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Roles of advanced information technology for restructured electric power industry in North America

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1. Introduction: Electric power utility industry — a legacy infrastructure

1.1 Evolution of electric utility industry in the twentieth century

The electric power utility service is one of the essential elements of modern life. Since the early commercialization efforts by Edison and others in late 1800s, followed by theoretical development in related physics, the electric power systems have evolved to become one of the most complex and gigantic systems the humankind has ever created[1]. Because the development of energy production and transportation infrastructure requires heavy capital investment such as dams, generating stations, transmission lines, its evolutionary process is relatively slow and has taken a long span of processes. Business returns on such investments were considered in twenty or longer years, but, once they are built (and properly maintained), for example, generating stations can produce its high energy output for thirty years and more.

However, the electrical utility industry seemed to have slipped into a status of an invisible infrastructure in the later half of the twentieth century. Particularly, since mid-1980s there have been no major installation of generating stations, partly because of the social and environmental concerns against nuclear power plants and fossil-thermal generation plants. Likewise, the capacity of power transmission networks have experienced little or no expansion since around this time. As the power industry matures, electric power-related technologies were regarded as "low tech" by young generations, and combined with reduced number of hiring in the industry, many power-related programs in universities are either closed or reformed to more modern-sounding ones such as "power electronics".

1.2 Information technology's roles in power — old and new

Nevertheless, in its heyday, the power industry was the technological leader of the time in many related fields — not only in power production and transportation, but also communication and information processing. A utility power system is very large — covering huge geographical area, spanning across the continents; for example, some remote generating stations are over 1000 km away from the load center (cities and industrial plants) where most of the consumers reside and use energy.

To make such complex and large systems viable and manageable, early "rationalization" efforts were intended to replace direct and local human observation and operation with remote monitoring and control. Such activities called for an extensive investment of early information technology, namely (mostly analog) communication and computing equipment — limited operations were automated initially. The research on practical application of modern digital computers to power systems started in the late 1950s. By early 1960s, numerical simulation of power systems was one of the first practical and successful applications of early digital computer systems outside of university laboratories. The development of such computer applications also contributed to the advanced concept of mathematics such as the sparse matrix methods — that was the state-of-the-art in the 1960s.

Technical progress in power engineering field, however, became nearly stagnant compared to other fast-growing industries such as tele-communications and computers. The communication in power industry, with a few exceptions, still use narrow bandwidth, and backbone computers for its central operation are mainly based on the mainframe computer architectures, although for off-line and human interface purposes, which do not require ultimate reliability, personal computers are widely used.

1.3 Restructuring power industry for competition

Since Britain privatized its national monopoly electricity utility and introduced market-based competition in the industry in 1990, many countries followed suit — North America was no exception. Initially, it seemed that the North American power industry was skeptical of its effects, however, eventually the business interests for restructuring took hold, particularly in those regions where electricity prices were high, such as California and eastern states[2]. While the power utility companies are mostly investor owned (i.e., private) in the United States, the main driving force of restructuring has been federal and state government initiatives, represented particularly by Federal Energy Regulatory Commission (FERC)[3]. Perhaps the impetus was more stimulated by other industries such as airline and telephone services that were deregulated earlier.

The deregulation of power industry may have been seen as a chance of revived interests from some business perspectives in information technology. In fact, there have been installations of new communication and computing infrastructure represented, for example, by an establishment of independent system operators (ISOs) and more recently of regional transmission organization (RTO). Many people of business and economics background rather than engineers have been involved extensively in the design of market mechanisms/ structures.

1.4 Frail power system "security" and new role of IT

As a few years of experiences are accumulated by the electric power system operation on the market-based structure, the negative effects of deregulation became apparent. It is mainly due to imperfection of market designs. For example, financial instability of local utilities is believed have lead such difficulties in California power crisis of early 2001. Besides, the short-cutting of minor maintenance activities, such as tree branch trimming near the transmission lines, has caused serious outages such as wide area blackouts in North America and Europe in the summer of 2003[4].

These incidents, although triggered partly by financial reasons due to increased competition, raised a question against the traditional concept of security of power systems and expert review is under way worldwide. Moreover, they revealed that the information security of the legacy power systems are vulnerable against such threats as cyber-attacks. People, experts and non-experts alike, have now realized that such a security problem could (and will) have significant impacts because the electric power system is, albeit essential, a sleeping (invisible) giant infrastructure.

