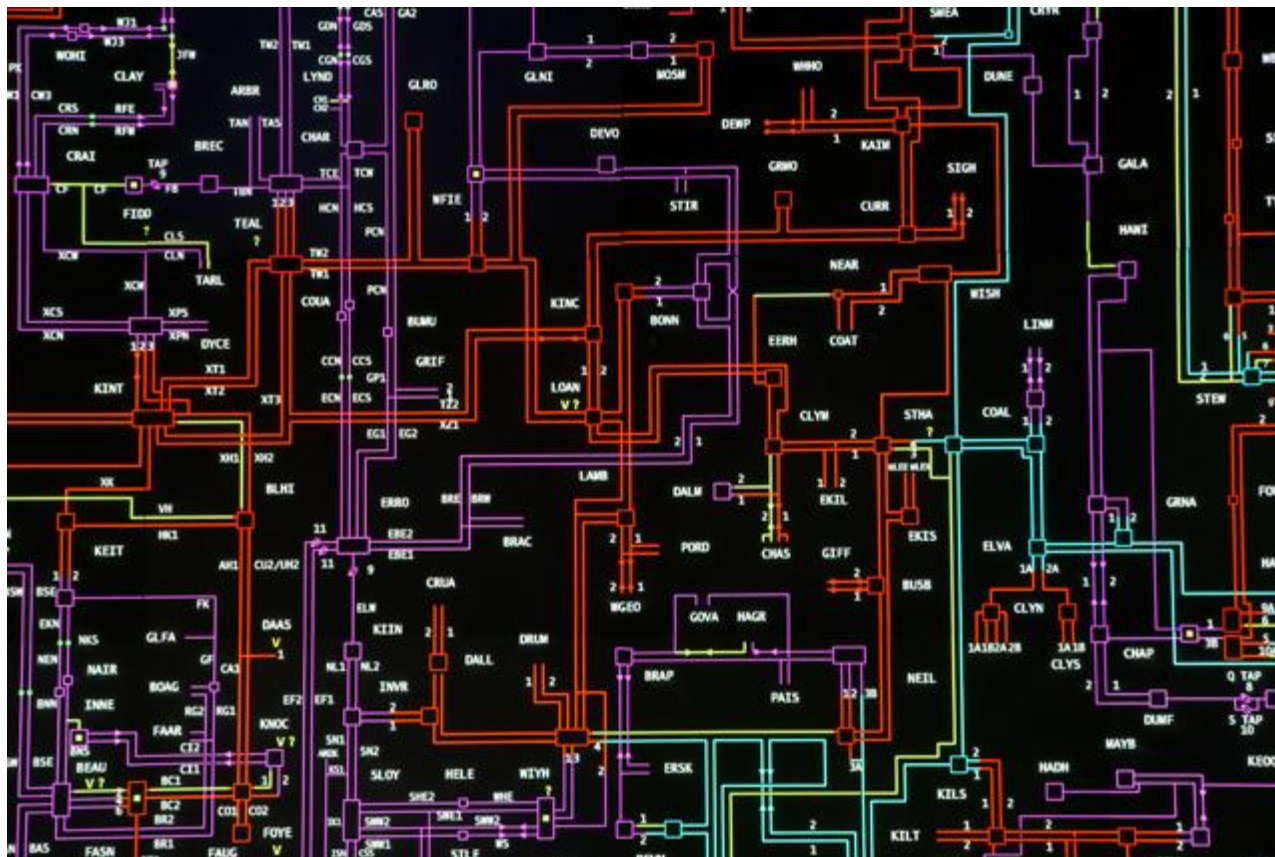


Synchronised switching: phase measurements provide key to grid stability

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Instruments embedded in the grid will help keep it running as tight supply and renewables make it less stable.

It took a matter of minutes on a hot Thursday afternoon in August 2003 for the lights to go out across the north-east of the US and Canada. Almost simultaneously, power plants separated by hundreds of miles were suddenly disconnected by their own safety systems from the vast power network that covers those countries.

First, the blackout covered just part of Ohio. Within half an hour, the lights had gone out in New York and across nine states in the US. It took two days before the power came back in many cities. Some rural areas had no electricity supply for a fortnight.

When a hot power cable in Ohio sagged into an overgrown tree and tripped the circuit breakers, operators working for electricity supplier FirstEnergy did not know what had happened because the monitoring system computer failed. A bug in the software prevented alarms generated in the network from making it through to operators before the program crashed, rapidly followed by a backup. Starved of alarms, operators did not realise how the effects of the first shutdown were beginning to ripple through the network.

Had FirstEnergy done a better job of keeping high-voltage cables away from trees, the blackout might never

have started. But the way that the sagging cable eventually brought down an entire power network triggered alarms in regulators and government: the nature of AC distribution makes it vulnerable to chaos as initially small effects spiral out of control.

Many of the systems in the north-east American grid failed because they started to move out of phase with each other. Eventually, the safety systems of individual plants turned off their connections to the grid to deal with the problem locally – and trigger a much larger, distributed problem. If control systems had a better view of how individual systems were oscillating differently, they could have brought the connections back into phase. But without the high-level view, it could not happen.

In some respects the situation for grid operators has worsened with the increased use of renewables in the supply network. Their contribution to the grid is far less predictable, though cleaner, than those of fossil-fuel and nuclear plants.

