# Under surveillance

## The world power struggle

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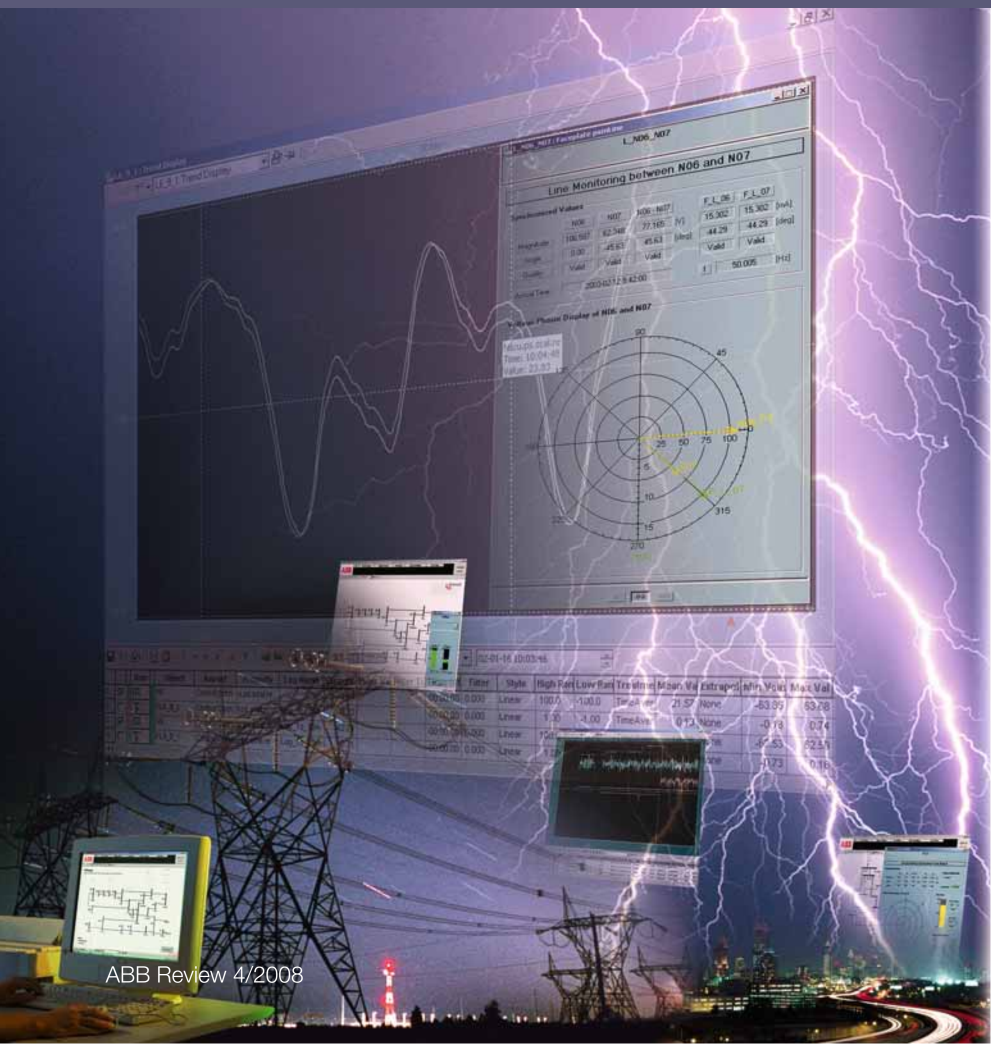
The demands on modern power networks are very different from those for which they were originally designed. Traditional power networks were built around large, centralized power plants, supplying power to the grid in a predictable manner. The one-way flow of power was maintained in these grids, despite hourly fluctuations in demand, thanks to the careful management of each section of the grid.

Today, modern power networks must cope with energy trading, which allows adjacent networks to exchange power, and renewable power sources, which are, by their nature, erratic.

