The control systems of today’s smart power-distribution grids have evolved significantly. Such systems improve system reliability by reducing the frequency and duration of outages. They also optimize asset utilization and increase power quality. But the scale of automation and the ultimate configuration of the system need to be considered carefully with each client. The decision to proceed must be based on a sound economic evaluation; it cannot simply echo the mantra of automation.

### Distribution Automation: An Opportunity to Improve Reliability and Quality

#### Why is this issue important?

**Distribution automation saves utilities and their customers money by reducing outages and lowering capital and operating costs**

When components of power distribution networks fail, the failure must be cured quickly to avoid power cuts or loss of load. Such cuts and losses can cost even a small utility and its customers millions of dollars annually. Studies in Chile and Thailand have estimated the value of energy demand that goes unserved owing to outages at between $360/MWh and $1,500/MWh (Concept Economics 2008). Because outages are expensive, utilities focus on improving reliability. Automation is one of the best tools they can use.

Tata Power Distribution Utility of India lowered its index of the average duration of system interruptions (known as SAIDI) from more than 2.3 hours to 46 minutes by investing in substation automation, supervisory control and data acquisition (SCADA) systems, and advanced distribution management. For some projects, the payback time for investments in automation can be as short as two years (Dondi, Peeters, and Singh, undated).

In another example, the California Energy Commission (2009) estimated that a range of interventions, including distribution automation, yielded an annual benefit of as much as $600 million. Such savings are of course the result of the increased system reliability and improved efficiency that come with automation. But the benefits noted in the study also include the ability to increase the penetration of distributed energy resources—such as photovoltaic devices, demand response mechanisms, and combined heat and power—that could not be integrated into the power system without the flexibility offered by distribution automation. The study concluded that 50 percent of project benefits accrue to utilities, with the remainder split nearly equally between customers and society in general.

Key advantages of distribution automation include:

- **Outage prevention.** Substation equipment (remote terminal units) can be used with power monitoring equipment to detect and correct power-related problems before they occur and before load must be shed, thus improving reliability and customer satisfaction (Csanyi 2015).

- **Rapid restoration/self-healing grid.** Automation systems can help with fast fault detection, location, and clearing, drastically reducing the duration of outages.

- **Reduced maintenance costs.** Preventive maintenance algorithms can be integrated into distribution automation systems to schedule maintenance and help deploy resources, thereby optimizing the use of resources, reducing labor costs, and extending equipment life.

- **Improved system utilization.** The vast amounts of data available through automated grids can help planners and operators to better understand system constraints (such as loading of lines and congestion points) so that systems can be operated at higher levels.

- **Longer equipment lifespan.** The traditional methods that utilities use to localize a fault on a feeder involve reclosing the faulty feeder many times, which strains electromechanical equipment and shortens its useful life.
Distribution automation is promising enough to allow leapfrogging over interim technologies and to help restore some utilities to viability. But we must also keep in mind that the power sector is capital intensive. Most utility assets have a long lifetime, and replacement cannot always be instantaneous.

What is distribution automation?

Modern automation systems combine and coordinate various components across the grid to improve reliability and performance

Power distribution systems have long included various types of automation. Relays that triggered circuit breakers in response to faults were an early form of distribution automation, one that protected life and property. However, once the circuit was broken, the faulted line or equipment stayed out of service even if the source of the fault was no longer present. So-called auto-reclosing breakers solved this problem by clearing transient faults and restoring power.

Distribution automation systems comprise rugged hardware, customizable logic, and a variety of services. Together, they detect faults, isolate trouble spots, and optimize reconfiguration of the network. Typical systems include: distribution automation controllers (DACs), protective relays, reclosers, voltage regulator controls, tap-changing transformers, conservation voltage reduction, volt VAR optimization devices, faulted circuit indicators, emergency generators, up and down ramp generators, and wired and wireless communications.

DACs also collect large amounts of data about the grid, which is very important to operators and planners.

The architecture for distribution systems can vary. Primarily, there are two types of architecture: decentralized and centralized. In a decentralized control network, DACs are located at local substations (figure 1a), controlling equipment on a portion of the distribution network. Each DAC communicates with the DAC in an adjacent zone whenever reconfiguration affects that zone. Such decentralized systems are cost-effective, scalable, and highly reliable. A centralized architecture (figure 1b), which is usually appropriate for a complex network, uses a single DAC to protect, monitor, and control the entire distribution system. This architecture supports large numbers of end devices through the use of front-end processors that provide data communications services.

Centralized systems offer a full system view for purposes of restoration, but they have the slowest restoration times. They also

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**Figure 1. Architectures for distribution automation**

a. Decentralized

![Decentralized Architecture](image)

b. Centralized

![Centralized Architecture](image)

Source: Schweitzer Engineering Laboratories.