The first is the increase in unbalanced voltage caused by single-phase photovoltaic systems feeding into only one leg of a three-phase grid. Reverse power-flow issues emerge with generation occurring in the distribution network. Power flow reversals increase the wear on tap changers (which control the voltage output of transformers) as well as potentially confusing control systems. “Tap changers have limited switching life cycles,” says Megger product manager Andrew Sagl.

The unpredictability of renewables can lead to rapid voltage changes, causing voltage regulation problems. “Since renewable energy is not providing constant voltage levels to the grid they can fluctuate substantially, causing voltage regulation problems. Some issues that are being seen due to rapid voltage changes include tripping relays as well as regulator failures,” Sagl adds.

The industry in America and Europe has responded by investing in real-time monitoring technology that can make sense of the shifts in AC frequency and phase across the network. An important technology to support this trend is the synchrophasor. Suppliers such as Psymetrix, acquired by Alstom in 2011, promoted the idea for grid measurement in the 1990s. The Bonneville Power Administration, a federal US agency, began to work on the technology in response to a massive blackout in California in 1996. But, outside China, it took the 2003 blackout in America as well as one in Italy for the industry to begin to adopt the technology more widely.

The core of the idea began in 1893 when Charles Proteus Steinmetz published mathematical techniques for analysing AC networks as they began to propagate across the western world. Virginia Tech researchers Arun Phadke and James Thorp came up with the idea in the 1980s of marrying phasor measurements to accurate time stamps derived from the atomic clocks carried by GPS satellites. The time stamping makes it possible to analyse how frequency and phase are varying within a network that spans an entire country. Without the time stamps, there would be no accurate way to determine whether changes in phase angle are appearing at the source or are caused by delays in transmitting the data across a network.

This remains an active research field as engineers try to develop ways to diagnose specific problems from movements in the data. The synchrophasor concept makes it possible to look at the difference between the measured phase angle at each point and an ideal reference cosine up to 150 times a second. An angle that is moving from high to low as the frequency falls points to problems on that part of the grid. What neighbouring units tell the operator will alert them to the significance of the problem and the possible cause. Utilities will replay the data they capture from their wide area monitoring system (WAMS) stores after a

failure to try to diagnose what went wrong and what they can do to avoid the problem in the future.

System inertia

The replay data has underlined concepts such as system inertia that have developed in recent years. Investigations by National Grid and the universities of Manchester and Strathclyde highlighted how seasonal changes in usage can affect stability. The high electrical inertia of large rotating motors in industrial plants coupled with the generators of fossil-fuel power stations leads to relatively high inertia that makes it easier to ride out small, sudden changes.

With the introduction of more renewables into the energy mix, inertia is trending downwards. The research indicates that hot days in summer could lead to the lowest inertia and the greatest risk of a failure affecting a large part of the network. Operators are beginning to look at deploying specialised plants to provide them with inertia on demand, using batteries and flywheels to restore the balance.

As part of its Ofgem-backed Enhanced Frequency Control Capability (EFCC) project, National Grid awarded a contract last year to Belectric UK to test large-scale battery storage in two locations. Centrica is looking at options for the EFCC project that use wind- and thermal-generation plants.

The growth in microgrids is seeing another wave of synchrophasors being deployed, as they are needed to manage their connection to the distribution network. The Illinois Institute of Technology (IIT) has implemented a microgrid on campus that acts both as a demonstrator and as a high-availability supply for the buildings there.

“We can run the campus as an island, without the help of an operator, although that does not usually happen unless there is an outage,” says Professor Mohammad Shahidehpour, director of the Robert W Galvin Centre for Electricity Innovation at the IIT. “We locally integrate renewables and other elements to allow us to operate in the form of an island.”

To monitor the microgrid, the IIT installed 12 phasor measurement units, combining data from those with readings streamed from a network of wireless sensors. The IIT’s microgrid will help support a second neighbouring microgrid being built with the local utility and suppliers including Alstom and Quanta in an area that contains one of Chicago’s biggest police stations. “If they go into island operation, they can share resources. And we will also help the utility to shed loads,” adds Shahidehpour.

As the understanding of phase data increases, operators are beginning to deploy systems that can provide operators with real-time visualisations of problems developing. However, according to Brett Burger, National Instruments principal marketing engineer, making automatic decisions based on the phase data is still some way off. “I see humans in the loop still,” he says. “You may have a hydropower dam that has a problem with its generator. The control room may detect that and an operator makes a phone call to figure out whether to spin up reserves or not. However, at the level of microgrids, I see more automated control to handle islanding.”

In 2014, Alstom Grid and other suppliers started work on the second phase of the synchrophasor programme initiated by Pacific Gas & Electric (PG&E). As part of the project Alstom is installing its model-driven Grid Stability Package to provide operators with analytics derived from the coordinated phase-angle measurements so they can make better decisions as to when and where to isolate parts of the network.

By moving to rapid-response energy-storage resources, and with the help of data from the WAMS that is currently being developed as part of its VISOR project, National Grid aims to save up to £200m per year from the cost of maintaining frequency. However, the project is still in its early stages, with rollout expected to happen after March 2018 when the research and testing phase is scheduled to be complete. The company warned in its six-monthly report published at the beginning of the year that its licensees are already beginning to see the effect of reduced inertia. “Even a moderate future uptake of renewables will impact the costs of managing the system significantly,” the report noted.

Better measurement is one step to ensuring that the future power grid will be able to cope with falling inertia.