The Intelligent Power Grid

by Jeffrey Taft, IBM

Electric utilities can respond to new regulatory and customer expectations by increasing power grid observability and using modern data integration and analytics software.

A number of organizations, such as the Electric Power Research Institute (EPRI) (IntelliGrid)[1], the U.S. Department of Energy (DOE) (GRID 2030)[2] and Battelle (GridWise™)[3], have offered definitions of the "intelligent power grid." These definitions have certain features in common: the concepts of reliable and economical power delivery, information flow and secure communications. The intelligent power grid is a tool for helping electric utilities focus on their evolving true business drivers; that is, to move from a "keep the lights on" approach to an emphasis on asset utilization optimization and life cycle management, cost containment, end-to-end power delivery chain integration and having a secure infrastructure. Electric utilities will need to use intelligent power grid technology to meet the electric energy needs of the 21st century. These needs include:

- Reliable delivery of high-quality power over a stable grid;
- Ability to meet or exceed mounting customer performance requirements; and
- Facilitating the digital ecosystem.

These needs are becoming increasingly difficult for electric utilities to meet in the face of a variable regulatory environment, complex industry restructuring and the changing nature of ever-more-complex customer loads based on the proliferation of digital systems. This evolving digital ecosystem not only presents new power quality demands, it also causes utility customers to have ever-higher expectations for the electric utility in terms of automation and intelligent equipment and systems functions.

What Is the Intelligent Power Grid?

The intelligent power grid is characterized by increased grid observability with modern data integration and analytics to support advanced grid operation and control, power delivery chain integration and high-level utility strategic planning functions. Some key characteristics of the intelligent power grid are:

- Grid equipment and assets contain or are monitored by intelligent IP-enabled devices (digital processors);
- Digital communication networks permit the intelligent devices to communicate securely with the utility enterprise and possibly with each other;
- Data from the intelligent devices and many other sources are consolidated to support the transformation of raw data into useful information through advanced analytics; and
- Business intelligence and optimization tools provide advanced decision support at both the automatic and human supervisory level.

For both transmission and distribution grids, a great deal of utility asset value resides in the substations, whereas for distribution grids, the vast zone between substations and customer meters contains significant utility assets whose status is unknown until a failure triggers a manual inspection or until a regular maintenance patrol discovers a problem. The goal of an intelligent power grid system is to provide greater observability and, therefore, greater controllability of these assets, thus enhancing power system performance and aiding in cost control and system planning.

The functions of an intelligent power grid system fall into both real-time and nonreal-time categories. In the real-time category, distributed sensing provides increased power grid observability for the purposes of power grid state measurement, power grid device status and health monitoring, failure detection and localization, power quality and reliability monitoring, and safety and security monitoring. Examples of such functions include demand distribution for load balancing; transformer, circuit breaker and tap changer monitoring; detection of energized downed lines, high impedance faults and faults in underground cables including arcing faults; and stray voltage monitoring.

In the non-real-time category, functions include the integration of existing and new utility databases so operational data can be fused with financial and other data to support operational optimization, asset utilization maximization and life cycle management, asset replacement optimization, strategic planning and capital expenditure planning, maximization of customer satisfaction, optimization of system performance metrics and regulatory reporting. Electric utilities already have many of the data sources needed to support analytics for these functions, but these data sources are usually siloed and, therefore, very difficult to combine. Worse, the operational data is usually sequestered in the Supervisory Control and Data Acquisition (SCADA) system and not readily available to support analytics or business intelligence tools. By providing a common integration point and an enterprise service bus, an intelligent power grid system can enable everything from data mining for strategic planning support to real-time-dashboard-type displays of daily asset profitability and asset failure system risk for utility executives.

Some elements of an intelligent power grid already exist in most electric utilities, but the effort to transform an electric power grid into an intelligent power grid involves much more than just hardware and software tools. It also requires a utilitywide business transformation to obtain the full benefit of this added technology. This transformation extends beyond simply monitoring power grid sensors and implementing some new alarms and key performance indicators. Proper integration of an intelligent power grid requires fundamental changes in how a utility functions, extending from grid operations to field service to inventory management to backoffice operations to inventory management to strategic planning. Properly used, the intelligent power grid can lead to streamlined and improved relationships with connected organizations in the power delivery chain, with regulators, and with consumers and the general public as well.

Intelligent power grid systems comprise five major components: data sources, data transport, data integration, analytics and optimization (see Figure 1). Clearly, intelligent power grid systems must have efficient means to distribute results. These means include publish-and-subscribe middleware, portals and Web-based services. These technologies are well-known.