At the same time, distributed electricity resources such as micro-turbines and fuel cells are making serious inroads into commercialization[5]. There is even a concept of replacing part of the conventional large-scale power systems with small-scale, localized power supply systems called the "micro-grids." These local resources could (in theory) enhance the security of reliable power supply, but they could also cast a shadow of information security if the new infrastructure is designed poorly. Therefore, both in conventional and new technical frontiers of electric power systems, information technology is expected to play a key role for their secure and reliable operation.

1.5 What is in this report?

In this report, the author first overviews the information processing infrastructure of conventional electric power systems. Then, the North American-style power industry deregulation and its impacts are summarized. Finally, the new roles of information technology in the changing power industry structure is reviewed in an extended context including the distributed electricity resources and related technologies.

2. Information technology in conventional power industry

An electric power system is a gigantic and complex system that spans wide geographical area and have so many components such as generators, transformers, and so on. These "components" are autonomous systems themselves, and equipped with their own control and communication systems — nowadays, often based on microprocessors. The complexity and vastness of power systems require telemetry of conditions on remote power plant equipments.

Old power system operations were "labor-intensive." All the power stations were staffed by many people. The old power equipments were operated largely in manual control. They used to make control decisions locally and, if necessary, communicate over a telephone — mainly by land-line — for a system-wide coordination. As the power system grew, and advanced control and communication technologies became available, such a "labor-intensive" approach did not make sense in terms of economy and reliability. The power companies moved quite early to install telemetry devices to gather information to central locations. Today's power industry may be called "information-intensive," which is remote and automatic to be more accurate. The power utility industry was also very early to adopt computer applications — even in late 1950s.

In the modern power systems, field data are gathered in a central location (called "control center" or "dispatching center") and the information is processed centrally to make it meaningful to human operators who make (higher-level and effective) operating decisions. Important decisions are made by experienced human operators. Such a system, based on telecommunication and computers, makes possible to operate the complex and huge power system by a few people — there are usually only three or four people working in shifts at a control center.

Figure 1 shows the overall diagram of the computer-based monitoring and control system for a large-scale power system.

The following are some key components as we try to understand the power system information processing infrastructure.

a) Remote Terminal Units (RTUs)

Remote terminal units (RTUs) are installed at local sites (power plants and substa-

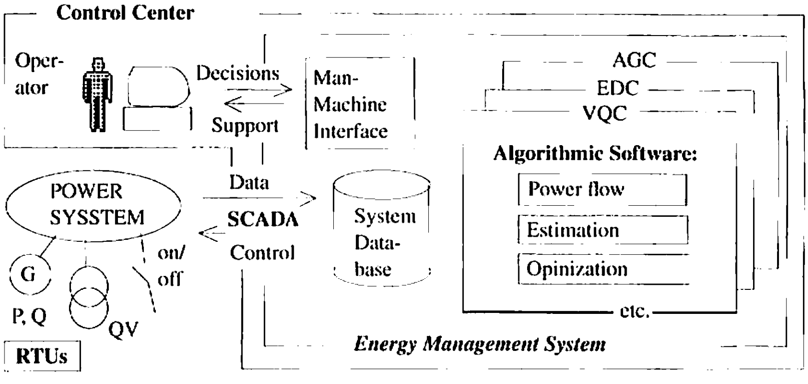


Figure 1. Computer application of power system control and monitoring

tions). Its purpose is to gather local information, such as power (P, Q), voltage (V) and the switch status (on/off), and to handle local controls. Some signal processing are done locally such as analog to digital (A/D) conversion, coding/decoding (such as BCD), filtering, tagging (for identification and possible prioritization), and so on.

There is at least one RTU at a station for local needs, and at important stations, there could be many RTUs, which are often linked with dedicated high speed local area network (LAN).

The data collected by RTUs are transmitted by the utility's own communication channel and stored in the database of the central computer(s). The host computer handles the database management, higher-level data processing, etc., to make the information more meaningful and useful for human operators. In a sense, we may see the combination of host computer and RTUs as server-client relations.

b) Supervisory Control and Data Acquisition (SCADA)

The SCADA (Supervisory Control and Data Acquisition) system is the name for the computer and communication system that handles the remote monitoring and control. There could be a dedicated SCADA computer or it could be one of the on-line applications of the host computer in the control center. Upstream (telemetry) information includes: voltages, currents, switch status (on/off), etc, and downstream (control) instructions include switch on/off, and various other adjustments.

