When grids get smart

Intelligent automation for distribution networks

Cherry Yuen, Duncan Botting, Andrew D.B. Paice, John Finney, Otto Preiss

The traditional delivery of electricity from large, centrally generated electricity units via reliable transmission grids onto tapered distribution networks must now be complemented by distributed generation to satisfy changing needs of modern society. The request for renewable sources to generate electricity, combined with the demand for greater energy efficiency, is redefining the traditional delivery mechanism.

On average, the majority of today's electricity generation and distribution systems waste over 60 percent of their energy in the form of heat before delivering any useful energy to the end user. One promising means of reducing these losses is through the distributed generation of electricity closer to the end user. This has led to a huge increase in demand for solutions such as micro-generation in homes and in industry to be linked with heating and cooling (micro combined heat and power [micro CHP] units) thus increasing total useful energy efficiency levels up to 85 percent.

Locally generated renewable sources such as wind, solar and micro CHP are creating new and challenging issues. While in the past the energy flow was unidirectional from the central source to the distributed consumer, now the two-way power flow of distributed generation must be managed. This power requires real-time coordination with the traditional power generation units in the grid. Distribution Network Operators (DNOs) now face the challenge of providing networks and services that can deal with this new paradigm – issues that were traditionally managed at the transmission level.

From passive to active grids

Distribution networks are thus moving from traditionally passive networks (ie, those that were planned for particular peak loads and for use as fit-and-forget networks) to more active or dynamically adapting networks in order to manage the increasing demands placed on them. Many small generator units could be run as one large power source, called a virtual power plant (VPP). The connection of smart "white goods" in the home (eg, refrigerators or freezers) could be managed by the DNO to provide active and reactive load control in the local network, taking smart metering to a new level of sophistication.

Energy storage solutions that smooth the capacity constraint issues could be part of what is now seen as an intelligent- or smart-grid future, which is based on active network management (ANM) and the associated intelligent automation system. Such an intelligent automation system also is required to assist the developing commercial and regulatory structures that are projected onto the physical electrical grid. The liberalized markets now have fragmented commercial stakeholders that require different, more flexible administrative solutions than the traditional vertically integrated control and command structures. Regulators require different parts of the supply chain to act and record transactions in a robust manner, while at the same time provide evidence of the most cost-effective delivery of their services.

An optimal smart electricity grid would – by utilization of the latest information technologies – be able to largely control itself. That is, it would be able to accept any kind of generation source, deliver power of any quality on demand, diagnose itself, and even heal itself through intelligent use of redundancies.

Governments are taking action to accelerate research, development and deployment projects to realize this vision of active network management. Examples include the IntelliGrid Initiative led by the Electric Power Research Institute [1] and the SmartGrids European Technology Platform [2] sponsored by the European Commission 1. ABB has been instrumental in the leadership of this new and exciting technology-intensive area and has been deeply involved in developing Europe's smart-grid vision.

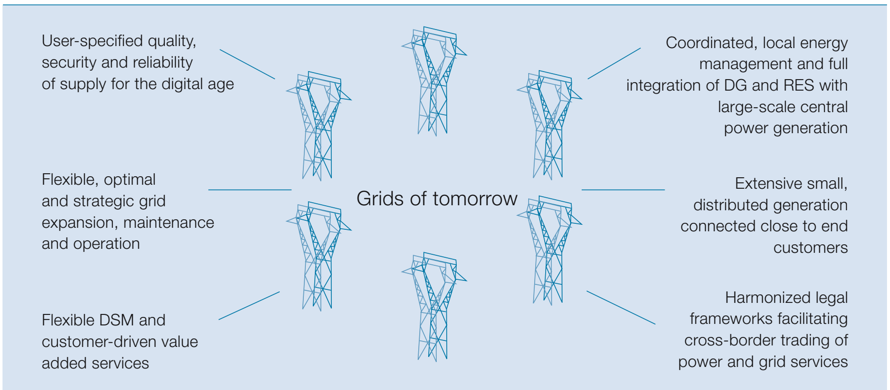
Technical challenges

Introducing this new smart-grid concept opens the door to previously unknown challenges. For example, the power flow may reverse as the generation capacity of one area exceeds the local demand and is used to compensate the load requirements in a neighboring area. These effects may be restricted to the low-voltage level, but may also be felt at the medium-voltage level, as illustrated in 2. Network congestion may result when the transfer capacity of the lines is reached or exceeded. This problem is exaggerated when the distributed energy sources are not close to the main energy consumers. The automation system that manages those challenging situations must have access to the real-time dynamic changing of the whole grid. This requires additional measurement, state estimation algorithms, and flexible control and protection settings.

Furthermore, the automation system should be intelligent enough to cope with generation profiles that may change with the weather and the time of day (eg, wind or photovoltaic generation). The result will be a continually changing distribution of power flow and direction, in contrast to the relatively stable, unidirectional power flow typical of a distribution network today. All of these functions require greater use of fast and reliable Information and Communication Technologies (ICTs).

