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training for blackouts

such situations require a pilot's mentality

THE TERM "BLACKOUT" CAN bring to mind several different images, depending upon your past experiences. For some we are reminded of the lights going out for a short period of time during a thunderstorm. Others may recall being without heat for several hours or even days following an ice storm. Still others have been affected by wide-scale outages for no apparent weather-related reason at all. The results of these blackouts range from inconvenience, to damaged food, lost business, injury, death, and even birth. The cost of a large-scale blackout is almost impossible to measure. The economic consequences alone can be billions of dollars.

In the United States, we expect our electric power to be 100.00% reliable as so many aspects of our lives depend upon it. Unfortunately, this is not possible. Blackouts do occur. Our job in the electric power industry is to mitigate the number, frequency, duration, and area over which blackouts occur.

Blackouts occur for a number of reasons. Although most are associated with weather, the impact can be wide ranging. Weather can blow down a single distribution feeder affecting a small region, or an ice storm can take out a major portion of a transmission grid affecting millions of people for days.

The Domino Effect

Power systems are designed and operated to withstand the loss of a single major transmission line or generating plant without affecting any customers. In most cases, when a single line or plant is lost, the system can be reconfigured in 30 minutes so that it can withstand another such loss. However, each time an element of the system is lost, the weaker the system gets, and it becomes harder to withstand the next loss. Eventually, the system grows weak, and one loss cascades into other losses. Cascading is analogous to the "domino effect." The loss of one element results in the overload of another. The overload causes the next element to then go out of service. The pattern continues, producing a large-scale power outage, leaving many consumers in the dark.

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Cascading blackouts are unique due to the very wide geographic areas that they affect. Their causes are complex and unknown for months after they occur, and it usually takes days to restore all of the affected customers. The first large-scale blackout, the Northeast blackout of 1965, and the latest large-scale blackout, the Midwest blackout of August 2003, as well as several in between are examples of cascading blackouts.

Cascading blackouts do not happen very often, perhaps once every ten years or so. Yet the results are economically devastating, and they do result in the indirect loss of life. Each time such a blackout occurs, recommendations are made and implemented that will reduce the chance of reoccurrence, but even so they do reoccur.

Training Can Help

One way in which we can improve system reliability is to train our operators specifically for these types of events. In February 2006, the North American Electric Reliability Corporation (NERC) announced its expanded system operator certification program. For the first time, system operators will have specific training requirements that they must meet to retain their operator certification. Among other criteria, these requirements call for at least 30 hours of simulation exercise training over a three-year period.

Many operators train regularly on sophisticated power system simulators that emulate their power systems. For the most part, this training involves faults, switching, and reconfiguring the power system should a specific single element be lost. This is valuable training and must be continued. The fallacy, however, is that this training deals with operating a relatively strong power system. Operators rarely train on weak power systems. The reasons for this are many. It is difficult to put today's power systems into a weakened state. To do so involves several coincidental outages. Because a weakened system comes about due to many

(continued on page 108)

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element outages at the same time, the number of combinations of elements that would bring about the weakened state is very large. It is difficult and somewhat fruitless to train to combat any one of these specific outage combinations as there are many and the likelihood of any one occurring is extremely small. But, by the same token, the small probability of a large number of events can result in a sufficiently significant probability that any one might occur.

How does one deal with preventing or mitigating the source of a cascading blackout when it can come from so many different directions? The common ground is that the symptoms of a weakening power system can be very similar regardless of the specific cause. These symptoms appear as unusual operating parameters [area control error (ACE), voltage, frequency]. While it would be great to know the immediate and specific cause of unusual operating parameters on a power system, it is not necessary to know these to take reasonable actions to head off a cascading power outage.

First, however, one must recognize the symptoms of a cascading power system and then respond and respond in time to these symptoms. Neither is obvious, and the addition of the time dimension provides further complication.

Pilots in Sick Airplanes

The problem is similar in many ways to a fighter pilot who finds himself in a sick airplane. The fighter jet has redundant systems and is designed to fly with the loss of one or two of its many systems. The pilot is trained to manage the aircraft for foreseen system failures. But he is also trained to "fly" that aircraft for the *un*foreseen system failures based on their symptoms, not diagnosing their causes. The reasons are obvious.

These pilots could be taught how to handle these life-threatening scenarios through manuals, checklists, and lectures. For good reasons, they are not. Two critical elements must be considered: time and stress. The pilot must determine the proper action and implement it in a *timely* fashion under an environment of increasing stress measured by his declining altimeter. To accommodate the elements of time and the accompanying stress, pilots undergo much of their training in flight simulators.

Given my Air Force background, including some familiarity with flight simulators, and my power system background and extensive familiarity with power system simulators, I decided to explore the premise that the pilot's dilemma with a sick aircraft and the power system operator's dilemma with a cascading power system are analogous.

A Power "Simulator"

I started with a simulation model of a power system containing over 20,000 buses. I quickly determined that it was difficult to make this system weak enough to learn anything general about the symptoms of decaying power systems. I learned about the idiosyncrasies of one specific problem on one power system but nothing that was universally or remotely applicable to other specific instances.

