Preventing Future Blackouts by Means of Enhanced Control: From Complexity to Order

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This talk is partially based on the
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Talk overview

- Motivation for revisiting the role of control in large-scale electric power systems;
- Some basic observations concerning control;
- Review of the sequence of events during a typical blackout; the role of control;
- Illustration on the NPCC equivalent system;
- A proposal to enhance current practice;
- Cost and benefits related to control;
- Conclusions.

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Motivation for revisiting the role of control

- Today's monitoring and control largely effective during normal operations;
- The impact of new monitoring and control equipment should be understood prior to installing it;
- It may be possible to use systematic control to manage the system over broad range of conditions (loading patterns and/or equipment status)

Some basic observations concerning control

- A closed-loop system response to the triggering event is very much dependent on the type of controllers and their coordination in the system as a whole
- Illustrations on the NPCC equivalent system later in this talk [1].
- CURRENT CONTROL IS NOT DESIGNED FOR GUARANTEED PERFORMANCE.

Basic issues with current control

- Primary controllers tuned for the assumed conditions in the rest of the system;
- As system conditions vary, the controllers could “malfunction” in a variety of ways (ranging from wrong logic, through being too slow and/or of insufficient capacity; lack of coordination) [2];
- Consequently, hard to ensure system-wide performance;
- Consequently, general tendency not to rely on control outside normal regions; missed opportunities to operate efficiently.
- A methodology is needed for SEAMLESS management of the system across a broad range of conditions.

Assumptions underlying successful hierarchical control [1,2]

- Each control area schedules its own resources to meet forecast load and scheduled exchanges with neighbors;
- There exists a multi-control area power flow solution for the scheduled net tie-line flows
- Sufficient voltage support;
- Slow deviations around forecast can be regulated by each control area in a decentralized way (using AGC, for example);
- Primary controllers stabilize fast dynamics locally.

Conjectured problems: During a blackout some (or all) of the hierarchical control assumptions are violated