This increased unpredictability in the grid creates an ever-greater demand for high quality surveillance to detect and report disturbances in the network. Poor visibility in the power system hampered network operators during the blackouts in Canada, the US and Europe in 2003. These disturbances spread more widely and lasted longer than necessary because operators were sometimes unaware of the scale of the problem.

The economic and social effects of such blackouts clearly demonstrate the need for improved monitoring systems that allow operators to know when and how to act to avoid a system failure. ABB's Network Manager™ Supervisory Control and Data Acquisition (SCADA)/ Energy Management System (EMS) are tried and tested technologies that can help manage the changing demands of today's power networks.




SCADA and EMS are the primary building blocks for a modern power grid control system 1. SCADA consists of measuring devices, communications and control systems, while EMS comprises various power system analysis functions. By working hand in hand, SCADA and EMS can create a highly visible transmission system for power system operators, allowing them to collect, store and analyze data from hundreds of thousands of data points in national or regional networks, to perform network modeling, simulate power operation, pinpoint faults, pre-empt blackouts and participate in energy trading markets.

EMS comprises of a series of processes that must be performed in a pre-defined sequence. An example of the real-time sequence is shown schematically in 2. For transmission operators, the two most important components of this scheme are the state estimator (SE) and the contingency analysis (CA).

The SE provides information about the state of the power system at any given time. It uses the SCADA input and the current network model to identify possible input errors (from telemetry and topology, as well as inaccuracies in network parameters) and calculates the best state estimate for the complete power system model, including branch flows and bus voltages, even in locations that lack physical telemetry.

## ABB's SCADA and EMS create a highly visible transmission system for power system operators, so they can perform network modeling, simulate power operation, pinpoint faults, pre-empt blackouts and participate in energy trading markets.

The SE is an important component of the EMS application since it alerts the operator to potential problems and indicates ways to improve the system's operation. It provides an estimate of the current state of the power system for the CA software, which then calculates the potential risks to the secure operation of the power network. The CA performs a series of "what if" scenarios for a large set of contingencies (mostly equipment outages), each individually simulated to pinpoint possible future security concerns, thus helping to prevent major disruptions in the system.

It used to be possible to perform offline planning studies for a limited set of operating scenarios to get a good overview of system security. This type of analysis is inadequate for today's power networks, because power flows are more unpredictable than ever. Deregulation in the power industry has meant that contracts to buy and sell electrical power in the new environment can differ significantly from those of a more regulated environment. Furthermore, the erratic nature of some renewable power sources, where changes in the weather greatly influence the power production, and an increased dissemination of controllable power system equipment, like high-voltage direct current (HVDC) and phase-angle regulators (PARs), cause even greater unpredictability.

As a result of these uncertainties in grid reliability, the Electric Power Research Institute (EPRI), declared several years ago that CA software should aim to process a target of 10,000 contingencies on a 20,000 bus model within 20 seconds.

Over the years, ABB has pioneered many advanced techniques and algorithms to meet these high processing requirements. Algorithms, such as the complete bounding technique [1] and sparse vector methods [2] form the foundation of today's modern CA package. These techniques alone may not be sufficient when considering wide-area contingency analysis. For such analysis, it also becomes necessary to take advantage of the parallel processing capabilities of modern computers.

Initially, ABB implemented the complete CA software package using parallel processing without making major changes to the software. The software has scaled extremely well and has, using Intel and Advanced Micro Devices (AMD) CPU x86 servers, provided an improvement of three times the performance on fairly large network models 3. This showed that the algorithms deployed in the ABB CA software are general in nature and can support both single and parallel processor configurations.

The processing speeds already achieved meet the EPRI targets using unmodified ABB CA software, however, further improvements in scalability can be expected in the future when algorithms are better tuned for parallel processing and new high performance computer technology is employed.

