6.14 Detection, Prevention and Mitigation of Cascading Events (S-19)

Summary	This project will investigate novel approaches using new technologies to provide effective control of cascading disturbances and to enhance reliability. When a power system is subjected to large disturbances, and the vulnerability analysis indicates that the system is approaching a potential catastrophic failure, control actions need to be taken to steer the system away from severe consequences, and to limit the extent of the disturbance. We are approaching the problem in three steps: 1. Detection of major disturbances and protective relay operations leading to cascading events. 2. Wide area measurement based remedial action. 3. Adaptive islanding with selective underfrequency load shedding.
Research Need:	Enhanced reliability of interconnected power systems and prevention of cascading outages
Research Stem	Systems
Academic Team Members	Vijay Vittal (Iowa State University-lead: vittal@ee.iastate.edu, 515-294-8963) Mladen Kezunovic (Texas A&M) and Mani Venkatasubramanian (Washington State)
Industry Team Members	Hydro Quebec, IREQ (Innocent Kamwa) MidAmerican Energy (Miodrag Djukanovic) Entergy (Sharma Kolluri)
Funding Period	June 1, 2002 to June 30, 2005
Budget	Vittal: $30,000; Kezunovic: $25,000; Venkatasubramanian: $25,000. Total: $80,000 per year for three years (2002-2004).

Project Description: With the advent of deregulation and restructuring power systems are increasingly being operated close to their limits. As the system become more stressed, weak connections, unexpected events, hidden failures in protection system, human errors, and a host of other reasons may cause the system to lose stability and even lead to catastrophic failure. When power system is subjected to large disturbances, and the vulnerability analysis indicates that the system is approaching a potential catastrophic failure, control actions need to be taken to steer the system away from severe consequences, and to limit the extent of the disturbance. We will approach the problem in three steps:

1. Detection of Major Disturbances and Protective Relay Operations Leading to Cascading Events.
2. Wide Area Measurement Based Remedial action.
3. Adaptive Islanding with selective underfrequency load shedding

Potential Industry Benefits: This project combines aspects from both the T&D stem and the Systems stem. It examines novel concepts in monitoring disturbances and failures in protection system operation. This analysis is then translated into a predictive assessment tool that can tell if the events are unfolding according to a viable course of protection action. If the course of protective relaying and related switching action is different and increases the system vulnerability, wide area measurement based control will be used to provide corrective action. If the corrective action fails, adaptive islanding will be invoked to break up the system into sustainable islands.

This project will provide member companies a view into the future where novel aspects from different technologies can be combined to provide effective control of cascading disturbances and enhance reliability.

Expected Outcomes:

1. Modeling and simulation tools that will incorporate disturbance monitoring and the interface with the relay modeling.
2. Strategies for wide area measurement based corrective control.
3. Development of a tool for adaptive islanding with generation shedding.

Technical Approach:

The approach used is a combination of advanced technologies, novel algorithms and refined fundamental concepts. The advanced technology involves the use of digital relays, wide area measurement systems, and fast power flow controllers. The novel algorithms to be developed are related to real-time fault location, neural network pattern classifiers, and predictive remedial action schemes. The fundamental concepts that will be revisited are the system-wide relaying, special protection solutions, transient and small signal stability analysis, and slow coherency grouping method. The following three study steps will be undertaken.

1. Detection of Major Disturbances and Protective Relay Operations Leading to Cascading Events

This task will be aimed at analyzing system disturbances and determining the ones that may cause relay operations leading to cascading events. This will be accomplished by implementing new approaches to automated fault analysis and developing the models of protective relaying schemes that may be used as a reference for real-time evaluation of the actions of existing protective relays. A combination of a neural network (NN) disturbance classifier and synchronized sampling (SS) fault locator will be developed to facilitate the analysis. The NN classifier will be used to detect and classify the disturbances that require protective relay action. The SS fault locator will use the output of the classifier to compute a very precise fault location for the selected transmission line of interest. Knowing that the fault has indeed occurred, being able to classify its type reliably, and having a precise fault location computed helps in confirming the security and dependability of operation of the existing relays. Once the reference of the expected protective relay operation is established in real-time, one can compare the operation that has taken place in the system and conclude if the switching actions aimed at containing the disturbance are appropriately taken. This leads to another evaluation step where the actions taken are compared to the ones that may have been taken if the relay operation was based on the more accurate assessment. Both inputs may be fed to the transient stability program to evaluate impact of the two scenarios. Once the transient stability evaluation indicates that the existing course of action may lead to instability, the alternative scenario is established as a reference for what has gone wrong in the actions taken and what may be the corrective actions needed. This process establishes a predictive assessment tool that can tell if the events are unfolding according to a viable course of protection action. If the course of protective relaying and related switching action is different then what is desirable and increases the system vulnerability, a conclusion about the initiation of an undesirable cascading event is reached.