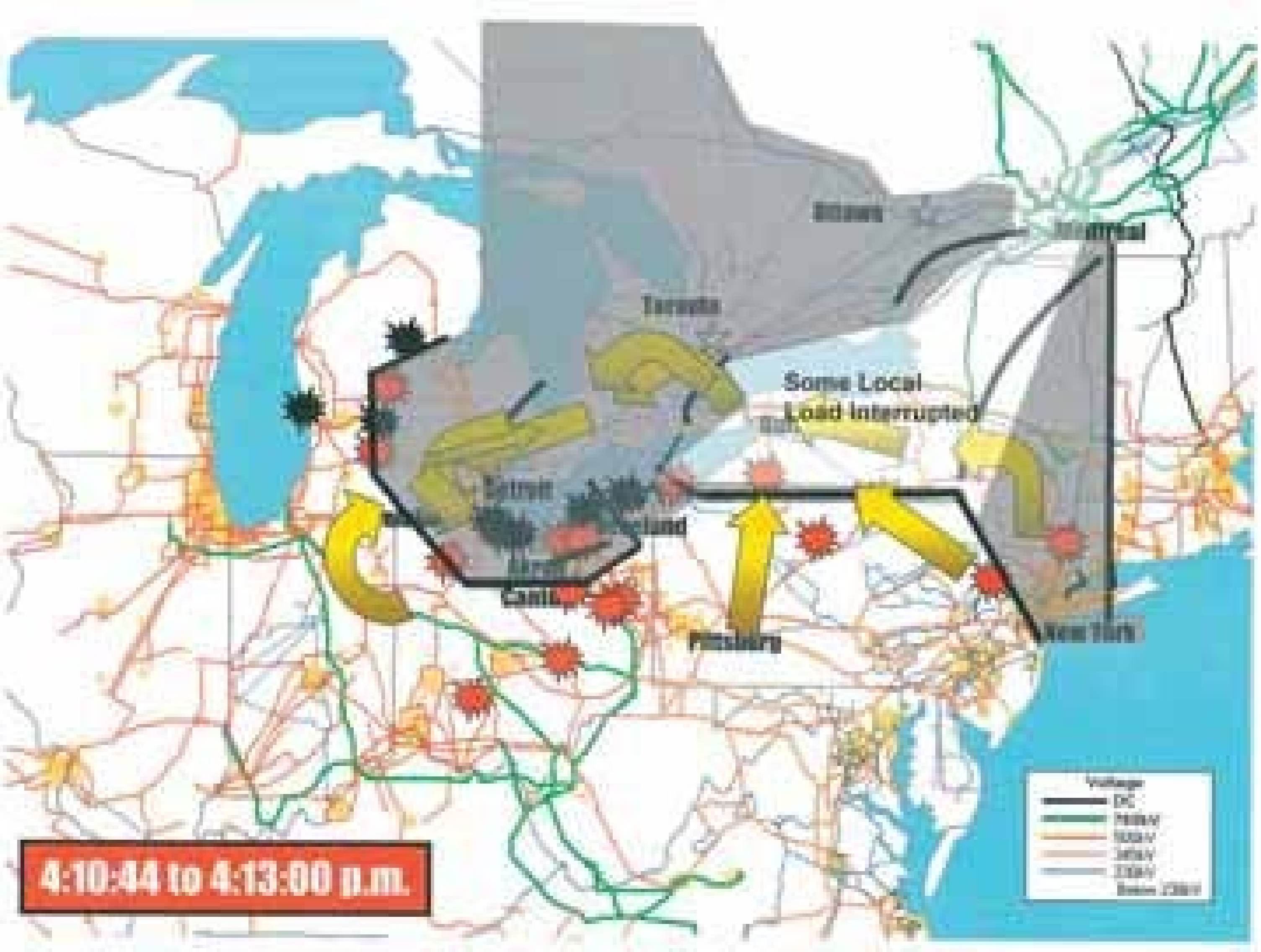
- Unless a CA knows about the outage in the other CAs, it continues the same schedules;
- Because of the loop-flows during the blackouts the net tie line schedules greatly change, but individual control areas do not adjust;
- Large loop flows generally cause voltage drops;
- Without rescheduling (more generally, adjustment of control settings of various types, on the system, power plants and users) there may not be enough resources to solve power flow.

Typical sequence of events during a blackout

- A piece of equipment disconnects in one control area (CA);
- This causes violations of limits on other pieces of equipment (in the affected and/or other CAs);
- Protection disconnects the affected equipment
- This further creates power imbalances/overflows/frequency deviations/insufficient voltage support (in the CA where the initial event occurred and/or throughout the interconnection);
- These are seen in slow inter-area oscillations and, ultimately loss of synchronism

Illustration on the NPCC equivalent system [3]

- An example of A DYNAMIC problem: A line carrying large power is tripped. This results in low frequency inter-area oscillations with common controllers; low frequency voltage oscillations.
- An example of STEADY-STATE FEASIBILITY problems during increased transfers (from PJM, through NYISO into IESO).



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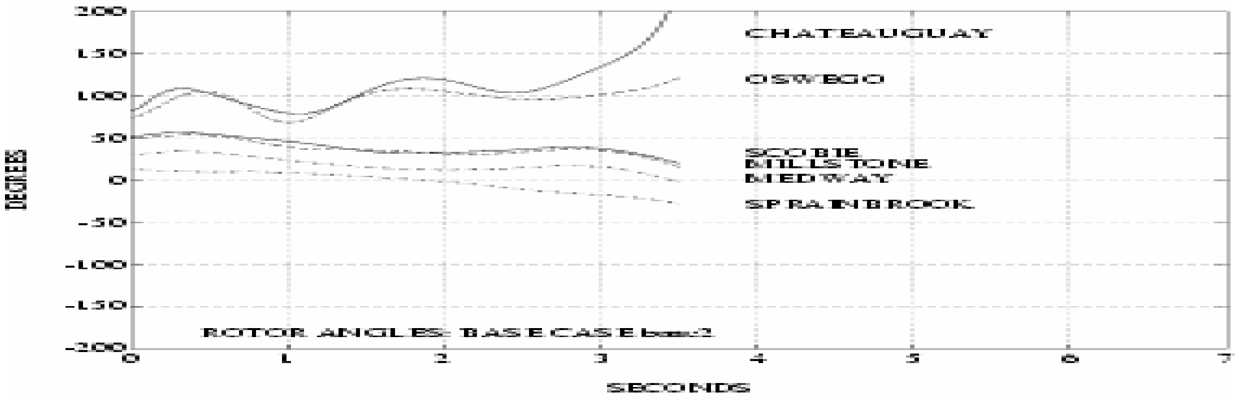
Possible role of enhanced control during abnormal conditions