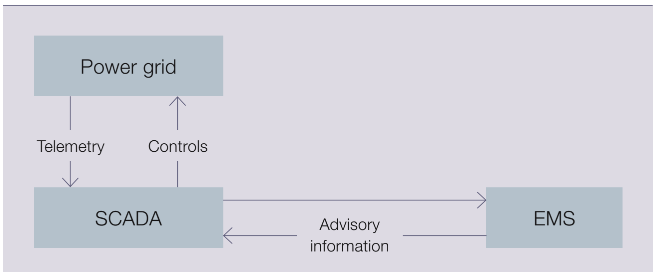
## ABB has pioneered many advanced techniques and algorithms to rapidly process thousands of contingencies.

### Assessing the power system

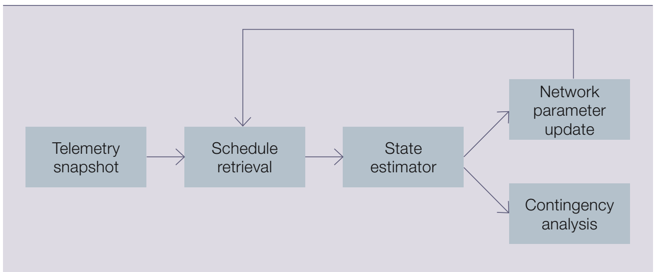
The data input to the SE, mainly telemetry and electrical model parameters, will always contain some degree of error or inaccuracy. Some of these inaccuracies will make it difficult for the SE to provide a precise assessment of the current state of the power system. This discrepancy between the estimated state of the power system and reality is, however, of little consequence if the availability of the SE itself is not dependable [3]. While the accuracy of the SE is important, it is of secondary importance to its availability. During the large blackout in the U.S. in 2003, an already difficult situation became worse when the SE failed to provide a result [4]. This means that the mathematical algorithms deployed to evaluate the state of the grid must be robust and implemented (ie, programmed) efficiently.

The high reliability of the assessed state of the network implies that it is obtained frequently enough to track any major changes in the grid. The re-

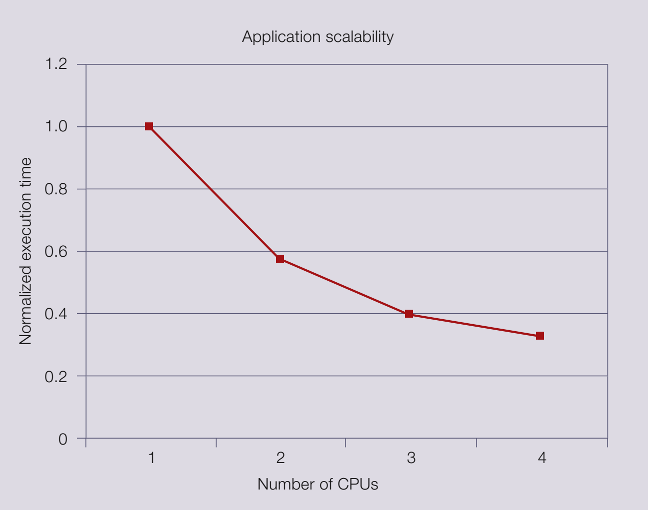
1 Overview of SCADA/EMS interaction with the power grid




2 EMS real-time sequence



3 Initial parallel scalability of the contingency analysis




4 Recent SE solution reliability (data supplied by the IESO)


liability of this SE software is not only a function of the SE software and telemetry from SCADA, but also of the supporting software, like the network parameter update (NPU) that is used to maintain set patterns necessary to generate data, eg, load or generation patterns. The SE solution is used as an input to NPU and the NPU output is in turn, used as an input to SE for locations lacking adequate physical telemetry. It is, therefore, unwise, to consider these as separate and independent functions because they form a single interdependent system.