A set of modeling and simulation tools that will allow evaluation of the concepts proposed will also be developed. Software for modeling of power system transients will be utilized for an assessment of relay operations. This software will be interfaced to the accurate relay models reflecting the interaction between the power system disturbances and switching actions initiated by the relays. This simulation arrangement will be used to establish the initial and consecutive protective relay operations leading to a cascading event. The outcomes of this simulation will be feed in an appropriate sequence to the transient stability program to assess the impact of the events on the system stability. A vulnerability analysis will be performed assigning the probability indices to the various scenarios of protective relay operations or misoperations. This outcome will serve as a guide for selecting realistic contingencies for the next analysis step where the appropriate controls for containing the cascading events and preserving the system stability are selected. Once the appropriate controls are defined, this simulation environment may be used to evaluate the effectiveness of the proposed solutions.

2. Wide Area Measurement Based Corrective Control

The evolution of large disturbances can be controlled effectively by coordinating the control responses over a wide-area network. Emergence of wide-area monitoring technology and real-time control infrastructures pave the way for implementation of fast remedial real-time controls which will shape the system response when the vulnerability analysis in Step 1) points to a potential black-out scenario. Potential remedial actions include a) generation tripping, b) mode switching of thyristor controls such as HVDC, SVC and TCSC, c) fast switching actions of series and shunt capacitor banks, and d) tripping of interruptible load. In the present day power system, there exists a complex set of remedial action schemes (RMS), each targeted towards mitigating one large disturbance. In the deregulated operating environment, with the diverse power-flow scenarios that are expected, maintaining these individualistic RMS schemes is becoming a challenging task. Therefore, it looks reasonable to look into alternate coordinated remedial controls, which evolve during the disturbance event by analyzing the actual system response from a wide-area monitoring scheme.

For instance, damping levels of inter-tie active power-flows can be used to identify potential small-signal instabilities. In the unlikely event of growing oscillations, a set of thyristor devices such as SVC's and possibly the exciters of critical generating plants can be switched from voltage regulation mode to a small-signal stability mode for aggressively damping out the oscillations in a coordinated fashion. The damping controllers should not weaken any other interarea mode while providing damping enhancement for a specific interarea mode and coordination of the devices will play a significant role in designing the small-signal stability controllers. Insertion and/or switching out of series and shunt capacitor banks can also be tuned with the power swing to provide damping benefits.

Similarly, unusually large fluctuations of inter-tie bus voltages or active power-flow levels can indicate large transient stability events including remote disturbances in neighboring areas. A set of emergency control actions including generation tripping, interruptible load tripping and shunt/series capacitor switching can be triggered by monitoring the tie-line flows and phase angle variations across the network. The response time of the control actions is highly critical for the transient stability controls relative to the small-signal stability controls. Control decisions have to be made within the first half swing of the disturbance to be effective. There are delays associated with the communication network for monitoring of the area wide system response and for conveying the control actions to the different devices There are also delays in carrying out tripping or switching actions by the relays on generators, loads and capacitor banks.
These delays inherently slow down the effectiveness of the control actions. Also, the emergency controls must be designed so that they do not respond to normal fault scenarios on transmission network during the fault-on periods. Therefore, they need to be carefully coordinated with the protective equipment as well.

In summary, the task will keep the primary focus on detection and mitigation of disturbances that result in small-signal instability of interarea modes by coordinated control actions. The project will also carry out preliminary studies on emergency control actions for transient stability enhancement by a) classification of the severity of the disturbance from monitoring of the tie-line flows and phase angle deviations and b) design of appropriate control actions such as generation tripping and load interruption for steering the system response towards transient stability.

3. Adaptive Islanding and Controlled Load Shedding

When the fast coordinated control actions in Step 2) fail to steer the system away from a break-up, as a last resort, we will adaptively break up the system into smaller islands at a slightly reduced capacity, but with the added advantage that the system can be restored very quickly. This is then followed-up with carefully designed load shedding schemes based on rate of frequency change. As a result, we limit the extent of the damage, and are able to restore the system rapidly. We refer to this corrective control scheme as adaptive controlled islanding followed by load shedding based on rate of change of frequency decline.

A critical issue in this approach is to determine where to form the islands. In order to form the islands the machines that will be grouped in islands will have to swing together. In our approach, a two time-scale method based on slow coherency together with the consideration of certain key factors is used to determine the islands. In this method, the structural characteristics of the system are analyzed to determine the interactions of the various generators to find the strong and weak couplings. The system state variables of an nth order system are divided into r slow states and n-r fast states. Thereafter, with a series of transformation and a grouping algorithm, we can determine the r groups of generators with slow coherency. The slow coherency based grouping method has the following explicit advantages:

- Slow coherency is independent of initial condition and disturbance.
- The two-time scale weak connection form best describes the oscillation feature of the large-scale power system: the fast oscillation within the group and the slow oscillation between the groups via weak tie lines.
- It also preserves the features of the coherency-based grouping. That is, independent of the size of the disturbance and the generator model detail.