- Adjust logic of primary controllers to avoid instability problems;
- Systematic coordination of the remaining resources to prevent steady-state imbalances and additional congestion (adjust settings on voltage support equipment, adjust power generated to avoid imbalances)

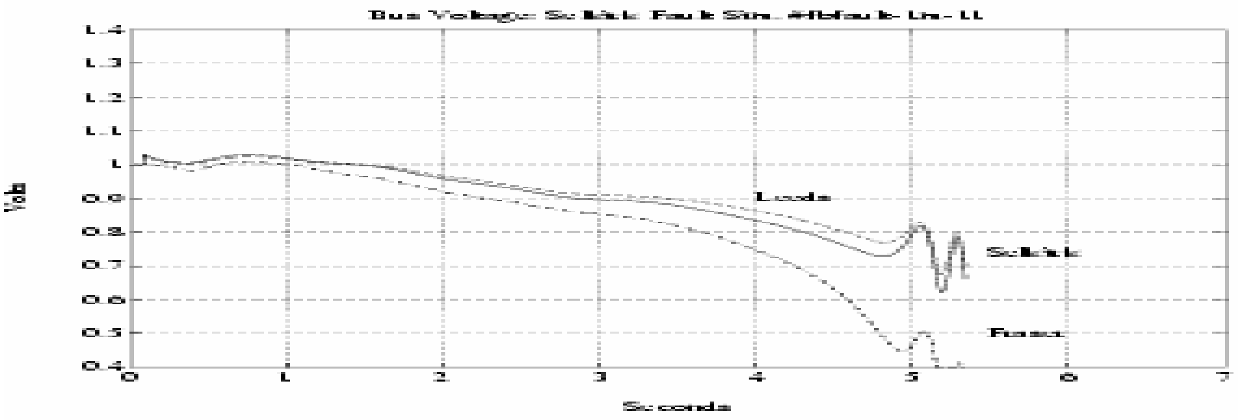
Potential of novel stabilizing controllers for preserving system integrity [1,4]

- A 38-bus, 29 machine equivalent dynamic model of the NPCC system
- It was shown to reproduce a multi-machine oscillation that occurred at .75Hz, involving groups of machines in NYC (modeled as Sprainbrook generator) and the northeastern part of New York State, as well as parts of Canadian power system (modelled primarily by the Oswego and Chateaguay units);
- The fault scenario selected for this test was a five-cycle three-phase short circuit of the Selkrik/Oswego transmission line carrying 1083MW. The oscillation grows until the Chateaguay generator loses synchronism, followed shortly by the Oswego unit.

