The bottom line

SCADA/EMS and SCADA/DMS systems ensure that power grids are efficient, resilient, and able to adapt to changes in generation, transmission, and distribution. Advancing technology is making SCADA systems more capable and enabling new monitoring and management applications. World Bank support for such systems is crucial to ensuring the sustainable long-term growth of power networks in developing countries. Meanwhile, the potential exists to significantly enhance grid management in many cases by activating already installed equipment.

Managing the Grids of the Future in Developing Countries: Recent World Bank Support for SCADA/EMS and SCADA/DMS Systems

Why is this issue important?

All but the smallest power grids depend on SCADA systems to operate safely and reliably

Supervisory control and data acquisition (SCADA) systems are crucial to ensuring that power grids supply electricity safely and reliably. Combined with a larger energy management system (EMS) that oversees the whole grid, or with a distribution management system (DMS) that oversees the proper functioning of a distribution network, SCADA systems mitigate against transient events that result in outages. Without SCADA/EMS and SCADA/DMS systems, it is nearly impossible to control any but the smallest power grids. Without such systems, larger grids are unstable and unreliable, prone to severe and prolonged faults. SCADA systems are necessary if power networks are to provide universal access, operate efficiently, and integrate renewables.

Following a series of blackouts in the northeast United States in 1965, an investigating commission concluded that it was imperative for utilities to develop a system, using then-new computers, to improve power system control and planning. The commission specifically called for control centers that were capable of rapidly checking the state of the interconnected power systems of different utilities to ensure that the grid remained in a safe and stable state. In response, a number of utilities developed EMS, which brought together data acquisition devices and systems, robust communication networks, and sufficient computational power and logic to ensure that the burgeoning interconnected power system continued to operate safely.

Owing to the limits of technology at the time, much of the necessary equipment had to be custom-built to ensure that it was able to function at the speed needed to respond adequately to changes in the grid (Wu, Moslehi, and Bose 2005). While in the short-term these custom devices provided a significant increase in the ability of utilities to maintain their power grids, they eventually proved to be a hindrance. These nonstandard legacy devices could not keep pace with the development of technology or with changing regulatory directives. The initial desire to have robust control mechanisms that were independent from other systems had a perverse effect: the systems were relatively inflexible and closed.

Since the creation of the first EMS, the deployment of sophisticated measuring devices as well as the addition of new types of generation and new types of load have markedly increased the amount of data that enters the system. Meanwhile, vertical unbundling of utilities, the diversification of markets for energy generation and sale, regulatory changes favoring renewables, and other major changes in the structure of the power marketplace have increased demands for such data. All this has required fundamental changes in the architecture of network management systems (Wu, Moslehi, and Bose 2005).

A modern SCADA/EMS system consists of a set of interconnected systems responsible for all aspects of the operation of the power grid: generation, transmission, consumption, technical and...
financial performance, and regulatory compliance. Key to all this is a SCADA system that gathers technical data from across the power grid and presents it in a single coherent picture. Having such a picture allows a utility or grid operator to ensure that the system is in optimal state by balancing supply and load, detecting and damping instabilities, recognizing and averting failures, and locating technical faults (Bertsch and others 2005). Many utilities and operators also augment a SCADA with a business management system, which feeds into financial and planning systems (Wu, Moslehi, and Bose 2005).

Similarly, a SCADA/DMS system consists of a set of interconnected systems responsible for the operation of the power distribution grid: management of medium- and low-voltage networks, integration of generation from decentralized renewable sources, network planning, technical and financial performance, and regulatory compliance. Because of the large number of assets in distribution networks, databases to manage the medium- and low-voltage networks are significantly larger than their EMS counterparts. SCADA is one key source of data, but further integration with geographical information systems and workforce management tools is essential in operating a power distribution grid.

Beyond these basics, the deployment of a technology known as phasor management units (PMUs) is making it possible to more accurately measure the performance of networks at increasingly smaller intervals and in ever-greater detail. PMUs are able to measure local energy conditions as often as once a cycle—50 times per second in a 50Hz system and 60 times per second for 60Hz systems. Along with accurate timing signals, available using GPS and other Ethernet network–based time distribution protocols, PMUs can be synchronized so as to offer grid operators extremely detailed and accurate information, allowing much faster responses to grid incidents and potentially preventing outages.

What are the current major trends in SCADA/EMS and SCADA/DMS systems?

Decentralization of control functions, integration of renewables, and the growing importance of regional power pools are the markers of today’s SCADA systems

Three major trends currently dominate the development of SCADA systems. Two are universal; a third is particularly evident in several World Bank countries.