The collected information is stored in the system data base, and the information is refreshed every one minute or so (depending on the priority). The application programs use the system data available from the database, rather than accessing individually to the remote sources.

c) Energy Management System (EMS)

While SCADA handles more of a routine data processing, the Energy Management System (EMS) performs more intelligent roles — central information processing to assist operation with assortment of application software, overlooking the conditions happening all over the target power system.

Again, an EMS may be a dedicated computer system, or it may be a set of applications on the central host computer. In reality, many power companies do not have a clear distinction between SCADA and EMS — at least in hardware-wise.

EMS applications are various and different in nature and control frequencies — some are full-automatic, others may need human assistance (partly manual and partly automatic).

Some of the typical on-line applications for operation are:

i) Automatic Frequency Control (AFC)

It maintains the power system with minimum frequency deviation (in an alternating current system, frequency is a function of power mismatch; Note that the frequency is only one throughout the connected electrical network.)

ii) Economic Dispatch (ED)

It optimizes the generator power output following the load to achieve minimum cost of operation.

Indication of time scales of different EMS functions are shown in Table 1.

Table 1. Time scales of energy management system functions

Function	Time
Operation planning:	1 week to 1 year
Generation scheduling:	4 hours to 1 week
Economic dispatch:	10 min. to 4 hours
Frequency control:	5 sec. to 10 min.

One very important thing to note here is that electric power system is an ultimate real-time system. Because electrical energy cannot be stored in large scale, and load power consumption is always changing (for example, we expect the lights to come on immediately as we turn the switch), power generators must follow the load in real-time. If supply falls short of demand, the system breaks down in a matter of several seconds. Therefore, real-time operation is possible only with the aid of computers and high-speed communication devices. Also, power system operation must be well-planned with good margins to achieve economic and reliable goals.

3. Restructuring power industry in North America

3.1 Overview

In recent years, the electric power utility industry has been experiencing a massive movement towards deregulation and restructuring in many parts of the world. First, Britain privatized its nationally-owned power utility in 1990, breaking it up to generation, transmission, and distribution sectors. It started a commodity trade market called the "power pool" which is open to electricity generation companies and regional distribution companies so that transactions are to take place on the spot fulfilling the balance of supply and demand. It created a chance of new investment of generation facilities to compete for their share of customers in the market, while the transmission network is maintained as a natural monopoly. Norway, in 1991, followed suit in a different approach mainly based on bilateral transaction models in contrast to Britain's pool model. Many south American and south Pacific countries, including New Zealand and parts of Australia followed the British model and deregulated their electricity utility services. Canada started its first electricity market in 1996.

The main idea of the power industry restructuring is to introduce an open market-based competition, particularly on the supply and wholesale sectors, for possible reduction of electricity prices. Along with the introduction of new and cost-competitive non-utility generators, the pricing structure has been deregulated so that the supply-demand balance determines the spot price of electricity in the market, as if a commodity (such as natural gas) were being traded. For the operation of the transmission system, independent system operators have been established, separately from the ownership of transmission facilities and financial interests of market participants, to maintain the integrity and reliability of the physical electric network.

