August 14: A Broader Perspective

Comments Submitted to the DOE Blackout Forum Dec 15, 2003

The Interim Report addresses the obvious causes and contributing factors of the August 14 blackout. However, a broader perspective of the 8/14 event and other recent events and near misses reveals some insidious problems that while not dominant causes on 8/14, may have contributed and may be increasing the likelihood of future similar events.

The Eastern Interconnection has changed from a relatively sparse mesh to a relatively dense one as transmission lines have been added to reduce constraints. As the density of the mesh has increased, the loading on all lines has increased. As each new line has been added, the loading on lines upstream and downstream of the new line as well as on parallel paths and lines has increased.

Likewise, phase angle regulators, series capacitors (in the west) and (occasionally) series reactors have been added to control line loadings in congested areas thereby allowing higher loadings over large areas. Shunt capacitors have been added to support the higher loading. The flexibility in placement of gas fired generating plants have allowed them to be placed where existing grid capacity is available, thereby increasing the loading on lines that previously provided margin.

This gradual increase in grid loading has had the deleterious effects outlined below.

- Multiple marginal N-1 Events increase risk of blackouts. At one time one most-severe N-1 contingency limited transfers in accordance with criteria. Likewise, that N-1 pushed one other element to its loading limit. Today, and increasingly, there are multiple contingencies with significant impacts, and for each one, multiple lines are pushed close to thermal limits. The result is a much greater risk of overload cascading, triggering latent failures, and voltage collapse.

- Higher stress on equipment and greater risk of triggering latent failures. N-1 events are increasingly likely to trigger latent failures and thereby lead to cascading. For instance, a mis-set protective relay or a relay with the proverbial bent contact is more likely to "nuisance" trip in response to a contingency elsewhere on the grid. Similarly, with lines at higher temperatures, they sit closer to sag limits with higher risk of tree contact and tree contact occurs more quickly following a contingency.

- Greater sensitivity to routine scheduled and forced outages. While routine scheduled outages and minor forced outages may not cause violations of criteria, they do add stress and reduce margins to an extent that is unrecognized. Studies following the two 1996 Western Interconnection events showed that at any given time there were 23 significant routine outages in the Northwest and that they reduced reactive reserves by as much as 200 Mvar. Operating studies do not usually consider these random outages and therefore overstate the robustness of the grid.

- Higher Reactive Losses and higher risk of voltage problems. New lines increase loading widely and the higher loading puts all affected lines higher on their reactive loss curves. The result is higher reactive losses under normal conditions, and a much greater increase in reactive losses during contingencies. This creeping growth in reactive requirements regularly outpaces planners efforts to meet reactive demands. It also increases the number of troublesome voltage contingencies and those contingencies increasingly involve combinations of routine and seemingly innocuous line, transformer, and generator outages. The result is an increasing risk of voltage problems.

- Greater difficulty in judging criteria adherence. Today's highly meshed and heavily loaded grid makes application of operating criteria a tedious task. Operations planning studies often fail to reveal violations. This is particularly true for voltage security where it is very difficult to identify the most troublesome contingencies. While most violations never come to light, post-outage studies showed the Northwest was operating outside of criteria on August 10, 1996.

- An increasingly difficult operator job. With many lines operating near continuous ratings and many close to or at emergency ratings following a contingency, operators have a more difficult time managing the grid and can more easily fail to address a contingency in a timely manner or can make mistakes that cause or contribute to an event. Contingencies impact larger areas and neighboring operators may be unaware that events on their own system will now have greater consequences.

- Non-grid elements are affected. For instance, a state estimator may fail to converge on a heavily stressed system after one or more contingencies have occurred.

The widespread higher loadings are compounded by Increasingly onerous load characteristics. Load characteristics have changed greatly over the last 20 to 30 years. Many existing load types such as lighting have changed from $P=V^{1.5}$ (incandescent) or $P=V^{1.0}$ (discharge lighting) to constant power (solid state ballasts, high efficiency lighting, etc). Switch mode power supplies now serve computers and many other devices (TVs) and impose a constant power load on the grid. Heat pumps and A/C now make up more of the load and are subject to stalling. All of the changes are in a direction that degrades system performance in several respects including aggravating reactive shortages and increasing the likelihood of cascading.