First, most modern SCADA/EMS and SCADA/DMS are shifting from having a central control room. The development of computing and communications hardware has proven to be a boon to the power sector, providing sufficient processing capability at every level to monitor and analyze local conditions and to respond appropriately. Even as there is less need for communication back to a central control room, the parallel boom in communications technology has allowed greater amounts of data to be reliably transferred for analysis. A typical high-speed SCADA system installed a generation ago would rely on a connection of just 9.6 kb/s for an entire area; by contrast, modern fiber optic networks are capable of connections at least six orders of magnitude faster, with extremely low latency. This enables much greater insight into the functioning of the power grid and opens new optimization avenues for utilities and operators (Wu, Moslehi, and Bose 2005).

PMUs are an example of a technology in the power sector that takes advantage of advances in computing and communications technology. They are embedded in a vast number of devices connected to the grid and are able to sample local electricity conditions as often as once a cycle. Collectively, they give a grid operator a real-time view of power networks where previous generation systems provided updates only 15 to 20 times per minute. PMU measurements are time-stamped to an extraordinary degree—with an average time-synchronization accuracy of under 500 nanoseconds (IEEE 2011), available through a combination of GPS and wireline timing signals. These measurements are transmitted to a node, known as a phasor data concentrator (PDC) with control (also known commercially as a synchrophasor vector processor). The PDC is able to analyze the synchrophasor measurements from several PMUs to
Many countries with phasor management units already installed are not taking advantage of the technical capabilities of these devices, which may not be fully operational because of the lack of adequate communications networks. These are all ready to be activated once the necessary communications network has been established.

Unfortunately, many countries with PMUs already installed are not taking advantage of the technical capabilities of these devices, which may not be fully operational because of the lack of adequate communications networks. A large number of dormant PMUs are embedded in the power systems of Sub-Saharan Africa (table 1). About two-thirds of these units are in South Africa, but about 425 are located in the West African Power Pool, comprehensively supported by the World Bank. Another 110 are in the East African Power Pool, and others are spread throughout the continent. These are all ready to be activated once the necessary communications network has been established.

The second major trend to be considered concerns the growing importance of renewables. New regulatory directives to increase renewable energy as a share of generation mean that modern SCADA/EMS and SCADA/DMS systems must take into account not just changing demand, but also variable, intermittent, and possibly decentralized supply.

A typical older grid had large coal-fired units, combined-cycle gas turbines, or hydropower plants to meet baseload, with peaking power provided by gas-fired turbines dispatched at predefined times—thus ensuring security of supply and providing frequency stability to the system (Singh and Singh 2009). With renewable sources being both variable and distributed, modern SCADA systems need to work in an integrated fashion to ensure that voltage and frequency of supply are maintained within prescribed operating limits. This may even require sophisticated modeling of very local weather patterns. Additionally, consumer-owned renewable generation may be injected into the distribution network, requiring DMS system upgrades.

If sufficient renewable capacity is unavailable, the SCADA/EMS will need to ramp up other generation sources, potentially rapidly, all while continuing to participate in energy markets to ensure the lowest cost (Järventausta and others 2010). Because many optimal renewable energy sites are remote from load centers, SCADA/EMS systems also need to ensure that renewables are not curtailed owing to capacity constraints on transmission lines. Finally, SCADA/EMS and SCADA/DMS systems are also expected to interface with new consumer equipment to conduct demand-side management. All of these factors significantly increase the computational burden on SCADA systems and require SCADA/EMS and SCADA/DMS upgrades to ensure that the grid performs optimally (Wu, Moslehi, and Bose 2005).

The third major trend in SCADA development is particular to World Bank efforts in the power sectors of client countries. The World Bank has been involved heavily in creating regional power pools—both within countries such as India, where disparate grids and planning processes led to inefficiency, and between countries, as with the East and West African Power Pools. The pools provide greater plant efficiency by allowing larger, more efficient units to be installed and operated at peak efficiency. Pools also offer greater efficiency by allowing power to flow optimally from generators to load centers. Finally, pools can lead to lower costs for consumers by exploiting efficiencies of scale. However, power pools are complex to manage, both from an operational perspective and with respect to legal and regulatory compliance. In established power pools, such as the European Internal Energy Market, power flow decisions are relatively straightforward. But in new