The reliability of the entire system is dependent on its components and their ability to work together. This, together with customized operator interfaces, is extremely important if high-level surveillance of the transmission grid is to be maintained so that operators can make appropriate, timely decisions to prevent a network failure.

### Meeting customer's needs

Several years ago, ABB received a large order for a complete SCADA/EMS and market applications system for the independent electricity system operator (IESO) in Ontario, Canada Factbox 1.

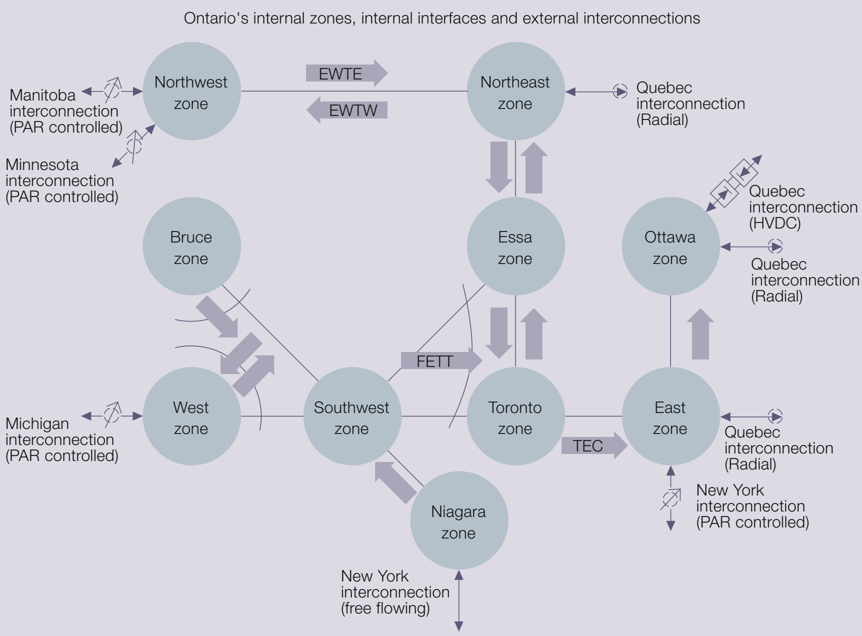
The IESO had very high reliability requirements in view of the fact that the results of the SE were going to support not only the EMS applications, but also the market operations systems that involve financial transactions [5]. There were also very high demands on the functionality of the CA, including the ability to accurately process approximately 3,000 "what if" scenarios, every minute, on computers purchased in 1999.

There were four main IESO requirements for the SE.

1. SCADA/EMS was expected to monitor market dispatch (generation and power exchange schedule) exactly
2. 100 percent of the market was to be dispatched (re-scheduled) every 5 minutes
3. Erroneous SE results needed to be identified before they were transmitted to market applications – the primary objective being security of the power grid

Factbox 1 IESO transmission system characteristics

The IESO network model has a size of roughly 4,000 buses and a peak load of around 25,000 MW. The IESO's transmission system is divided into 10 different zones with different characteristics with respect to the availability of telemetry, level of stress, generation mix and external interfaces. There are external connections that use PARs to control the tie-line flows so as to avoid exceeding thermal limits.



4. Initial conditions (base case) were needed for real-time system security monitoring and contingency analysis

**ABB's CA software is general in nature and can support both single and parallel processor configurations.**

To meet the customer's requirements, ABB has significantly enhanced its EMS product. Improvements were made to the availability and quality of the SE solution, together with the speed and accuracy of CA and all supporting functions.

During the implementation of the project, ABB worked closely with the customer, discussing and evaluating their needs and delivering the best possible solutions. This required the IESO to improve the quality of the power system data and ABB to enhance the software so that a highly reliable grid surveillance system could be achieved 4. The availability of the SE improved over time as a direct result of these cooperative efforts.

ABB has deployed its expertise in the area of network solutions, as well as research and development, often directly resulting from joint IESO-ABB analysis, identifying the source of inaccuracies or reasons for non-convergence. The recent significant increase in SE availability can be directly attributed to the latest NPU and SE software enhancements [6].