The amount of data required to perform the various smart-grid functions

1 Vision of future grids (from an EU report on European SmartGrids Technology Platform). DG: distributed generation; RES: renewable energy resources; DSM: demand side management



is enormous and diverse. Data come from different sources and systems (eg, SCADA[1]) and energy market platform, and are both historical and real time with sampling rates varying according to the specific functional and communication requirements. In the new ITC system, a balance between additional sensors and sophisticated state estimates must be found to keep costs low.

The next challenge is to integrate the new ICT architecture with the infrastructure that is already installed by the utilities. Many DNOs are operating electrical and ICT infrastructure that is at least 10 years old and not fit for the rich data flow necessary for ANM. The use of different data communication standards and the inadequate bandwidth of the communication channels are a barrier for an implementation of smart grids in the near future.

Besides the management of the technical performance of a smart grid, the ANM also should support the manifold administrative tasks of the grid operators. In a smart grid, generation unit operators and distribution infrastructure providers are different legal entities with the same need for automating the accounting procedures of their business.

The way forward

Building the next generation of active power delivery networks requires a mixture of new technology, existing technology deployed in new ways, existing asset infrastructure utilized in an optimum way, and changes in operating practices by electric utilities. Progress in such a complex, multi-stakeholder research and development effort can only be made with collaborating teams. ABB is involved in the following team-based projects.

AuRA-NMS

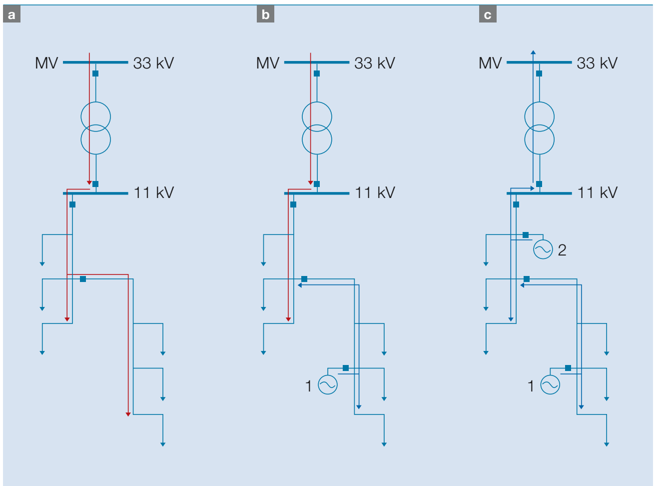
Autonomous Regional Active Network Management Systems (AuRA-NMS) is a collaborative research and development project sponsored by the UK Engineering and Physical Sciences Research Council (EPSRC), that seeks to demonstrate new network operation concepts in the United Kingdom. In addition to ABB, the consortium includes two network operators (ScottishPower and EDF Energy) and the contributions of seven UK universities, including Imperial College London.

An optimal smart electricity grid would be able to largely control itself.

The goal of AuRA-NMS is to demonstrate the benefits of active network management using a distributed architecture that is integrated into existing control and asset infrastructure. This includes the use of innovative battery storage to understand the merits of trading opportunities, the support of constrained capacity related to overhead lines and cables, and stability control of the network due to various types of distributed generation. The project also aims to provide automated solutions to complicated constraint management.

ABB's new Station Automation Series COM 600 is the network management system controller used in the project. Designed to complement the substation automation and network management systems already in service by ScottishPower and EDF Energy, the COM 600 series offers interoperability and extensibility through support of the IEC 61850 standard, and provides a certain level of legacy protocol support for the DNOs' existing feeder automation devices.

2 Uni-directional flow a, reverse flow only in one section of the 11-kV feeder b and reverse flow via a 33-kV/11-kV transformer c



Furthermore, ABB is deploying a new energy storage system at an EDF Energy substation where wind generation interfaces with a weak medium-voltage network. The new dynamic power compensator, SVC Light Energy Storage, is a revolutionary combination of ABB's SVC Light STATCOM[2] with a record-setting 6-kV DC battery system composed of efficient and environmentally friendly energy storage cells.

Microgrids

This project, supported by the European Union, seeks to identify the promise and address the challenges of proliferation of microgrids in Europe. A microgrid is a loosely defined, self-sufficient interconnection of distributed generation, residential and industrial load in a low-voltage network without a persistent connection to a larger, stronger grid. In addition, the creation of ad hoc microgrids by islanding pockets of a larger network has the potential to stop cascading outages while keeping critical loads online.

ADDRESS

Active Distribution networks with full integration of Demand and distributed energy RESourceS (ADDRESS) is another ambitious project involving several utilities, multiple power-system and white-goods vendors, telecommunications companies and numerous universities. Their goal is to develop a commercial and technical framework to realize the full benefits of active networks with distributed resources.