<table>
<thead>
<tr>
<th>Country</th>
<th>Dormant PMUs</th>
<th>Country</th>
<th>Dormant PMUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botswana</td>
<td>61</td>
<td>Namibia</td>
<td>253</td>
</tr>
<tr>
<td>Congo, Dem. Rep.</td>
<td>22</td>
<td>Niger</td>
<td>1</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>2</td>
<td>Nigeria</td>
<td>251</td>
</tr>
<tr>
<td>Djibouti</td>
<td>2</td>
<td>South Africa</td>
<td>2,308</td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>8</td>
<td>Swaziland</td>
<td>80</td>
</tr>
<tr>
<td>Ghana</td>
<td>170</td>
<td>Tanzania</td>
<td>3</td>
</tr>
<tr>
<td>Kenya</td>
<td>64</td>
<td>Uganda</td>
<td>19</td>
</tr>
<tr>
<td>Mauritius</td>
<td>33</td>
<td>Zambia</td>
<td>20</td>
</tr>
<tr>
<td>Mozambique</td>
<td>31</td>
<td>Zimbabwe</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,448</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Schweitzer Energy Laboratories calculations.
pools, particularly those that are supply constrained, a comprehensive SCADA/EMS that is able to correct for changing supply and demand in multiple grids is essential to ensure that such pools run efficiently and effectively.

What has the Bank done to support SCADA/EMS and SCADA/DMS deployments?

The Bank has supported SCADA/EMS and SCADA/DMS installations for years—with excellent results.

In the Bank's early SCADA investments, the technology was applied to control systems for individual components of energy systems, such as individual generators. The first system-wide SCADA project financed by the World Bank, the Distribution Automation and Reliability Improvement Project (P042268) in Thailand, dates back to 1996. That project involved the installation of 1,600 remote control switches, 156 remote terminal units (RTUs) in as many substations, an extensive microwave radio network that spanned most of Thailand, and a comprehensive EMS and business management system to improve power system efficiency, strengthen system operations, and automate billing. The project successfully increased the reliability of the Thai power grid and significantly improved the financial health of the utility.

More recently, the Bank has invested about $162 million for SCADA in eight power projects in seven countries, as well as the countries of the West African Power Pool (table 2). This support for SCADA amounts to about 8 percent of the total $2.06 billion in Bank financing for the power projects involved. The Bank has also leveraged an additional $945 million from other sources for these eight projects, which cover five of the six World Bank regions. In the past two fiscal years, demand for SCADA and EMS system installations has significantly accelerated, and the World Bank has responded with projects to support such installations.

The following brief notes highlight challenges and opportunities in a few Bank-supported SCADA projects.

**West African Power Pool: First Phase of the Inter-Zonal Transmission Hub Project (FY 2011).** As a first step toward integrating the grids of Burkina Faso and Ghana within the West African Power Pool, the World Bank financed a transmission line connecting the substation at Bolgatanga in Ghana with the Zagtouli substation in Burkina Faso’s capital, Ouagadougou. As part of the transmission line connection, the Bank financed an EMS that was able to remotely control both substations from either end to ensure that both grids were stable. After a delay in procurement owing to reallocation of funds between the three major donors financing the project, the project is now under way. When complete, it will cut average monthly

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**Table 2. IBRD/IDA-financed SCADA/EMS deployments, FY2010 to Q3 FY2016**

<table>
<thead>
<tr>
<th>FY</th>
<th>Project ID</th>
<th>Project Name</th>
<th>Country</th>
<th>US$ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>P094919</td>
<td>First Phase Inter-Zonal Transmission Hub</td>
<td>West African Power Pool</td>
<td>0.46</td>
</tr>
<tr>
<td>2011</td>
<td>P114971</td>
<td>Energy Sector Strengthening Project</td>
<td>Paraguay</td>
<td>16.00</td>
</tr>
<tr>
<td>2014</td>
<td>P144534</td>
<td>Renewable Energy Integration</td>
<td>Turkey</td>
<td>32.50</td>
</tr>
<tr>
<td>2015</td>
<td>P120014</td>
<td>Electricity Modernization Project</td>
<td>Kenya</td>
<td>10.00</td>
</tr>
<tr>
<td>2015</td>
<td>P131558</td>
<td>Transmission Efficiency Project (TEP)</td>
<td>Vietnam</td>
<td>55.00</td>
</tr>
<tr>
<td>2015</td>
<td>P143689</td>
<td>Clean and Efficient Energy</td>
<td>Morocco</td>
<td>5.00</td>
</tr>
<tr>
<td>2015</td>
<td>P146788</td>
<td>Second Power Transmission Project</td>
<td>Ukraine</td>
<td>41.50</td>
</tr>
<tr>
<td>2016</td>
<td>P153743</td>
<td>Electricity Access Expansion Project</td>
<td>Niger</td>
<td>1.50</td>
</tr>
</tbody>
</table>

outages in Burkina Faso from 130 hours to 8, benefiting some 20,400 customers, and reducing tariffs by about 4 percent on average.