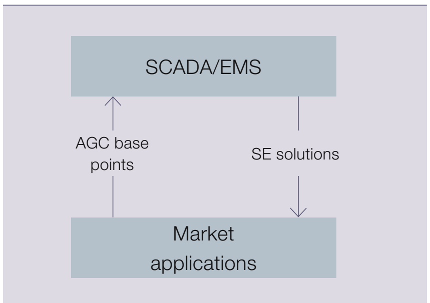
It should be pointed out that the SE availability numbers achieved on the IESO system are much higher than those in other systems Factbox 2. The SE analysis is performed every minute as part of the real-time sequence 2. Therefore, a shift in the reliability from 99.7 to 99.8 percent has reduced the number of unavailable SE solutions by more than 40 each month.

**The SCED identifies the least expensive generating and demand management resources required to meet the power needs of the region, while considering the overall security of the transmission system.**

The iterative SE solution provides very high accuracy, which is required to support the CA as well as market applications. This is achieved through the Business Management Systems (BMS) network-security-constrained economic dispatch (SCED). The SCED identifies the least expensive generating and demand management resources required to meet the power needs of the region, while considering the overall security of the transmission system. The interaction between the EMS and BMS (market applications) is shown schematically 5. The SCADA/EMS sends the current state of the power system to the BMS market applications, which then perform the economic dispatch based on predictions, five minutes into the future and returns new generation base points to the SCADA/EMS.

With the introduction of ABB's upgraded surveillance system based on the improved EMS, the operators of the Ontario power grid are confident that they have taken an important step to minimize the risk of future blackouts.

5 SCADA/EMS – BMS interaction (AGC – Automatic Generation Control).




Factbox 2 SE reliability requirements

According to [7], "the average reliability of the state estimator in the US industry is 95 percent." In [8], more specific numbers are provided by a North American utility:

- 93.2 percent in 2001
- 97.3 percent in 2005

The SE reliability requirements for the Midwest Independent Systems Operator (MISO) have been set to 97 percent. The same level is also favored by the Electric Reliability Council of Texas (ERCOT).

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**References**

[1] **Brandwajn, V., Lauby, M. G.** (1989). Complete bounding method for AC contingency screening. IEEE Trans. *Power Syst., 4*(2), 724–729.
[2] **Tinney, W. F., Brandwajn, V., Chan, S. M.** (1985). Sparse vector methods. IEEE Trans. *Power App. Syst., PAS-104*(2), 295–301.
[3] **Wollenberg, B.** (2004). Power system state estimators: Designed for reliability or accuracy? *8th International conference on probabilistic methods applied to power systems.*
[4] http://www.iwar.org.uk/cip/resources/blackout-03/index.htm (April 2004). Chapter 4 of Final report on the August 14, 2003 blackout in the United States and Canada: Causes and recommendations. *US-Canada power system outage task force.*
[5] **Danai, B., Kim, J., Cohen, A. I., Brandwajn, V., Chang, S. K.** (2001). Scheduling energy and ancillary service in the new Ontario electricity market. *Proc. Institute of Electrical and Electronics Engineers Power Industry Computer Application Conference.*
[6] **Brandwajn, V., Jiang, X., Liu, G., Johansson, M. L., Fahmy, G.G.** (2006). State Estimation for Ontario Market System. *IEEE PES General Meeting*
[7] http://www.oe.energy.gov/DocumentsandMedia/Distribution_State_Estimation_Meliopoulos.pdf (June, 2008) Distributed state estimation. Georgia Institute of Technology.
[8] **Lefebvre, S., Prévost, J., Crainic, E., St-Arnaud, R., Horisberger, H., Lambert, B.** (2006). Practical experience with state estimation. *RTE Workshop on robust state estimation and load forecasting.*