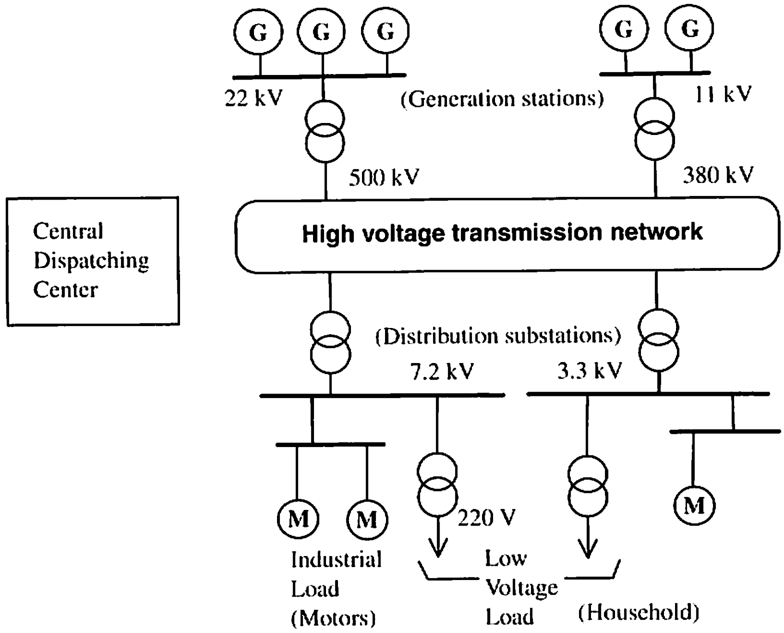
American experts may claim that the beginning of power industry deregulation was the 1978 US Public Utility Regulatory Policy Act, which was introduced to encourage energy purchases from a small, independent generators, mainly based on renewable energy resources such as wind, solar, and geothermal energy. The reaction toward a full-scale deregulation in U. S. was relatively slow after the British lead for deregulation, partly because the U.S. utilities are regional, relatively small-scale, and privately owned. However, perhaps convinced by examples of the deregulation of telecommunication and airline industries, U. S. federal government took a strong initiative from the mid-1990s, publishing the Notice of Proposed Rulemaking ("mega-NOPR") in 1995 by Federal Energy Regulatory Commission (FERC), followed by FERC orders, No. 888 and 889 in 1996 and 1997[6], respectively, that encouraged American industries to adopt the market-based operation by obtaining licenses from FERC.

3.2 Market structure

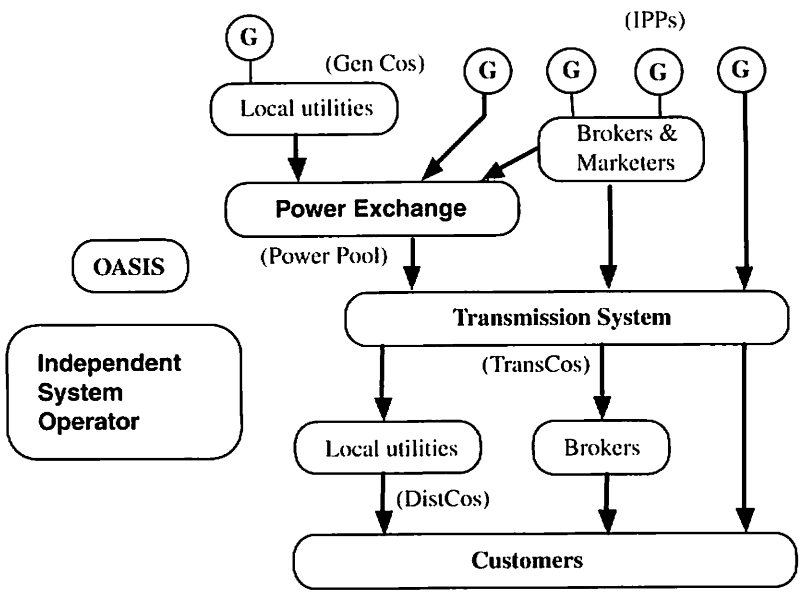
Figure 2 compares the electric power industry structure before and after the deregulation, in the perspective of "bulk" (high capacity in high voltage) power system operation. Although there are some regional differences of implementation styles and progress stages, the general steps of deregulation are described as below.

In the conventional industry structure (i.e., regional monopoly), a single utility company has established a "natural monopoly" owning and operating all the facilities from generation sources to distribution to the customers. Usually, there is a central dispatching center which gathers the information on the system conditions by telemetries and processes the information centrally by an energy management computer (SCADA/EMS scheme). This so-called "vertically integrated utility" structure was believed to achieve the best efficiency by the economy of scale. However, as the technologies progressed the small-scale turbine-generators achieved the same or even better efficiency as the largest-scale units and the stranded costs in nuclear facilities became apparent, which was perceived to be unfairly subsidized by more energy-efficient, low cost customers.

The core idea of power industry deregulation is to introduce high-efficiency non-utility generators and to competitively supply and/or procure electric energy on a market mechanism. This requires separating product (energy) from transportation (network). To make electricity networks as "common carriers" accessible by utility owners and independent producers alike[2], (functional) unbundling of transmission and distribution (T&D) sector from generation sector was installed. Practically, FERC requires the separation of accounting of transmission and distribution sector in utility companies, in return to licence "entrance" into the deregulated market. Following this order, many conventional utilities either separated out their generation sector as independent companies or divested to third parties. (Some publicly-owned utilities such as Tennessee Valley Authority and Los Angels City Water and Power Department are exempt from such requirements but they are voluntarily functionally unbundled to market their power.)



