit.

Specifically, this report addresses the following:

- Constraint relaxation practices are observed with high occurrences in real-time operations, both under pre-contingency and post-contingency conditions; we summarize CR statistics from several ISOs to show that CRs usually occur with very high influence on the markets, often causing locational marginal prices (LMPs) to spike.
- Shifting from power flow limits to conductor temperature limits increases dispatching flexibility.
- Use of conductor temperature limits for CR decisions over a specific time interval, i.e., a sequence of 5-minute market solutions, requires the initial temperature and conductor loading for that time-interval
- Risk, as used in this report, is a probabilistic metric quantifying the effects on system security level of heavy circuit loading; it can be applied to both pre- and post-contingency operating conditions; it can be computed using either power flow or conductor temperature.
- The methodology of P-RBCR is free of penalty price; the determination of appropriate penalty price has been a challenging issue facing ISOs, as it results in excessively high operational risk if too low and LMP spikes if too high.
- The CR decisions proposed by P-RBCR are less risky and more cost-efficient than that from the industry-based CR methodology.
- We have illustrated the P-RBCR approach on two systems. The first is a small IEEE test system; it provides conceptual insight into the performance of P-RBCR relative to the method currently employed within the industry. The second is a system developed using

public data to reflect the topology, conditions, and some actual constraint relaxations of the network managed by the New York ISO; this system illustrates the performance of P-RBCR in situations that are reasonable captures of those faced by the market operators of one ISO.

Project Publications:

- [1] Y. Al-Abdullah, M. Abdi-Khorsand, and K. W. Hedman, "Analyzing the impacts of out of-market corrections," *2013 IREP Symposium*, pp. 1-10, Crete, Greece, Aug. 2013.
- [2] Y. M. Al-Abdullah, M. Abdi-Khorsand, and K. W. Hedman, "The role of out-of-market corrections in day-ahead scheduling," *IEEE Transactions on Power Systems*, vol. 30, no. 4, pp. 1937-1946, Jul. 2015.
- [3] Y. M. Al-Abdullah, A. Salloum, K. W. Hedman, and V. Vittal, "Analyzing the impacts of constraint relaxation practices in electric energy markets," *IEEE Transactions on Power Systems*, vol. 31, no. 4, pp. 2566-2577, Oct. 2015.
- [4] X. Guo and J. McCalley, "Risk-based constraint relaxation for security constrained economic dispatch," *North American Power Symposium*, 2015.
- [5] A. Salloum, Y. M. Al-Abdullah, K. W. Hedman, and V. Vittal, "Risk-based penalty price determination procedure for transmission constraint relaxations," *International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*, 2016.
- [6] X. Guo and J. McCalley, "Risk-based constraint relaxation with high penetration of wind resources," *Intelligent System Applications to Power Systems (ISAP) Conference*, 2017.
- [7] J. Kwon and K. W. Hedman, "Offline penalty price determination method for transmission thermal constraint relaxations," *Electric Power Systems Research*, accepted for publication, Aug. 2017.
- [8] X. Guo and J. McCalley, "Risk-based predictive constraint relaxation," *IEEE Transactions on Power Systems*, to be submitted.

Student Theses:

- [1] Yousef M. Al-Abdullah, *Energy Market Transparency: Analyzing the Impacts of Constraint Relaxation and Out-of-Market Correction Practices in Electric Energy Markets*, Ph.D. Dissertation, Arizona State University, Tempe AZ, Mar. 2016.
- [2] Ahmed Salloum, *Impacts of Base-Case and Post-Contingency Constraint Relaxations on Static and Dynamic Operational Security*, Ph.D. Dissertation, Arizona State University, Tempe AZ, Mar. 2016.
- [3] Jonghwan Kwon, *Performance Enhancement of Power System Operation and Planning through Advanced Advisory Mechanisms*, Ph.D. Dissertation, Arizona State University, Tempe AZ, expected in Nov. 2017.
- [4] Xian Guo, *Constraint Relaxation and Cascading Contingency Monitoring: A Risk-Based Approach*, Ph.D. Dissertation, Iowa State University, Ames IA, expected in Dec. 2017.