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Controlling the Grid

By Mark Fitzgerald

Given the limitations of the current regulatory and planning landscape, the idea of modernizing the grid can often feel daunting. Regulators, planners, and designers have been using centralized models of grid design, operations, and profit-making for a long time. Some may have even forgotten just how vital high asset utilization is in a capital-intensive industry.

About 20 years ago Denmark's power system experienced similar issues: rising costs, congestion, instability, and dependence. Faced with the threat of prices eventually topping $1.00/kwh, the country decided to take action by shifting its grid framework from primary to local generation. Since the late-80s, Denmark has transformed its electric system from central station generation and net importing of electricity, to a grid cell structure of distributed wind, small combined heat and power (CHP) units, and the advanced distributed controls to monitor and control it.

Today an ongoing grid project in Denmark is expected to accommodate a higher penetration of renewable and distributed energy while enhancing system controllability and reliability. This project is a great example of the possibilities of a modern grid that is able to optimize existing assets, serve advanced generation and storage options, self-heal, enable markets, and deliver the quality of power needed for the 21st century.

The Problem

A few years ago the grid system in Denmark reached peak capacity. There was not enough room to accommodate additional renewable power. Distant faults on the grid were causing protection relays to trip local generators and uncontrolled volt-ampere reactive (VAR) flows were prevalent across transmission and distribution boundaries.

“We had to deal with a system that was designed to carry currents from a high voltage level to a low voltage level,” recalls Per Lund, Ph.D., a systems research expert who is heading the pilot project. “So you have to imagine a system where 55 percent of the total installed capacity could be sent to the medium at low voltage networks.”

In response, Denmark’s transmission system operator, Energinet.dk, began investigating ways to establish a system of coordinated control without having to invest in new infrastructure. With wind turbines and combined heat and power plants located throughout the country, the challenge was to implement intelligent control systems that could transform these intermittent resources into aggregated blocks that behaved like conventional power plants.

“All of the wind turbines are operated as the wind is actually blowing and all of the combined heat and power plants are operated on a heat demand basis,” adds Lund. “That adds up to thousands of distributed generators, starting and stopping as they please.”

Swings in power flow patterns, continued load growth, and the demand for larger power transfers over longer distances had also increased Denmark’s vulnerabilities to major system disturbances and blackouts. Pushed to its physical limit, the country’s power system needed a comprehensive overhaul that involved intensive on-line analyses to better coordinate controls across the entire grid.

The Solution

One of Energinet.dk’s first steps was to engage the services of Spirae, Inc. for a pilot project in Denmark. Spirae, which operates a grid simulation laboratory at Colorado State University in Fort Collins, began working with Energinet.dk to test a power management system that could operate portions of Denmark’s distribution system as a fully controllable power plant by utilizing local generation and load assets.

“The basic idea is to turn all of these machines from passive generators to active generators without having to redesign the power system,” explains Lund. “And we’re doing that by duplicating the network through a data communication system that is fast enough for us to get online access to all of these machines. Then on top of that we’ve built what we call a cell controller.”

The cell controller model features a primary control center that can communicate with a cell controller and multiple subcell and site controllers. Because these assets are already in place in Denmark, implementation costs have been minimal. Indeed, the bulk of the cost so far has been the time invested in data analysis and in synchronizing the right mix of resources. The team has successfully taken parts of the distribution networks that have a massive influx of energy from wind-turbines and CHP plants and converted them into an active network.

“The ability to aggregate resources that would otherwise be sitting idle is quite tremendous,” says Sunil Cherian, Ph.D., the president and founder of Spirae. “Taken collectively, wind turbines and other synchronous machines provide a port to the high voltage grill and offer enormous capacity in terms of voltage control and frequency control.”

If, for instance, there is a fault on the power system, nearby generators will trip off the network without damage. During a blackout situation cell areas are sustained and work to support the power system. They also offer quick black starting capabilities. The IT infrastructure relies on a high speed data communication system as well as numerous computers and embedded processors that interact through networks with standardized interfaces based on message-oriented middleware and web services. This process entails a distributed system where the locations of data, software, and hardware are transparent to the user.