(a) Before (regional monopoly by vertically integrated utility)



(b) After (market-based competition with ISO maintaining network)

Figure 2. Electric power system operation — before and after the deregulation

In many deregulated system, at or around the same time as the T&D unbundling, commodity exchange markets ("pool" in U. K. and Canada) are opened for public auction of electric energy. Although it is called the "spot" market in the power industry, the reality is a one-day or hours-ahead forward, because the power system operators need several hours to prepare the actual electricity generation and transmission systems to accommodate power flows as agreed by sellers (suppliers) and buyers (customers).

There are two major ways to implement this "spot market" — mandatory pool and voluntary pool. In the mandatory pool system, adopted by early Britain and PJM (Pennsylvania-New Jersey-Maryland) system, for example, all the suppliers and customers of those regions must trade through the spot markets. For financial hedging, such mechanisms by bilateral agreement as "contract for differences" (in which sellers pay back buyers if the market price is higher than the strike price, and vice-versa) are offered. In the voluntary pool, implemented in Norway and early California, suppliers and customers can make direct bilateral contracts outside of the market ("over the counter"), and only the limited portion is traded through the open market.

Spot market trading takes place every half an hour to every hour schedule, 24/48 times a day. At each hour, in theory, market ("pool") operators gather information of equivalent cost (supply) and benefit (demand) function parameters from market participants and aggregate the characteristics to find the market clearing price. In reality, however, a market clearing price is determined by the highest price bidder who fulfils the last portion of demand. There have been many questions raised against such a market clearing mechanism, because it can result in speculative high prices, but many market operators still use such a pricing scheme. This situation is often aggravated by the lack of elasticity on the demand side.

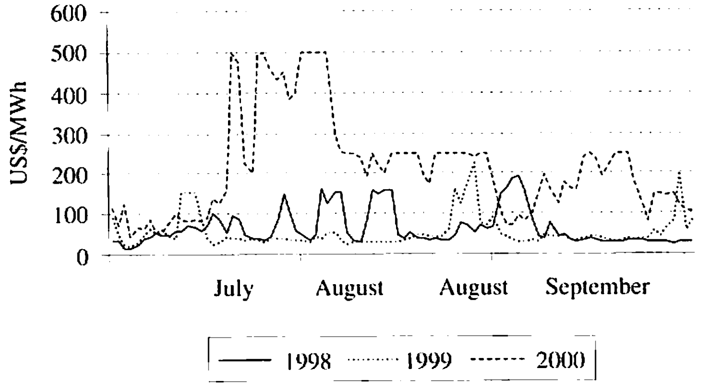
One of interesting characters of power exchange markets is that they are "virtual" markets. First, there is no trading floor. The market auction is held in cyberspace using Internet technologies such as being done in eBay (in most of the power exchange cases, however, bids are anonymous). Second, one can be licensed as a marketer even if they do not have any electrical equipment. In fact, many marketers (including traditional utility companies) act as aggregaters for either suppliers and distributors, or other middle agents as "power brokers." Under the market-based power systems, therefore, the flow of money is separate from physical flow of energy. There have been many financial instruments devised or adopted from other commodity markets.

To make the physical operation of electric power systems neutral to all the market participants, independent system operators (ISOs) are established for each region of deregulated systems, and the control of major transmission systems are concentrated to ISOs. While conventional utility companies in the region still own the power equipment, the authority of central control decisions were handed over to ISOs. In many deregulated systems, ISOs operate the ("virtual") energy market as well as other markets such as "ancillary services," making the final balance of supply and demand in real-time. Prior to the market auction, the ISOs calculate the available transmission capacity and informs the market participants through a virtual bulletin board system called OASIS (Open Access Same-time Information System). After the market trading is settled, the ISOs then calculate and publish locational marginal prices (LMPs). Because of power losses and transmission network "congestion" (capacity being used up), the final locational prices may be different from the market clearing price.