SCADA = supervisory control and data acquisition
DMS = distribution management system
DAC = distribution automation controller
FEP = front-end processor
“Systems must have the flexibility to change topology (or configuration) so as to reduce losses and restore power as quickly as possible.”

require the most bandwidth for operation and a full distribution management system. Decentralized systems, on the other hand, require lower bandwidth, are more scalable, and provide stability at a relatively lower cost (compared with centralized systems).

To be able to use any of these configurations, the underlying distribution network must be properly designed. The topology (or configuration) of the network determines which mode of operation can be supported. Radial circuits, for example, do not lend themselves to significant automation because there are no alternate paths to supply power to healthy segments when there is a fault. An optimal distribution system ensures that operating conditions such as system voltages and line loading are fully satisfied and that the system is operated at the highest efficiency and with the lowest rate of system losses. Because numerous events can affect the operating conditions of distribution systems, systems must have the flexibility to change topology so as to reduce losses and restore power as quickly as possible.

Operating conditions also can change seasonally or in response to special events. Under these conditions, the network operating criteria, including recommended thresholds for voltages and line loading, may be breached, leading to higher losses and potential overloads. Even under such conditions, it is paramount to restore service to as many customers as possible after a fault occurs, at least to those located on healthy sections of the network.

The location of line breakers, or remotely controlled switches along the feeders, makes it possible to achieve both goals: maintaining acceptable operating conditions while also meeting demand to the extent possible by modifying the topology of the network, a process known as reconfiguration. Reconfiguration involves closing some switches and opening others so as to maintain optimal operating conditions and avoid technical losses while transferring loads from the healthy portions of faulty feeders to neighboring feeders that are operating normally. In an ideal reconfiguration scenario, all loads are served; overcurrent protective devices are coordinated; lines, transformers, and other equipment are kept within current

1 According to the Electric Power Research Institute (EPRI), a DMS is a “decision support system that is intended to assist the distribution system operators, engineers, technicians, managers and other personnel in monitoring, controlling, and optimizing the performance of the electric distribution system without jeopardizing the safety of the field workforce and the general public, and without jeopardizing the protection of electric distribution assets.”

Box 1. Network reconfiguration for service restoration

The figure below shows an example of a distribution system with three feeders in which switches have been located to increase flexibility in system operation. The five steps for reconfiguring the system after a fault are:

- The feeder relay clears (eliminates) the fault.
- Switches 1 and 2 open to isolate the fault.
- The feeder relay recloses to energize the feeder up to the location of switch 1 (upstream restoration).
- System reconfigures by choosing the best option from the possibilities indicated in the table for fault 1 (downstream restoration).
- The fault is repaired and the system is restored to normal.

The first four steps ideally should be completed within a minute. System reconfiguration changes topologies and line flows, and short circuit values also change. Therefore, equipment duties (or current ratings), voltage profiles, and equipment loading have to be checked. Most distribution automation systems also allow operators in the control room to simulate some of these sequences using real-time data without interrupting normal operations.

Reconfiguration options for the system

<table>
<thead>
<tr>
<th>Fault</th>
<th>Open</th>
<th>Close</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>1 and 2</td>
<td>T1 or T3</td>
</tr>
<tr>
<td>F2</td>
<td>8 and 9</td>
<td>T1 or T2</td>
</tr>
<tr>
<td>F3</td>
<td>12 and 13</td>
<td>T2 or T3</td>
</tr>
</tbody>
</table>

Three-feeder system illustrating switch locations for service restoration

Legend:
I, II, and III = distribution feeders
1, 2, 3, … 14 = switches
F1, F2, F3 = faults
T1, T2, T3 = tie (or interconnecting) switches
s = load
DiSTriBuTion AuT omATion: An opporTuniTy T o improve reliABiliTy AnD Qu AliTy

capacity limits; and voltage drop is held within limits. Box 1 shows how distribution automation can be used for fault location (or detection), isolation, and service restoration.

How has the Bank supported distribution automation projects?

The World Bank is investing in distribution automation through four projects while widening the field for future advances elsewhere

From fiscal year 2010 to 2015 (FY 2010–15), the World Bank committed $378 million to four projects that explicitly included distribution automation (table 1), the largest of which is the Eletrobas Distribution Rehabilitation project in Brazil. Through other projects, though, the groundwork for subsequent deployment of distribution automation is being laid. An example is a project to strengthen the grid by converting radial lines to looped configurations. While this cannot be categorically described as a distribution automation project, it is an important step toward a system that can make good use of distribution automation.

