PSERC

Preventing Voltage Collapse with Protection Systems that Incorporate Optimal Reactive Power Control

Final Project Report

Power Systems Engineering Research Center

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Project Team

Venkataramana Ajjarapu, Project Leader, Iowa State University
A.P. Sakis Meliopoulos, Georgia Institute of Technology

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Information about this project

For information about this project contact:

Venkataramana Ajjarapu
Department of Electrical and Computer Engineering
Iowa State University
Ames, IA 50010
Tel: 515-294-7687
Fax: 515-294-4263
Email: vajjarap@iastate.edu

Power Systems Engineering Research Center

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For additional information, contact:

Power Systems Engineering Research Center
Arizona State University
577 Engineering Research Center
Box 878606
Tempe, AZ 85287-8606
Phone: 480-965-1643
Fax: 480-965-0745

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Executive Summary

In recent years, new attention has been given to system disturbances that have cascaded due to voltage instabilities and to unwanted relay operations. Unwanted relay operations due to voltage instabilities and transients have not been well understood. In this project, voltage instability phenomena were studied to develop a comprehensive approach for mitigating the effects of voltage transients and instabilities on designed operation of a protection system. The comprehensive framework covers monitoring, predicting, and assessing system performance for secure power system operation. The developed framework and methodology provide advanced tools use optimal control strategies that can be used to avoid voltage collapse with respect to system-wide voltage instability and undesired protection system operations. The project's specific objectives were:

- to develop realistic models that accurately model voltage dynamics and their effects on protective schemes
- to develop fast and flexible schemes for assessment of voltage stability and relay status
- to develop optimal strategies to prevent voltage instability and maintain adequate relay margins.

The project objectives were accomplished in two integrated steps.

1. Optimal Strategies to Maintain Adequate Voltage Stability and Relay Margins (Volume I)

In this step of the project, we identified schemes for fast and flexible assessment of voltage stability and relay status. Then we developed optimal strategies for maintaining adequate voltage stability and relay margins.

Voltage stability margin (VSM) assessment for online monitoring is a challenging problem computationally. We developed a predictor and corrector based framework to estimate VSM at local buses. The framework applies a Thevein Equivalent method as a predictor to approximate the maximum power that can be transferred. Since Thevein Equivalent is a linear approximation, it cannot consider system operational constraints which cause the VSM estimate by the predictor to be too optimistic. This optimistic estimate especially occurs when the load level is far away from the maximum loading point. We applied a corrector to adjust the predicted VSM to a more realistic value.

The new predictor and corrector based approach can address "what if" questions in an online environment. For example, from the present operating condition, the approach can predict the future margin under various contingencies and scenarios. To assess the effects on the protection system, the relay margin is applied to determine the intended relay status and identify critical relays after contingencies. According to the operating criteria for post-contingency security, the voltage stability margin and relay margin should be maintained at adequate levels. An optimal reactive power control scheme is developed to prevent voltage instability and relay margin violations. Operators can use this information for possible control actions against voltage instability. We tested our approach on a New England 39-bus system. We simulated various contingencies and scenarios. The predictor

and corrector based VSM estimation was very fast and accurate. Based on the relay margin of each relay, critical relays were identified in the test system under several different operating conditions. By performing the optimal reactive power control after contingencies, the system voltage profile, the voltage stability margin at load buses, and the relay margins were improved to insure that system operating criteria were met after any of the contingencies.

Our research provides a proof of concept of the proposed framework. In future work we can test the developed tools on a large utility system. With the above framework, we used existing control sources to maintain relevant margins. In future work, we can identify where and how much supply of additional control sources would be needed when the existing control sources are not adequate to meet system operating criteria.

2. Incorporating Relays in a Power System Model with Dynamic Loads for Voltage Transient and Stability Analyses (Volume II)

Relay operation due to transient voltage phenomena is unneeded if the voltage transient is stable and the system will eventually return to normal voltages. If relay operation did happen in these cases it will deteriorate system conditions and may result in a cascading series of relay operations and eventual system collapse. Therefore relay operation must be inhibited if the voltage transient represents a stable event.

In the second step of this project, we studied the impact of voltage transients and voltage instabilities with an integrated power system simulation model that explicitly represents the load dynamics (mainly motor loads) and the dynamics of reactive power sources. Examples of reactive power sources include generators, over and under exciter limiters, and static VAR sources. The power system model was augmented with relay models. Two specific relays were modeled: (a) overcurrent relays and (b) distance relays.

Two test systems were developed to demonstrate use the augmented simulation model for analysis of voltage instabilities and protective systems. The results illustrated that voltage instabilities during recovery from disturbances can cause excessive current flows that may affect the operation of overcurrent relays and of the impedance seen by distance relays. Distance relays are especially vulnerable to mis-operation because these phenomena exhibit simultaneously low voltages and high currents creating the possibility of load encroachment. The level of these phenomena is dependent upon the specific circuit parameters, and the type and amount of dynamic loads. As a result, it is difficult to develop general guidelines for predicting the level and impact of these phenomena.

Based on these results, we conclude that the proper way to apply the proposed methodology is to study specific systems that are heavily loaded with motor type loads. The prototype power system simulation model has the capability to model a limited number of relays since the objective of the project was to simply demonstrate the feasibility of the approach. To achieve the capability of modeling and comprehensively studying the response of a system, we recommend that the developed methodology be augmented with a full set of relays and further developed into a commercial grade computer program.