**Turkey: Renewable Energy Integration (FY2014).** Turkey has committed to increasing wind energy in the country from 2,700 MW (4 percent of installed capacity) to 20,000 MW (20 percent) by 2023. Wind energy being less predictable than traditional fossil fuel or hydropower plants, the Turkish transmission company operator, TEIAS, required a large upgrade of its SCADA system to cope with integration of large amounts of wind power and to ensure that power was efficiently dispatched in response to demand. While higher-voltage substations already had RTUs installed, many of these were functionally obsolete, and medium-voltage substations, which often serve as the integration point for wind power plants, had not been upgraded with RTUs at all. To make matters worse, the existing EMS did not have any capacity to predict wind, the transmission network itself was close to capacity, and the distribution networks were overloaded.

In response, the World Bank financed a $300 million project to address both the need for additional transmission and distribution capacity and to better support the integration of a greater share of wind into the Turkish grid system. About 10 percent of the project financing, $32.5 million, supported the upgrades to the EMS and SCADA systems. The project also drew $50 million from the Clean Technology Fund, of which half went toward the EMS and SCADA system upgrades. Though there has been a delay in the supply of the RTUs owing to insufficient staffing at TEIAS, contracts for SCADA/EMS system upgrades have been awarded, and installation is proceeding. When the project is complete, the EMS will connect 600 MW of new wind generation and will be able to predict wind at 15-minute intervals. The changes will add 1,730 GWh of power and reduce emissions by 0.7 million tons of CO₂ annually. Additionally, 80 percent of all substations will have RTUs installed, up from 33 percent, and a dedicated renewable energy operations center will be functional.

**Kenya: Electricity Modernization Projects (FY2015).** The Kenya Power and Lighting Company (KPLC) is responsible for the transmission and distribution of electricity to approximately 2.7 million customers. KPLC has made impressive strides toward the goal of electrification of all Kenyan households. However, due to past underinvestment, the current transmission and distribution systems are overstressed and unable to cope with new demands. On average, a Kenyan customer experiences 12 hours of interruptions a month. To address these concerns, the World Bank has put together a comprehensive program to overhaul the Kenyan power sector. Key to improving service delivery and reliability is an approximately $10 million upgrade of the existing SCADA/EMS system. This will bring monitoring and control of an additional 60 key substations to the 86 already managed by the SCADA system. Post-project, 90 percent of the substations operated by KPLC, covering the vast majority of customers, will be monitored and controlled by the utility’s EMS. Following resolution of a protracted budgeting discussion, the project has begun the procurement process. At completion, the SCADA upgrade is expected to contribute to cutting the system average interruptions duration index (SAIDI) in half.

**Vietnam: Transmission Efficiency Project (FY2015).** Electricity Vietnam (EVN) has seen a rapid growth in electricity demand—averaging 10–15 percent a year since 2008. Transmission investments are urgently needed to reduce network overload, cut load shedding, and meet expected growth in demand. At the 500 kV and 220 kV levels, which form the backbone of EVN’s transmission network and connect to the various distribution companies, incompatible standards, miscommunication, and decaying equipment have contributed to unreliability in the network, resulting in prolonged and severe faults. A lack of computing equipment means that most records are kept on paper, increasing the error rate and making it very difficult to prioritize and plan long-term maintenance.

To address these problems, as part of a $55 million refurbishment of key EVN substations, the World Bank will support the installation of a SCADA system to improve monitoring and management, reduce faults, and ensure that correct procedures are followed during power restoration. The contracts needed for the SCADA system are expected to be awarded by mid-2016. When complete, the project will increase the total system transfer capacity by 80 percent, reduce shed generation by 5GWh a year, and reduce faults by a quarter.

**Morocco: Clean and Efficient Energy (FY2015).** Morocco has been a leader in the use of renewable energy in North Africa. The country has already worked with the World Bank on large renewable...
projects such as the Ouarzazate Concentrated Solar Power Plant. To ensure that power from these extensive investments is fully utilized, the World Bank is supporting the establishment of a national renewable energy dispatch center. Studies show that such a center can reduce the present $8–$9/MWh integration costs of renewable energy by at least half.

The new dispatch center, to be co-located with the national electricity and water utility company’s primary load dispatch center, will have a comprehensive SCADA system. This system will provide forecasting functions for generation from renewable sources, real-time tracking of output (crucial for efficient scheduling and dispatching), and data analysis for further system planning. Procurement is proceeding on schedule. When operational, the project is expected to help Morocco avoid 78 million tons of CO2 emissions.