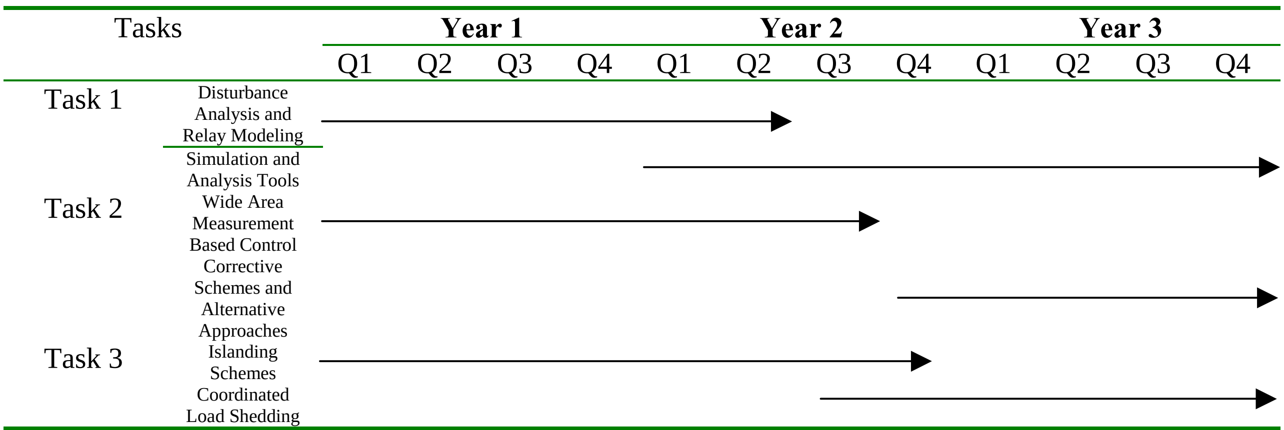
Appropriate software is available to perform the slow coherency based grouping and determine the inherent machine groupings. In order to determine the exact boundaries of the islands, we will develop an approach to automatically identify the cut sets on the interface network between two islands and then choose the optimum cut sets. We will apply a set of criteria in determining the boundary of the islands:

- Generation load imbalance consideration. We need to minimize the generation load imbalance in each island. The reduction of the imbalance reduces the amount of the load shedding once the islands are formed. And it also makes it easier for each island to be capable of matching the generation and load within prescribed frequency limits and facilitates restoration.
- Topological requirements. This would require the analysis of the branch data to determine the lines that need to be disconnected in order to form islands. Tie lines or EHV lines will act as the monitored lines in practice. But the relatively lower voltage lines, such as 230kv lines, can also be monitored to be the remote tripping subjects.
- Restoration considerations. Each island has to have the black start capability that is sufficient for critical equipment. Each island has to have proper voltage control capability to maintain a suitable voltage profile. Each island must be capable of being monitored by the control center for security checks and coordination. Synchronizing devices need to be available near the boundary of the islands for re-closing the circuit and restoration function.

In order to issue islanding command in time, we will deploy BPA's R-Rdot out of step relay to detect the out of step condition and initiate tripping, even remote tripping for cooperative operation. The relay only requires local measurements and satisfies our need for a decentralized solution to catastrophic events. Currently this type of relay has been updated in combination with the decision tree method using phasor measurement.

Finally, we will develop a load-shedding scheme considering both the conventional under frequency load shedding and shedding based on the rate of frequency decline, after careful investigation of the NPCC criteria and former experiences.

Work Plan:



Related Work: The three investigators have done substantial work in specific areas related to this project under support from NSF, BPA, WAPA, NASA, and EPRI. This project extends this work in new directions and integrates interests from two Stem areas. This work also complements the activities in CERTS related to real time control. In terms of hidden failures and relay modeling this work builds upon the previous efforts of Jim Thorp supported by PSERC.

How this Work Differs from Related Work: This project differs form the other efforts in this area in terms of the novel approaches considered in integrating disturbance analysis and relay modeling to judge vulnerability, use of wide area measurements to activate and coordinate corrective control, and as a last resort use of adaptive relaying coupled with a new scheme to shed load.

6.14.1 Project Status

Status as Reported for the May 2002 IAB Meeting

Work progress since the report for the December 2001 IAB meeting
This is a new PSERC project that will start only in June 2002. A student who will work on this project has been identified and has started work at Iowa State University. This student is currently being funded by funds available at Iowa State University.

A student has started working on the project at Washington State University. He is from Columbia and is currently funded by a Fulbright scholarship.

Two students will be working on this project at Texas A&M university.

Description of work activities and anticipated project outcomes/deliverables by each project team member during next reporting period
As given in the workplan.

Description of and reasons for any revisions to the workplan that was reported for the December 2001 IAB Meeting
No changes.

Students working on the project during the next reporting period
Xiaoming Wang, msamwang@iastate.edu
Jaime Quintero, jquinter@eecs.wsu.edu.
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6.14.2 Project-Related Documents

Work on this project is just beginning

Click here to return to the Project Overviews