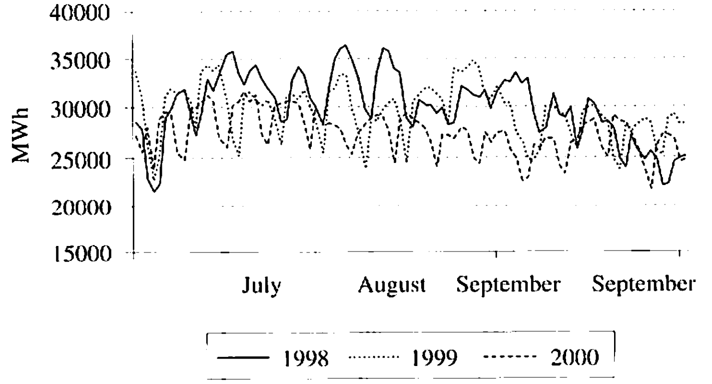
3.3 Power industry deregulation — Success or failure?

Even though over ten years of experiences have been accumulated in the deregulation of power industry, it may be (still) early to judge whether it was a success or failure. According to FERC of U.S. government, which have been advocating the power industry deregulation, there have been mixed results (i.e., "success" and failures)[7]. At least, retail electricity prices have not been substantially declined as expected, but in some regions they may have gone up. Britain has reformed its market-based system to bilateral transaction-based operations (more like successful Nordpool, now covering all Scandinavian countries). Other places like New Zealand and Alberta (Canada) experienced very high price spikes.

California's debacle drew the media attention of the world, and is worth reviewing here[8]. It is now largely believed be caused by the flawed market design. Unlike microecomic theories, electricity demand is not elastic (because electric energy cannot be stored in a large scale), demand has remained largely constant as the wholesale prices soared as shown in Figure 3. Worse, the region's regulators mandated the conventional utilities to purchase from the exchange market, while freezing the retail prices that they can charge their customers; no other means of purchasing electricity, such as forward contracts, was allowed. Some clever marketers, such as Enron, seem to have acted speculatively to manipulate the market prices. As the rising market prices brought the local distribution companies to huge debt, the suppliers held back their electricity, because of fear of not being paid by the near-bankrupt utilities, thus causing the shortages of power to balance the demand,



(a) Market price



(b) Electricity demand (through market)

Figure 3. California market prices

the system operator had no means but to cause rotating outages. That eventually resulted with one utility company going bankrupt and the power exchange market shutdown with mounting debt.

Perhaps the most important impacts of deregulation in North American electricity industry may have been accelerating mergers of fragmented and financially frail regional utilities and integration of power system control into a so-called regional transmission organization (RTO). This may be viewed as a different form of re-regulation by FERC under the mask of "deregulation" as FERC now advocates PJM-style RTOs[9].

The deregulation also benefited the newly-emerging distributed resources, such as co-generation plants and wind turbines. At least, the deregulation provided new marketing opportunities to appeal potential customers in such marketing approach as environmental-friendly "green power" suppliers. Distributed resources are discussed in more detail in the separate section.

4. Advanced requirements in information technology

4.1 2003 summer blackouts in North America and Europe

In the summer of 2003, a number of large power blackouts have hit the eastern North America and Europe (Table 2[4]). The scale of these incidents was considered to be the worst in history — affected millions of people in the region, interrupted emergency and ordinary services and business activities, and caused indirect damages such as traffic accidents due to failed traffic lights, for over a day. Just as the large blackouts in New York City area in 1966 and 1977 prompted the creation of North American Electric Reliability Council (NERC) and subsequent rules and standards to maintain the quality of electric power utility industry, these unfortunate events have provided an opportunity for experts and policy-makers to revive the public attention to the importance and complexity of electric power utility and related technologies.

4.2 Why the blackouts happened?

While the exact causes of these large scale blackouts were investigated by international task force of experts, it may be interesting to peek into the "not so high-tech" background of these technical incidents, particularly focusing on the August 2003 North American blackout[10].

Large blackouts are typically caused by a sequence of unexpected rare incidents with complex interactions, which eventually cascaded into a wide area disturbance. Natural causes such as weather conditions often trigger some of these small events[4]. On August 14, 2003, the eastern United States and Canada was experiencing a high temperature, which

Table 2. Large-scale power blackouts in 2003

Date	Region	Duration	Affected population
August 14, 2003	Northeast United States and Canada	24 + hours	50 M.
Sept. 23, 2003	Sweden and Denmark	5 hours	5 M.
Sept. 28, 2003	Italy	5–9 hours	57 M.