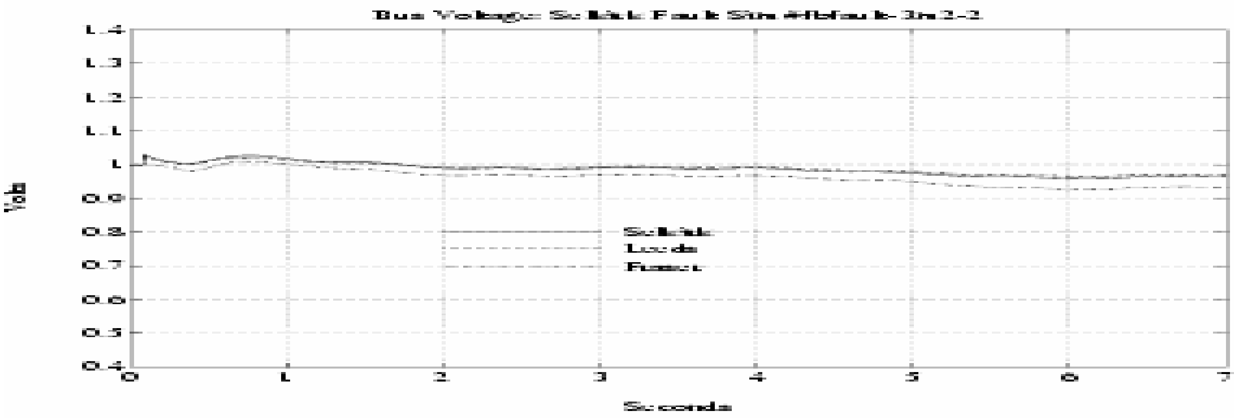
Rotor angles -- base case for Selkrik fault



Voltage response with conventional controllers-base case Selkrik fault



Bus voltages with new controllers [4,6]



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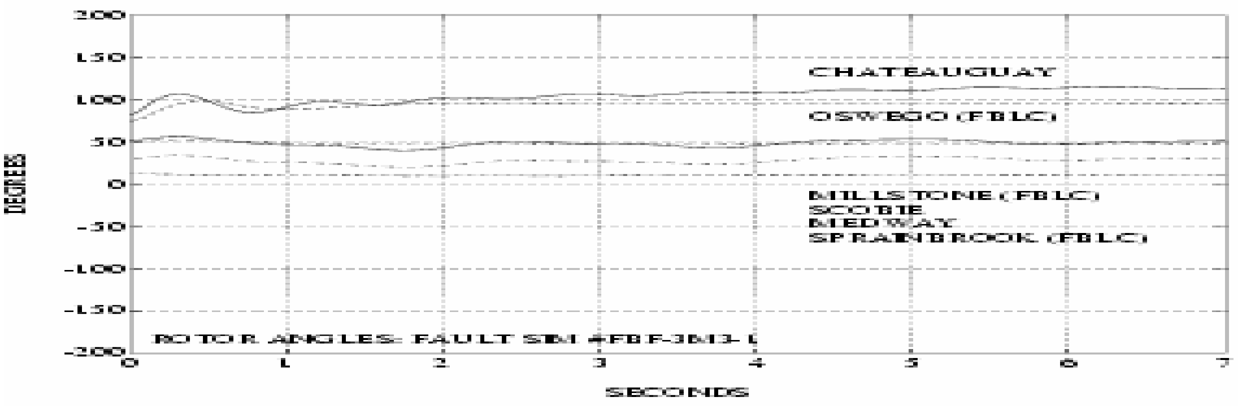
Rotor angle response with the new controllers (FBLC+ODSS) [4,6]



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Summary of potential of FBLC+ ODSS controllers

- It is possible that these controllers could avoid loss of synchronism while the conventional controllers can not
- It also was shown that the same controllers are ideal for preventing sub-synchronous resonance [7]
- Therefore critical to consider while designing SPS of the future
- No fast communications required. Therefore simple to implement.

Possible ways of adapting primary controllers

- More adaptive decentralized controllers (various nonlinear high-gain controllers—sliding mode control; feedback-linearizing control (FBLC); observation decoupled state space combined with FBLC logic)
- A combination of coordinating signals and change of logic (coordinating signals identifying when the system response is qualitatively different and it requires change in control logic in order to stabilize dynamics)
- NONE OF THE CURRENTLY IMPLEMENTED CONTROLLERS ARE CURRENTLY AFDAPTIVE except the multi-modal Hydro-Quebec PSS)

Dependence of feasible interconnection transfer on scheduling practices

- Base case for the given NPCC system in 2002 and the 2007 projected load [3]
- Case #1-the same, except the entire real power generation was re-scheduled in order to support an increased wheel from PJM (Alburtis) through NYISO to IESO (Milton) –the maximum feasible wheel 1,200MW
- Case #2-the wheel from PJM (Waldwick) through NYISO to IESO (Milton) –the maximum wheel feasible 100MW
- NOT SUFFICIENT TO ONLY SPECIFY NET TIE LINE FLOWS