Failing that approach, I went to the other end of the spectrum and experimented with a small seven-bus power system model with five generators and 11 lines. Perhaps the limitations were my own, but I found this still too complex. There were too many parameters and too many combinations to watch to learn anything applicable to the general problem of cascading power systems and the critical decision making of cascade intervention.

With a great deal of humility, I created a power system using two buses, two lossless lines, and two generators. Now with this system, I was all the way back to the basics with a system of simple topology (see Figure 1). The modeling of the individual components was complex in that the generators were modeled with automatic generation control and automatic voltage regulation and the capacitor banks were represented with effective megavar modeled correctly as a function of voltage squared. The transmission lines were modeled as distributed inductive and capacitive elements.

With such a simple system, one quickly learns the impact of the loss of critical elements as pretty much

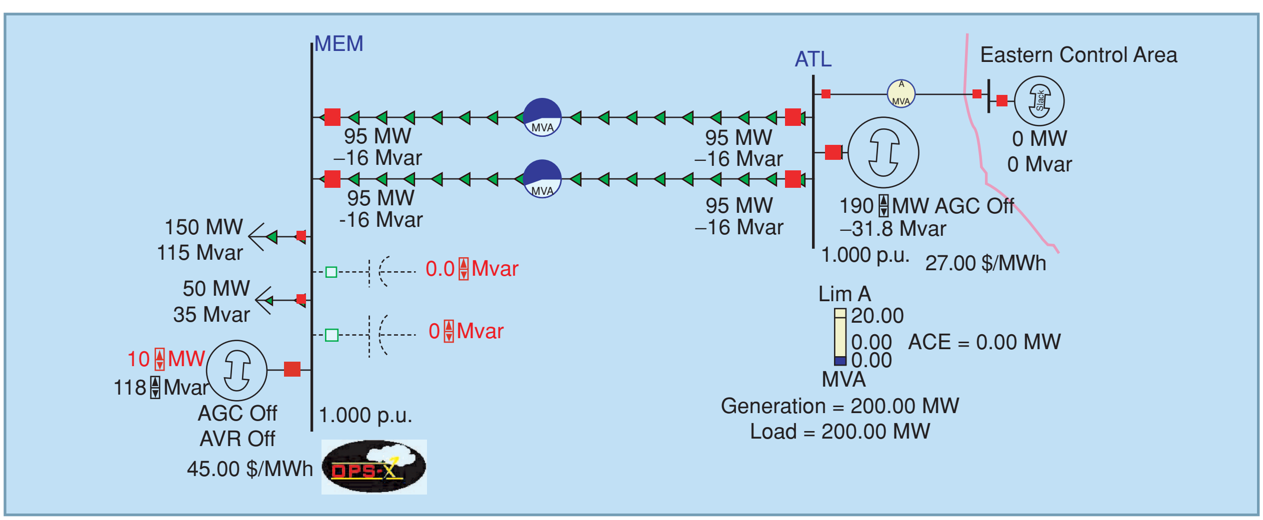

figure 1. A simple power system designed for emergency condition analysis.

all elements are critical. Maybe, more importantly, one learns how to operate the system so that the loss of an element is mitigated.

This was only part of the problem. I still needed to put the time dimension to the situation, and I needed feedback on the state of the system. I needed a clock and an altimeter. For these items, I turned to PowerWorld Corporation's new feature in power system simulation called time step simulation (TSS). This feature allowed me to change power system conditions with time. I could implement contingencies much like a flight simulator, throwing varying situations at the operator and watching him respond. I put several readouts on the one-line diagram: ACE, voltage via color contouring, and line loadings via pie charts. These were the equivalent of the altimeter and air-speed indicator. Now with time marching on and conditions deteriorating if no action is taken, the operator is faced with making the right decision in a timely fashion. If he does not, he crashes.

Armed with my two-bus power system "flight simulator," I approached several very knowledgeable power system experts and asked them to try it out. Most were not initially impressed with the idea of doing battle with a mere two-bus system but they humored me. I was surprised and so were they. They could readily solve two-bus power systems in their heads but the time element and changing conditions made them like the first batter to see a curve ball. The experts "swung mightily" and missed! As with any batter, they wanted to see that curve ball again, and so they did and they quickly learned to hit it.

They came away richer in their understanding of operating a power system in real time and the impact of changing conditions. They came away with a new awareness of critical decision making under stress. They saw how their thought processes were distracted and confused by impending doom. They learned to anticipate and to think and act proactively. They learned what actions fixed problems immediately and how to jump ahead of cascading elements. And, for the most part, it was evident how to apply these general solutions to the complexities of their every day operations.

And so my premise was tested and confirmed. It is one thing to understand the principles and theory of flight and an altogether different experience to fly a rapidly descending aircraft with a failed hydraulic system. The same goes for power systems.

To complete the picture, Powersmiths International and PowerWorld decided to develop my power system flight simulator into a full-fledged power system training tool. It runs on a custom version of the PowerWorld Simulator program. We have developed five training modules of increasing complexity. The modules are each NERC certified for a total of 40 NERC CEUs. More information is available at www.opsxpert.com.