The greater grid mesh density, compounded by onerous load characteristics has rendered out-of-step block and trip protection ineffective. Out-of-step block and trip protection was fairly effective when interconnections were few and long (the 1950's, the 1960's and into the 1970's). Today our widely interconnected systems do not behave as simply as the two-machine models on which out-of-step protection theory and settings are based. Stalling motors can defeat out-of-step block and trip protection. Today it is difficult to spot out-of-step block and trip protection so that it captures instability and where out-of-step block and trip protection is applied, it's successful operation is largely luck.

The reader will recognize some of the above as issues germane to 8/14. A look at many grid events from the last five to ten years will show that all of the above are emerging hazards.

Solutions?

Solving the problems of wide-spread high loadings and difficult load characteristics will not be easy. I don't profess to have all the answers, but the following thoughts come to mind.

- Enforcement of present criteria will help little. Today's criteria are based on experience that predates today's grid and are in need of a major overhaul. Tools to implement probabilistic criteria have long been available and should be applied. Criteria must compensate for the effects of higher loadings and more onerous load characteristics and include the effects of routine outages.

- Adding transmission may not help. New transmission may simply allow grid loadings to increase and compound the problems listed above. New regional transmission may simply facilitate larger blackouts. Only if transmission is added to reduce loadings will it improve reliability.

- Latent failures and sag limits demand attention. Line monitoring may help with the sag problem but may also allow higher loadings under today's criteria thereby exacerbating other problems. Latent failures demand unprecedented attention to detail during maintenance.

- New technologies such as FACTS may reduce already thin margins as well as further complicate an already too complex system and lead to more complex behavior that can befuddle operators.

- Protection to deal with cascading simply does not exist and is not on the horizon. Wide Area Protection and Control may eventually help but is many years away. An interim solution is urgently needed.

- Segmentation of the AC grid by HVDC (back-to-back and line conversions) has been discussed since the early 80's and its time may have come. It would solve some of the consequences of higher grid loading and greatly increase transfer capability.

- The operations paradigm needs a major overhaul. Operators need more reliable and timely information. Wide Area Measurement Systems (WAMS) will eventually help but only if operator training and tools that address wide-spread effects are greatly improved. Primarily, every control center must have responsibility for a coherent section of the grid. Control area boundaries must be selected based on rules that enhance reliability.

- Undervoltage load shedding is woefully underutilized though it has been an inexpensive and known technology for 25 years. Many systems will see dramatically improved reliability from widespread use of undervoltage load shedding. Undervoltage load shedding may have greatly limited the 8/14 catastrophe.

- Maximum Credible Disturbances (MCDs) and Possible but Improbable (PBIs) events need much more attention. Traditionally MCDs and PBIs are limited to station outages and ROW outages while they come in myriad other forms (e.g., 8/14). More attention to mitigation of such events would reduce the risk of cascading. Tools exist for this purpose but are rarely applied.

- System modeling practices need an overhaul. Routine system outages are not treated in contingency analysis. Protection is not modeled in MCD or PBI studies or routine contingency analysis. Loads are not properly modeled. These are simple upgrades that are long overdue, particularly in light of today's highly stressed grid.

Summary & Recommendation

The natural maturation of the grid has resulted in an erosion of reliability. This problem needs attention. The effort should start with a rigorous assessment of reliability over the last 20 years to quantify and characterize the developing weaknesses. Then cost-effective solutions to those weaknesses should be developed and criteria should be adjusted to ensure those new solutions as well as traditional solutions are applied sufficiently to ensure a reasonable level of reliability.

Solutions should be part of a plan to improve reliability in the near term and not an R&D agenda for application in 20 years.

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