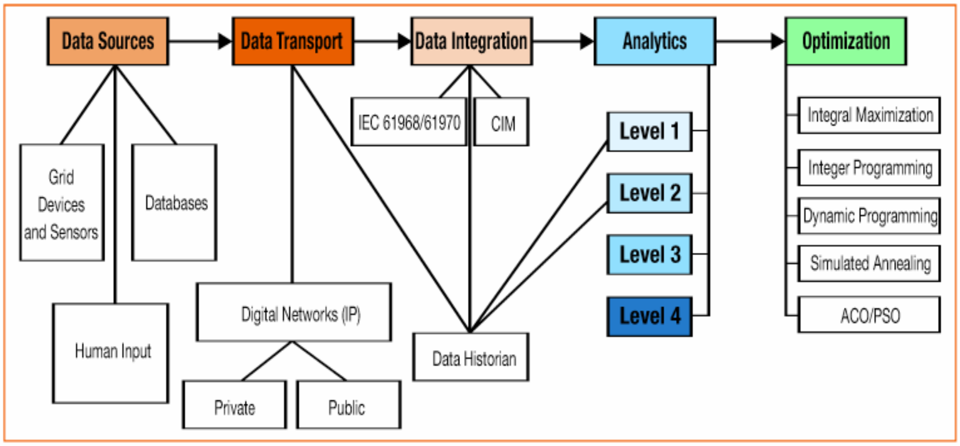


figure 1 *Intelligent Power Grid System Principal Components*

Source: IBM Application Innovation Services

Data Sources

Data for the intelligent power grid can come from many sources, including sources that the utility already has. These include substation instrumentation, intelligent grid devices, meters, smart sensors, utility databases, human input and sources external to the utility. Some distribution grid control devices, such as capacitor controllers, recloser controllers and sectionalizers, already contain digital processors and can collect power line data that is useful for various power grid analytics. Many of them require only a communication channel to make the data accessible. In some cases, new sensors such as line monitors must be deployed, especially on distribution grids. In all cases, a communication infrastructure must be in place to transport data to the data warehouse.

Data Transport

A wide range of wired and wireless communications technologies are available to transport data for an intelligent power grid. There are more than 20 communication technologies that an electric utility might consider for use in an intelligent power grid system, including MPLS, WiMax, BPL, optical fiber, mesh WiFi and multi-point spread spectrum. The key characteristics that any communication technology supporting an intelligent power grid should have are high-bandwidth, IP-enabled digital communication (IPv6 support is preferable), encryption and cyber-security support and quality of service and voice over Internet protocol (VoIP) support. In addition, the utility must carefully consider issues of mobility and roaming support. If the utility is planning to use the communication infrastructure for converged data and voice services, it will have to support not only telemetry but also automated field-force functions such as field-crew voice communications and data download/upload for work orders, reports, timesheets, equipment specifications, maps and real-time grid instrument readings.

Data Integration

Utilities make use of many kinds of databases and many applications that have embedded databases, such as GIS. In addition, real-time data from substations and grid sensors must be integrated into the intelligent power grid system. These data sources do not communicate via common standards, and many of them are not made to support high volumes of queries. Since these applications are being used to support utility operations, they must not be loaded down with frequent data requests from the analytics stack. To solve these problems, we turn to two technologies: message-oriented middleware and data warehouses.

Middleware is software that provides a means to connect dis-parate applications and databases. Middleware provides the extract-transform-load paradigm – a means to obtain data from one application's database and transfer it to another application in the appropriate form. Adapters are frequently used to perform the customization. Middleware can also implement the publish-and-subscribe paradigm (implemented via advanced messaging) and the enterprise integration bus as part of a service oriented architecture. In this manner, the number of required point-to-point connections is minimized, and applications are decoupled from each other so that a change in one application does not have to ripple through to the rest of the applications.

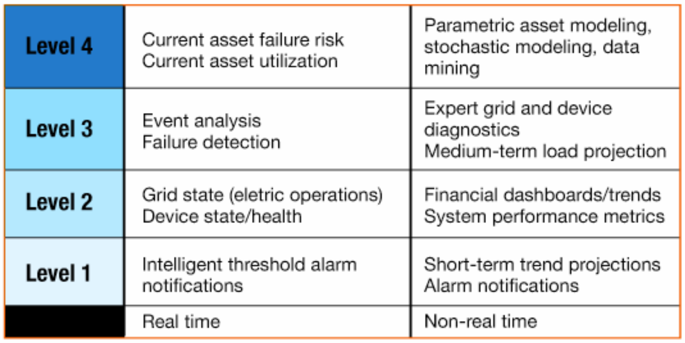
The data warehouse acts as an aggregation point for data from many sources, including the real-time sensor data. The data warehouse also isolates the other utility databases from the potentially high volume of data requests from the analytics applications. We recommend using the common information model (CIM) standard that arose out of initial work at EPRI and now is becoming an open-source standard through the IEC as the basis for structuring the data warehouse. CIM is not a database or database design itself – rather, it is a generic template that can be used to create a model of any specific utility. The CIM model, in conjunction with IEC standards 61968 and 61970, can be used to define a CIM-compliant database. With enterprise service bus middleware and a common language for describing utility assets and structure, it is then possible to implement a CIM-structured data warehouse upon which the analytics operate.