**Ukraine: Second Power Transmission Project (FY2015).**

Energy demand and supply dropped significantly in Ukraine during the 1990s: generation fell from nearly 300 TWh in 1990 to 170 TWh in 2000. Since then Ukraine has seen robust demand growth, but it still has excess supply potential that could serve as a revenue stream to allow Ukraine’s power grid to interact with the European Internal Energy Market. The World Bank's Second Power Transmission Project will fund an EMS to allow Ukraine’s power grid to interact with the European Internal Energy Market.

The project supports the refurbishment of key sections of the transmission infrastructure that are at the end of their useful life: some 16,700 km of transmission lines are more than 30 years old, and 229 transformers are at least 25 years old. New substations are planned to support present and projected load growth, but also, crucially, to enable the transmission system operator, NPC Ukrenergo, to tie into the European power grid operated by the European Network of Transmission System Operators for Electricity. The World Bank is providing financing for an EMS that will enable Ukrenergo to dispatch power into the European Internal Energy Market after ensuring that domestic needs are met. After a short delay for Ukrenergo and regulators to clarify aspects of the enabling law, the project is in the procurement process, with tenders to be launched in mid-2016.

**Niger: Electricity Access Expansion Project (FY2016).**

Niger has seen extremely fast growth in electricity consumption since 2001—averaging 8.5 percent a year, more than twice the average GDP growth for the same period. However, the growth in demand has been met primarily by below-cost electricity imports from Nigeria, which itself is capacity constrained. Thus, Nigelec, the state-owned utility, is embarking on a plan to increase domestic generation capacity and to reduce reliance on imports, even as it expects to see accelerating growth in the use of electricity over the next decade.

To help Nigelec meet its electrification and service reliability targets, the World Bank has developed the Electricity Access Expansion Project, which will expand and reinforce distribution networks in seven urban areas, benefitting some 330,000 customers. As part of the reinforcement, the World Bank is helping Nigelec study the installation of a SCADA system to manage its high- and medium-voltage networks to improve system reliability and allow centralized control of the distribution networks. The project is expected to become effective shortly.

What have we learned from our engagements, and where do we go from here?

**SCADA/EMS and SCADA/DMS system deployments in World Bank–financed projects have closely followed global trends**

In many of the poorest countries, where access has been the predominant challenge, World Bank projects have crucially supported the deployment of basic SCADA systems that enable a utility or grid operator to understand how their networks are functioning and address basic operational issues, such as fault detection and restoration.

In countries where the grid is more sophisticated, World Bank financing has enabled more-advanced applications—from providing operating and planning tools crucial to the long-term development of the power-grid to integrating renewable energy with forecasting systems. In most cases, such projects are in the early stages of implementation, but they are uniformly identified as critical to further progress in the power sector.

Through its support of SCADA/EMS and SCADA/DMS projects, the World Bank has helped many countries meet their power growth needs. With increasing focus on integrating variable renewable
energy and other measures (such as demand-side management as a means of controlling emissions from power generation), the need for SCADA/EMS and SCADA/DMS systems is expected to grow. It will be important to ensure that this growth occurs systematically rather than on an ad-hoc basis. Without a consistent development path to follow, there is a strong risk that the installed systems may be incompatible, which may be worse than having no system at all. The Bank can continue to help build its clients’ capacity for the preparation of technical specifications for SCADA/EMS and SCADA/DMS projects, drawing heavily on international standards prepared by the International Electrotechnical Commission and Institute of Electrical and Electronics Engineers.

One relatively quick and easy option is to work with clients to maximize the potential of equipment already installed. As seen, a number of already-installed PMUs are not enabled. Enabling even a fraction of these synchrophasors through an appropriate communications network would enable the countries to operate more-stable grids by locating and damping out instabilities that cause outages. Such stability in national grids is also likely to have positive benefits in regional power pools, as the grids are able to integrate more closely without fear of contagious instability. Countries successfully completing such projects would be able to leapfrog over many developed countries in understanding and controlling their grids. World Bank support is likely to be crucial to ensuring the financing of such projects and providing the technical expertise needed to best utilize these advanced technologies.

Another important area for Bank engagement is to emphasize the importance of SCADA/DMS systems in client countries. With an estimated 80 percent of customer power outages occurring because of incidents in medium-voltage distribution networks (Zhang, Gockenbach, and Borsi 2005), and with unbundling continuing in client countries, investments in SCADA/DMS are essential. Integrating geographical information systems and work force management tools with SCADA/DMS will allow utilities in client countries to improve availability, reliability, and quality of power supply to consumers and industries.

References


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