Effects of voltage scheduling in support of higher power transfers [5]

- With the voltage scheduling optimized within +/- .03pu range, w/o any real power rescheduling the maximum power transfer increased to 2,900MW into both Alburtis and Waldwick;
- With the voltage scheduling optimized within +/- .05pu the feasible transfer increased to 3,100MW at boht Alburtis and Waldwick.
- With both voltages optimized within +/-.05pu and real power re-scheduled by the NYISO, the maximum wheel possible around 8,800MW
- CLEARLY VOLTAGE RELATED PROBLEMS;
- THESE ARE ILLUSTRATIVE EXAMPLES, ON THE EQUIVALENT SYSTEM. MORE DETAILED REPRESENTATION OF PJM MAY REQUIRE THE REDUCTION OF FEASIBLE WHEELS.

Effects of Phase Angle Regulators (PARs) scheduling of the tie-lines between the control areas [5]

- Case #1—with PARs scheduling within their maximum capacity limits, wheel of 8,800MW possible by using real power generation only.
- Case #2—with PARs , the maximum wheel into Waldwick without re-scheduling real power inside NYISO is 500MW (a 400MW increase)
- PARs HAVE HUGE EFFECTS ON FEASIBLE TRANSFERS ACROSS CONTROL AREAS.
- MAKING THESE MOST OPTIMAL AT THE INTERCONNECTION LEVEL REQUIRES ON-LINE COORDINATION ACROSS THE CONTROL AREAS.

Summary of the potential for on-line coordination for increased feasible power transfers across CAs

- It is not sufficient to run power flows and contingency screening for the assumed net power exchange with the neighbors;
- A multi-layered coordination of the interconnection is essential for making the most out of the available resources w/o making it too complex (getting rid of CAs is not an automatic solution; as a matter of fact it is not even desired because of huge monitoring and decision making complexity).

A proposal for multi-layered management of a large multi-CA interconnection [1]

- It is essential to create a tertiary layer for monitoring tie-line flows and regulating these according to the well-defined interconnection criteria (this is important for 1) ensuring feasible scheduling of power exchanges; 2) communicating change of major equipment status; 3) preventing slow inter-area oscillations; and 4) implementing open access for economic reasons w/o endangering system reliability;
- At the same time, the design must be done so that each layer keeps its decentralized, autonomous decision making, while coordinating with the higher layers.

Conclusions: Some difficult R&D questions

- Choice of performance criteria for various layers (trade-offs between reliability margins and economic efficiency);
- Minimal information structure between the layers to guarantee that the performance criteria are met;
- Limits to decentralization of primary controllers (smart, adaptive decentralized gadgets and/or fast communications).
- In [1] one possible vision introduced, but this is not the only one. On-going work, would like to involve interested industry.
- TRADEOFFS BETWEEN COMPLEXITY AND PERFORMANCE.

Conclusions: Cost and benefits related to system control

- This question needs to be addressed as the industry structure evolves;
- Possible to make the case that the entire interconnection would benefit (measured in terms of whatever criteria chosen, such as total generation cost; enhanced reliability);
- A multi-layered approach would allow for moving toward interactive decision making for establishing tradeoffs between sub-objectives of individual stake-holders (or CAs) and the system as a whole.
- More work is needed; yet, it is straightforward to show that generally less reserve is needed with more effective on-line control. The cumulative cost of reserves is easily lower than the estimated benefits.

Key references:

- [1] Ilic, M.,Allen, E., Chapman, J., King, C., Lang, J., Litvinov, E., Preventing Future Blackouts by Means of Enhanced Electric Power Systems Control: From Complexity to Order, IEEE Proc, Nov 2005.
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- [6] M.D. Ilic and J.W. Chapman, "Decentralized Excitation Control for an Electrical Power Utility System," U.S. patent number 5 483 147, 1996.
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