Analytics

We define analytics as the computational and logical functions, displays and messages that provide high-level presentation or interpretation of grid data, or decision support, based on the processing of intelligent power grid data. The analytics functions transform data into actionable information and, as such, require access to and integration of many data sources, including real-time grid data and various utility databases.

There is no limit to the number of analytics that can be created for a utility and as grids become more observable, more analytics will be required to support advanced grid control and business operations. Furthermore, each utility will choose its own customized set of analytics, and the same system can be used to generate technical and business intelligence analytics.

We break analytics down into four categories (see Figure 2):



Level 4	Current asset failure risk Current asset utilization	Parametric asset modeling, stochastic modeling, data mining
Level 3	Event analysis Failure detection	Expert grid and device diagnostics Medium-term load projection
Level 2	Grid state (eletric operations) Device state/health	Financial dashboards/trends System performance metrics
Level 1	Intelligent threshold alarm notifications	Short-term trend projections Alarm notifications
	Real time	Non-real time

figure 2 *Analytics Functions*

Optimization

At the highest levels, decisions involving the commitment of significant financial assets to utility projects require solutions to optimization problems that are generally too complex to be solved manually. In these cases, we can apply a variety of advanced mathematical tools to the data contained in the intelligent power grid data warehouse. These tools are well-known but have not been widely applied to utility decision support due to the lack of integrated databases needed to drive them. Some of these tools are integer programming, integral maximization, dynamic programming and simulated annealing. These techniques can be encapsulated into solution tools that operate as part of the analytics architecture for an intelligent power grid system.

A key and recurrent problem in the electric utility industry involves how to select an optimal set of assets for replacement or upgrade on a limited budget. The solution to this problem is an example of a problem requiring advanced analytics support: It requires integration of several data sources and makes use of sophisticated data mining techniques to build abstract asset parametric models and then applies advanced mathematical methods to determine the optimal solution.

Implementing the Intelligent Power Grid

Implementation of an intelligent power grid is a large-scale undertaking. Fortunately, it may be broken down into stages using the LOGO concept. LOGO stands for “levels of grid observability,” and it refers to the concept of increasing grid observability in an incremental fashion. This allows the utility to break the intelligent power grid implementation into phases with power grid observability and, therefore, supported analytics functionality and corresponding benefits increasing in definable stages at each phase. Some typical layers or stages that a utility might consider are: existing databases, substation data, meters, smart grid devices and new sensors. Each of these groups can be a layer in a LOGO-based intelligent power grid implementation strategy. Taking advantage of LOGO requires the utility to create a road map for implementing the intelligent power grid, which system implementers can use to derive phased plans.

Determining the hard benefits of an intelligent power grid can require thinking about how the utility will work in the future after business transformation has occurred, taking into account the effects of back-office functions such as logistics, service dispatch, call center operation, training, human resources and inventory management. Every utility has different costs and, more importantly, different operating and business factors. When preparing the pro forma cash flow analysis, it is important to take into account the fact that the benefits can only accrue as infrastructure build-out occurs and as business operations adapt to make the best use of the new tools and techniques.

Ultimately, the most compelling benefits an intelligent power grid can offer are the most difficult to quantify. These include improvement in system performance metrics, improvement in customer satisfaction, improved ability to supply accurate information for rate cases with corresponding improvement in regulatory relations, improved visibility of utility operations to senior management, improved access to historical data for strategic planning purposes and, perhaps most importantly, improved support for the digital ecology.

The first item is difficult to equate with money because utilities are presumed to be meeting these goals as part of normal operations. Unfortunately, this is less and less true because deregulation has created a situation where power grids that were originally built for reliability are now being operated for economy, leading to reduced reserves and, therefore, reduced stability margins.

The last item bears some discussion as well. Power quality has been assumed in the past, but as the digital ecology grows, more and more nonlinear loads are placed on the grid, causing more and more harmonic distortion. At the same time, devices attached to the grid have become more sensitive to variations in voltage and frequency that used to go unnoticed. These two effects, coupled with the public's awareness of how electronic technology has improved the functionality of many other common products and services, are causing a gap between customer expectations for the utility and the utility's ability to meet those expectations. Perhaps worse, degradation in power quality causes real economic losses. In 2003, EPRI subsidiary Primen estimated the cost impact of poor power quality on the U.S. economy to be in the range of $119 billion to $189 billion.[4]

Conclusion

The value of the intelligent power grid goes far beyond the electric utility; it reaches to all points in the power delivery chain and to all aspects of the modern information society and economy. Ultimately, these factors provide complete justification for investment in the Intelligent Power Grid.

Endnotes

1. IntelliGrid: www.epri-intelligrid.com.
2. "GRID 2030: A National Vision for Electricity's Second 100 Years." United States Department of Energy, Office of Electric Transmission and Distribution, July 2003.
3. GridWise: www.gridwise.org
4. Primen was quoted in "GRID 2030: A National Vision for Electricity's Second 100 Years." United States Department of Energy Office of Electric Transmission and Distribution, July 2003.

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