Spirae has been busy running validation and scalability tests on a cell controller at the Engines and Energy Laboratory at Colorado State University. In 2006 it installed a cell monitoring system in a pilot area in Denmark that contains approximately 3MW of loads, two CHPs, and four 1 MW wind turbines. The entire cell controller region has been divided into three areas. Testing and implementation of the first area is slated to be complete by the end of 2008.

“We will move to area two, if and when we have succeeded in area one,” Lund says. “When we are finished in area two, then we will take on the full cell area. We anticipate that by 2011 we will have demonstrated this cell controller concept for a large and full-scale distribution region. After we have accomplished that, we plan on rolling this project out over the entire country.”

Benefits

One of the most immediate benefits of the pilot project has been the value gained through streamlining existing assets. Wind turbines and CHP plants have been channeled to ensure a more reliable and sustainable power system. In the event of major power disturbances, system operators are capable of separating the grid into self-sufficient islands that can prevent widespread blackouts and restart the primary grid using distributed energy resources.

“Let’s say that we know we are facing a blackout situation,” Lund posits. “Then we will utilize these cell areas to actually support the power system. Even if the high voltage system fully blacks out, we will maintain supply of the distribution network by utilizing all of those distributed generators in the cell networks. If we keep the cell areas up and running, a major blackout will not occur.”

Cost control, reduced transmission and distribution electrical losses, and more efficient power production are other benefits that stem from the cell controller project.

By bolstering the quality and efficiency of asset management, the cell controller will improve load factors while decreasing system losses—delivering on-demand performance at a minimal cost. The ability of the cell controller to communicate at high speeds with each and every asset will serve to minimize disruptions, execute decision-support algorithms, dynamically control the flow of power, and restore service quickly. Assessing faults, low voltage, poor power quality, overloads and other undesirable system conditions are other capabilities executed by the system to ensure effective maintenance and stability.

Another benefit is the potential of the cell controller to enable dynamic markets for ancillary services at the distribution network level. The expansion of transmission paths, the aggregation of renewables, and the ability to position resources within a reliable distribution system is likely to foster market participation and generate new revenue streams.

"We realize that this project will never be rolled out across the entire country unless there is business in it," points out Lund. "It will only happen if we can show to the owners of all of those distributed generators that there will be new market opportunities for them to play on. So we will certainly need to start developing these markets."

According to Lund, if Energinet.dk can define a number of distribution network cells with a total sum of generators equal to a base load power station, then it might be able to open up a market for reactive power control. "Reactive power is injected into the power system where it is needed," he explains. "You can't transport reactive power over high voltage lines as you can with active power. So the idea is that we would open up a market where we could inject reactive power exactly into the system where it is needed. This would give us a very high quality of voltage control over the system—much more than we have ever had before."

Lessons Learned

Although this project is still in its early stages, both Energinet.dk and Spirae have learned plenty so far about carrying out a coherent and comprehensive plan to optimize assets, accommodate future transmission capacity, and ensure the security of long-term supply.

"A lot of what we've learned is related to trying to frame the problem correctly," explains Cherian. "Making sure that we do the right things with the right assets has not been an easy task. I also think that we've gained a pretty good appreciation of the difficulty involved in collecting the data that's needed to properly test the cell controller and validate its performance."

The Engines and Energy Conversion Laboratory at Colorado State University has been especially valuable in facilitating this learning process, according to Cherian. "The lab's been a great resource," he adds. "Although we are dealing with much more data than you would need once this is all proven out, what we are learning through software simulations has been of great benefit to us out in field. Learning how to calculate the dynamic response of a wind turbine, for instance, was much more complicated than we expected."

The team is also working to replicate certain flow phenomenon in the field for close behavioral analysis in the lab. Much of this process involves careful observation of how the cell controller is managing transmission and distribution capabilities. Model performance is validated against lab performance and then scaled up to assess renewables and other embedded infrastructure.

According to Lund, the level of cooperation and collaboration from owners of wind turbines, CHP plants, and distribution companies has been outstanding. "These owners are working on this project on a voluntarily basis," he says. "They have been extremely generous in opening their facilities to our staff. They've also brought a strong sense of national pride to the mission. I guess everybody feels that they are helping to redesign the Danish power system."