The Eletrobas project sought to improve the finances of six distribution companies located in Brazil’s relatively poorer provinces, the only companies not privatized a generation ago. Shrinking federal subsidies, the high cost of servicing remote and unpopulated areas, and poor long-term planning provided the impetus for a comprehensive smart grid project designed to address revenue loss through advanced metering infrastructure and to improve reliability through distribution automation. Despite initial challenges with procurement, the project is on track.

In Vietnam, the Distribution Efficiency Project sought to improve the performance of Vietnam’s power corporatons by providing reliable electricity services of high quality through: (i) introduction of SCADA systems; and (ii) introduction of automated metering infrastructure, a key feature of which is two-way communication between meter and utility.

The Kenya Electricity Modernization Project seeks to reduce the duration of system interruptions. The utility, Kenya Power and Lighting Company (KPLC), is implementing various projects to automate and enhance the operational flexibility of the distribution network—particularly at the medium-voltage level. The project aims at achieving 90 percent automation of the networks in Nairobi by installing a thousand load break switches in the 11, 33, and 66 kV networks, with associated remote terminal units and communications features enabling remote control and operations.

How relevant is distribution automation to the World Bank’s clients with weaker power grids?

All grids can benefit from various levels of automation, but not all grids (even in advanced power systems) are ready for advanced automation. One could argue that for those parts of the grid that are hard to reach, maximum automation offers several of the benefits discussed previously. However, these benefits need to be balanced with the costs of distribution automation. Relatively large investments, especially in communication systems, are often required to take advantage of the benefits of advanced automation systems, whereas the load on such grids is typically small.

Operating a highly automated grid also calls for a different set of skills for system operators. Considerable training is usually necessary. But of greater importance in distribution automation projects is to assist clients to understand how much automation they really need. The scale of automation and the ultimate configuration of the system

Table 1. World Bank commitment to distribution automation projects, FY2010 to Q3 FY2016 (millions of U.S. dollars)

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Project name (country)</th>
<th>FY</th>
<th>Commitment to distribution automation</th>
<th>Total WB commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P114204</td>
<td>Eletrobras Distribution Rehabilitation (Brazil)</td>
<td>2010</td>
<td>293.90</td>
<td>495.00</td>
</tr>
<tr>
<td>P125565</td>
<td>Electricity Sector Support (Senegal)</td>
<td>2013</td>
<td>1.00</td>
<td>85.00</td>
</tr>
<tr>
<td>P125996</td>
<td>Distribution Efficiency (Vietnam)</td>
<td>2013</td>
<td>62.80</td>
<td>448.90</td>
</tr>
<tr>
<td>P120014</td>
<td>Electricity Modernization (Kenya)</td>
<td>2015</td>
<td>20.00</td>
<td>250.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>377.70</td>
<td>1,278.90</td>
</tr>
</tbody>
</table>
need to be considered carefully with each client. The decision to proceed must be based on a sound economic evaluation; it cannot simply echo the mantra of automation. The required analysis should also include the costs and benefits of alternative communication technologies that can be used to achieve the desired objectives.

In some cases, proper consideration of a distribution automation project may also require changing the mindset of operators who are used to long-standing operational protocols. Capacity building therefore needs to go beyond conventional training. For example, extensive training in which operators can use simulators to become comfortable with the system could help open up their thinking. Finally, the communication needs of the grid also must be clearly outlined to ensure interoperability.

A further challenge to distribution automation is ensuring interoperability of components from various manufacturers. Quite often, distribution grids grow organically; in such cases integrating components can be challenging. To maximize interoperability, the Bank could assist clients with the formulation of smart grid roadmaps that identify the desired policy goal and chart a pathway to meeting objectives (see, for example, Madrigal and Uluski 2015). Such a roadmap can inform the construction and rehabilitation of transmission substations and lines while systematically factoring in communication needs to ensure that capacity and communication are improved together.

The development of proper technical specifications for distribution automation projects is also critical. For example, as information technology improves and Internet speeds increase, it is often simply assumed that existing IT can be used across all power system applications. This is not a safe assumption. While it is generally acceptable to attempt multiple message deliveries in IT, message delivery in the operations technology (OT) context of a distribution automation project needs to be swift and 99.99% reliable. OT protocols ensure interoperability and reduce investment costs. This is important because, as we deal with our clients, we need to ensure that projects do not tie them to specific vendors. With growing interconnectivity, cyber-security becomes an issue and needs to be dealt with in technical specifications.

References


This note draws from original work by Juan M. Gers and Héctor Enrique Peña on network reconfiguration for improved reliability and presentations by Amandeep Kalra and David Dolezilek of Schweitzer Engineering Laboratories. It was peer reviewed by Leopold Sedogo. The authors wish to thank the reviewer and contributing staff of SEL, including André du Plessis, for their assistance. The authors acknowledge support received from Morgan Bazilian.
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