Active network management

Current network management practice is mostly based on a centralized SCADA system, which regularly gathers online measurements from the

Footnotes

[1] SCADA: Supervisory Control and Data Acquisition
[2] STATCOM: static compensator

telemetric points in the distribution network. The traditional communication infrastructure of SCADA systems has been designed to acquire data about once or twice every minute and to send out control commands whenever necessary. A higher data acquisition rate has not been required by the existing applications. However, these low data rates are insufficient when more complex distributed generation networks must be managed.

To overcome this problem, one can either improve the communication infrastructure to enable faster data rates, or store the online measurement data in a local substation and exchange the relevant data among the substations to perform sophisticated real-time applications. The amount of data stored is less than that stored for the SCADA database, because each substation is responsible only for its own part of the network. It can then allow data to be stored at a higher frequency, eg, once per second or microsecond, depending on the application. Since most data is stored locally, the requirements for communication from substations to network control centers are relaxed.

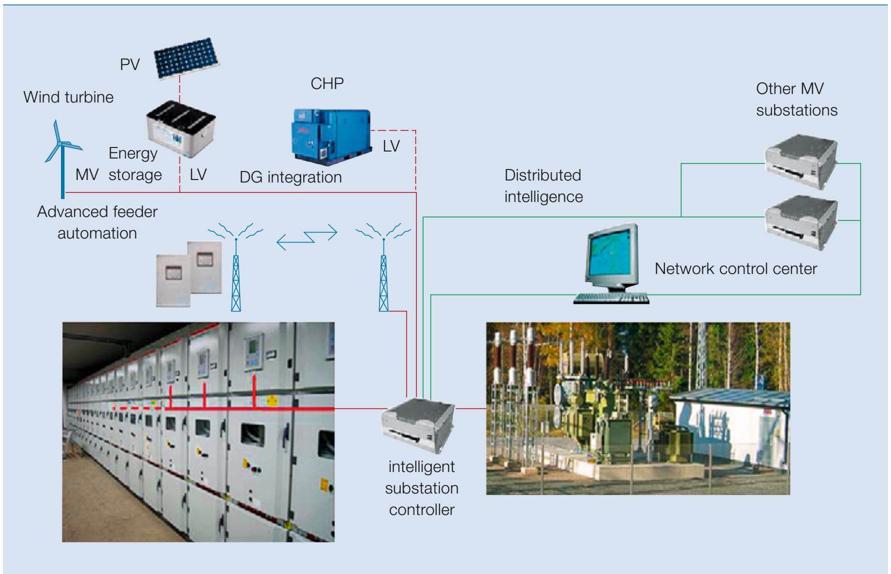
This promising approach requires decentralized algorithms that seamlessly integrate into a now reduced central SCADA control function to ensure optimal local operation. The localized controllers have sufficient intelligence that enables them to coordinate with each other, and thus ensure reliable global operation.

Indeed, some of these new required functionalities are similar to those available in the energy management system (EMS) today – eg, meshed load-flow analysis and generation forecast – which now have to be used at a local level. More importantly, instead of passively responding to events in the distribution network, an active network should be able to predict (based on monitored and trended information) what is likely to happen and act on the data in a proactive manner. This forecast applies to both generation and load.

A further important feature of an active network is the ability to adjust the settings of the Intelligent Electronic Devices (IEDs) – eg, protection relays – according to the real-time operating states of the network. While traditional relays support very few settings to adjust themselves to the power flow conditions, the integration of distributed generation requires an increased number of settings to operate the network efficiently and reliably in real time. This results in a more sophisticated, dynamic setting based on online data and careful coordination of all concerned relays.

3 shows an example of active network management based on decentralized control. The intelligent substation controller, which is installed in several medium-voltage substations, has gateway functionalities, ie, it can translate data in the process communication protocol to the network control center communication protocol and vice versa. In addition, distributed intelligence is hosted in these controllers.

3 An active management system based on decentralized control



First steps taken

The highly integrated, multifaceted approach to realizing an intelligent or smart grid can only be managed with the collaboration of all involved stakeholders. A small but significant part of this cooperation addresses the intelligent automation systems for distribution networks and in addition the implementation of active network management. ABB is making important contributions in all aspects of this work, providing new devices that will enhance the local power supply as well as researching the communication and control technologies that form the basis of an intelligent distributed system.

Cherry Yuen
ABB Corporate Research
Baden-Dättwil, Switzerland
cherry.yuen@ch.abb.com

Duncan Botting
ABB Power Technologies
Stone, UK
duncan.botting@uk.abb.com

Andrew D. B. Paice
ABB Corporate Research
Baden-Dättwil, Switzerland
andrew.paice@ch.abb.com

John Finney
ABB Corporate Research
Raleigh, USA
john.finney@us.abb.com

Otto Preiss
ABB Corporate Research
Baden-Dättwil, Switzerland
otto.preiss@ch.abb.com

References
[1] www.epri.com/IntelliGrid (November 2007)
[2] www.smartgrids.eu (November 2007)