(M. = million)

caused the power consumption soaring due to air-conditioning — a typical summer load. Because a power transmission wires are made of highly-conductible metals such as copper, as they carry a heavy load of electric currents, their temperature also rise eventually causing the wires to sag. Transmission wires are designed to maintain some clearance to the ground even in such a condition. However, in northern Ohio, one of the transmission lines touched an overgrown tree causing a short circuit; the line was tripped out of service by a protection gear. Had it been under a normal condition, this incident had been well contained to this particular location. However, as a nature of complex network, already stressed by high temperature, the heavy load current migrated to other transmission lines causing similar incidents elsewhere.

Electric power systems are equipped with sophisticated protection systems to localize the impacts of these small mishaps, and are designed with some redundancy to survive with a loss of local equipment. However, as there are such incidents occurring about the same time (in August 14 blackout, there were 5 or more records of such tree-touching faults[11]), the combined effects can make the large power system vulnerable. Eventually, the system lost a relatively large nuclear generator (which is more sensitive to disturbances compared to other generating equipment) causing the imbalance of power and overload of other transmission lines due to diverted power flows. It cascaded into non-stoppable large-scale disturbances that eventually resulted in power outages covering a large area of eastern United States and Canada.

Experts who investigated the blackouts claim, in retrospect, that the power system operators could have done more to stop the gradually cascading events that happened over two hour or so period. For example, transmission wires touching trees could have been prevented by proper maintenance of transmission right of way. However, tight budget under competitive industry environment might have postponed it. NERC, on the other hand, does not have an enforcing authority of quality standards in such cases. A lack of emergency reporting procedures from local utilities to wide-area operators such as ISOs was also pointed out. Generally, a low level of investment in the transmission sector, compared with the generation sector in recent years, was a major contributing factor. The transmission systems have not seen a major expansion since the mid-1980s and under the heavy load, the system has been operating with tight margins. In a sense, the system was already under stress due to preexisting conditions.

4.3 Revived interests of information technology in power engineering

The calamity caused by the wide-area blackout was regrettable, but in a long run, it may have been a wake-up call to review the situations of such an essential infrastructure as electric power albeit neglected until the disaster strikes. It particularly reminded us of updating the information processing technologies applied to revive the stressed electric power systems. Among the possible improvements, the author hopes to draw attention of the readers to the following four areas.

a) High-speed remote measurement and communication

Conventional RTU/SCADA backbone technology was established in 1960s, and its slow, low bandwidth capabilities are intended mainly for steady-state, non-emergency measurements. Digital telemetry devices based on modern microprocessors combined with high speed communication links, can detect small signs of system instability in its early stages, and it makes early preventive actions possible. High-speed measurement system, such as wide area phasor measurement devices[12], have been developed and field tested for power utility applications since early 1990s, but it seemed have lacked the focus of practical applications. These devices should be integrated into the upgraded SCADA/EMS framework. On the other end, high capacity data handling capabilities of SCADA computers is also needed.

b) Intelligent alarms

Once a wide area outage happens, even in the early stages of crisis, human operators in the control centers can be lost in the deluge of alarms[13]. To find out the critical information and make effective decisions, it is desirable to filter and prioritize essential information out of massive information coming in almost randomly at the same time in case of blackouts. In early 1990s, such software systems were planned and developed using "expert systems" approach, but they found only a few applications mainly due to waning academic interests in expert system technologies and limited investment interests in researches by the industry. Such intelligent alarms should be reviewed and redesigned in the context of up-to-date information technologies.

c) Robust applications

Many EMS application software assume near steady-state (i.e., no major disturbance) conditions for its models. However, in the storms of cascading outages, voltages and frequency may go down or up far beyond the assumed ranges. In such situations, iterative numerical solution algorithms often find no solution, thus would be no help for the human operators. Non-iterative, high-speed, robust applications are highly desirable to survive the large disturbances leading to a wide-area blackout.

d) Training simulators

However well-equipped with advanced computers and intelligent software, it is eventually the human operators who make decisions and take actions against the threats of power systems. Operator training simulators were developed and installed as an extended EMS function, but it is reported that in many utilities it is under-utilized[13]. The lack of experienced trainers (or instructors who are familiar with the simulator) may be part of the problem, but investing in good training simulator with intelligent, human friendly interface would lead to higher quality personnel with lower cost of operation.

Although the recent blackouts were triggered by natural causes and wide-spread due to inherent physical vulnerability of power systems, through the inivestigation of blackouts and successive reviews, it was pointed out that conventional RTU/SCADA/EMS framework is also vulnerable against potential cyber-attacks. The conventional practice of the industry to protect the information processing system from hackers and other threats were, for example, to use dedicated communication systems separated from common access, but in these era of sophisticated cyber-attacks, the information security will be certainly the subject of future upgrade for power system applications.

5. Information technology for distributed energy resources

One of the very interesting topic of recent development in energy sector is the maturity and commercialization of many distributed resources. Distributed energy resources (DER), or distributed generators, include such technologies as wind turbines, photovoltaic (PV) cells, micro-gas turbines, and fuel cells. Most of these technologies are either established or near commercialization and becoming economically competitive against conventional technologies. The advantages of distributed resources are, for example:

a) offer more choice in fuel supply options
b) cut energy costs for end-users
c) can achieve higher energy conversion efficiencies
d) deliver greater power quality and reliability
e) are quieter and less polluting
f) can eliminate, reduce or defer utility transmission system upgrades and many more.

Many of the distributed energy technologies are also based on renewable resources[5] and/or highly energy-efficient, therefore considered to be more environmentally friendly than conventional technologies such as fossil fuel-combusting thermal electricity generation. Under the deregulated electric utility industry structure, they seem to be finding a niche position as environmentally-friendly energy suppliers such as under a "Green Power" banner. Under many government-supported programs, some environmentally-conscious customers can purchase specific kind of energy such as from wind for an additional charge[14].

Combined with recently-developed energy storage devices such as super capacitors, flywheels, and flow batteries, the distributed resources are presenting a potential alternative of energy supply infrastructure. In many parts of the world, industrial consortiums are formed and testbeds of "micro-grids" are being built for evaluation of their capabilities[15]. Micro-grids are low voltage local power systems interconnecting multiple distributed resources. The system can not only allow greater local control of electricity delivery and consumption but also provide thermal energy recovery and distribution (such as hot water supply and air conditioning) achieving a very high energy efficiency overall. It is expected that some part of electricity generated in the micro-grids can support high quality electricity to sensitive loads as server computers even if the utility power suffers a blackout. Figure 4 shows an image of micro-grid.

One of the purposes of the micro-grid testbeds is to identify the needs and develop the telecommunication infrastructures and communication protocols required. To facilitate the interoperability of one or more distributed resources interconnected with electric power systems, an industry standard is being drafted by The Institute of Electrical and Electronic Engineers (IEEE)[16]. It describes functionality, parameters and methodologies for monitoring, information exchange and control for the interconnected distributed resources. If such an independent power system is to operate on a market-based information (such as switch-

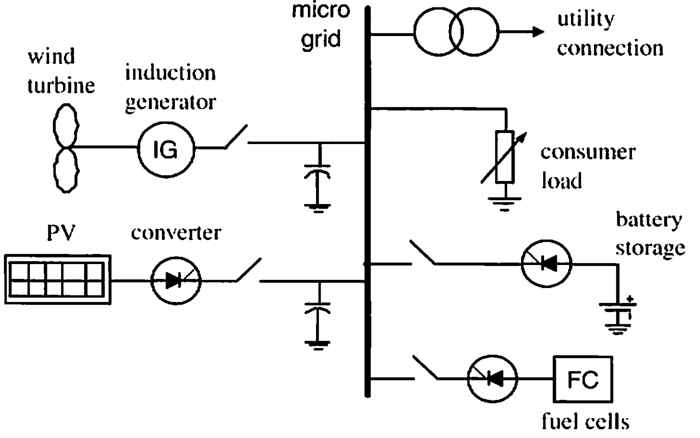


Figure 4. Micro-grid

ing to local resources when utility electricity price is high), the security of information exchange and processing will be the major concern of cyber security.

5. Summary

In this report, based on an overview of the information processing infrastructure of conventional electric power systems, the process of electric power industry deregulation and its impacts have been reviewed. The new roles of information technology in the changing power industry structure has been examined in an extended context including the distributed electricity resources and related technologies. More information can be found in the list of related sources in References.

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