19

Flexible, Reliable, and Intelligent Electrical Energy Delivery Systems

Alexander Domijan, Jr.
University of Florida

Zhidong Song
University of Florida

19.1 Introduction

There have been considerable changes in today's power systems in recent years, due, in large part, to the emergence of competition and deregulation in power industries. The goal of deregulation is to provide the customer with reduced costs. The global competition between utilities leads to utility cost-cutting, downsizing, and reducing maintenance on both transmission and distribution systems. Power systems that are hierarchically integrated are separated such that tasks normally carried out within traditional organizations have been open to competition whenever practical and profitable. This process, which is called "unbundling," consists of unbundling of vertically integrated utilities, unbundling of functions within a corporation, and service unbundling. As a consequence, the common structure in the deregulated power industry is the separation of the generation, transmission, and distribution business into separate entities. There is, however, a possible drop in service quality as a result of deregulation. Additionally, installation and penetration of distributed generators (DGs) and distributed energy storage systems (DESSs), allocated in the demand-side of power systems, have been increased. Unexpected power quality problems may occur, because these distributed facilities are operated independently and are uncommitted to the operating situation of power systems.

Power quality issues have become more important in the face of this open competition. In recent years there has been an increase in the number of system loads and controls that are sensitive to power quality, as well as an increase in the number of system loads that are themselves a source of poor power quality (such as harmonics caused by static drives). Loads such as computers, process controls, and communications equipment are more sensitive to power quality variations due to frequent system disturbances than is equipment applied in the past. On the other hand, there has been continuing growth in the application of power electronics devices, both to improve the overall power system efficiency and to facilitate controls. This is resulting in increasing power quality problems on power systems, for these loads themselves are major causes of the degradation of power quality. Yet awareness of power quality issues is increased by the end users who need a high quality of power for their equipment and are becoming better informed about such issues as voltage sags, swells, surges, harmonic distortions, interruptions, outages, undervoltages, overvoltages, electrical noise, frequency deviations, impulses, transients, and notches. They need to understand how the disturbances will affect sensitive loads and therefore develop appropriate specifications, or install appropriate power conditioning systems [1]. Harmonics, for example, can result in equipment heating and voltage stress, communication interference, and control malfunctions. Voltage sags of only a few cycles can cause tripping of drives, loss of computer data, or errors. As a matter of fact, utilities are being challenged to improve the quality of power delivered by every possible means.

Power quality, therefore, is the benchmark by which we may judge the success of our problem solution. Reliable and secure power service needs to be made available to customers. Customers, who need a high quality of power for their equipment and are becoming better informed about power quality issues, provide the principal motivation for the utility industry with unbundled services and greater reliance on competitive forces. They, then, would be free to select their desired level of power quality. There is opportunity for enhanced value of service through greater choice among customized and competitive services. Yet the utility industry itself, under the threat of competition, on the other hand, is likely to be forced to offer a variety of valued-added unbundled services and prices to customers to increase customer satisfaction. It may be assumed that the customer or market will play the lead over that of the energy supplier. Information-based electric suppliers, both with and without generation sources, will be able to attract large portions of market share from the traditional suppliers. Therefore, electric utilities must be prepared to develop a strategic methodology both to satisfy their existing customer base and to capture additional customers as competition unfolds. One way to accomplish these goals is via the business strategy of providing unbundled or differentiated services/products. The rapid advance in technologies such as power electronics, small-scale energy generators and storage, and computer control has made feasible distributed systems and the unbundling of power services.

Advanced technologies including power electronics, together with new coordination mechanisms, should be taken into account to ensure the quality of an unbundling service on reasonable levels. New system configurations and control schemes are desired under the above situations. Many technical problems need to be solved. The new concept of Flexible, Reliable, and Intelligent Electrical Energy Delivery Systems (FRIENDS) is such a methodology for electric power infrastructure development and information management systems to realize such an unbundled power quality service.

19.2 The Concept of FRIENDS

What Is FRIENDS?

Similar to the early days of the electric utility industry, a product, unbundled power quality services, is needed first to create a market. The unbundling of power quality services, defined as permitting several levels of power quality at a differentiated cost, is a business concept that achieves its potential in the presence of technologies that can provide specific customers with more than one level of power quality. Ideally, such technologies would provide a range of user choices, of readily calculable economic value, that could be reoptimized as the needs of the user evolve. This then allows expansion of the FRIENDS infrastructure (from revenues generated by the first products introduced) to reach a larger market for services rendered. This process is not likely to be implemented suddenly. Rather, a systematic approach, [2] as illustrated in Fig. 19.1, is the more likely scenario for this century. The enabling products are those

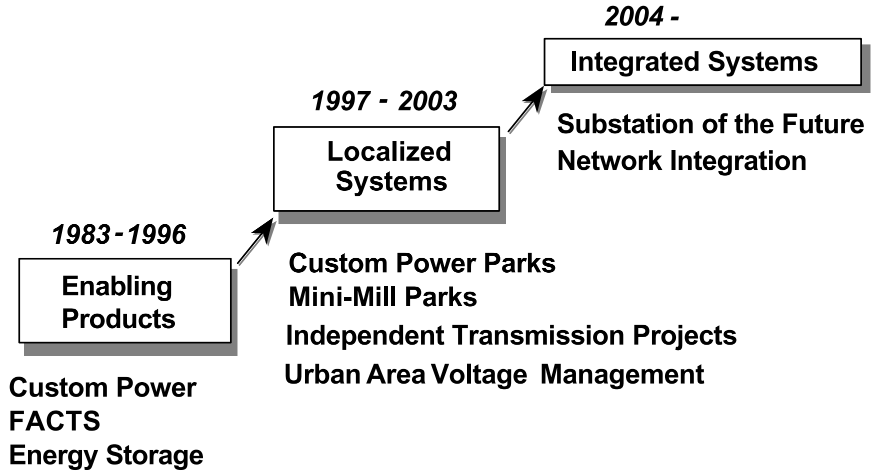

FIGURE 19.1 The evolution to FRIENDS.

that permit a flexible and reliable tailoring of electrical supply that are promoted by the concept of unbundling.

The result of the process will lead to fully integrated and distributed power systems—FRIENDS. Such power systems, with substations using quality control center (QCC) concepts, will give the distributor the ability to provide multimenu (custom) services to customers. The customers can select the supplier according to the power cost by automatically selecting the supplier and accounting for the power cost. For providing multiquality power supply, the QCC in FRIENDS can control and operate customer's switching facilities with a priority order, such as customer's switchboard, panel-board, and/or electric apparatus, via a powerful communication network and intelligent computers. The priority order here means the customer's reliability power supply and that the customer can decide this order. However, in an emergency case, the QCC will control those switches flexibly. Moreover, in the near future, utilization of DC power on the customer side may become general. It is expected that the QCC will have ability of supplying DC power directly to customers. In such a case, reverse power flow from customer to the QCC is also DC power so that the loss of an AC-DC converter can be expected. Multimenu services for each consumer can be realized by using information through data communication lines.

The FRIENDS systems can be operated without interrupting power supply by flexibly changing the system configuration after a disturbance occurs. Each customer, as a consequence, can select the quality level of power independently through QCCs. Multimenu services for each consumer can also be realized by using information through data communication lines. In addition, distributed generators (DGs) and distributed energy storage systems (DESSs) will be allocated on the demand side of FRIENDS. Energy-conserving measures can be expected with the full use of flexibility of the system configuration and advanced demand-side management (DSM). On the other hand, the custom power park concept [2] is geared toward a local system, but may be integrated in the overall QCC concept of FRIENDS. Furthermore, the unbundled services provided, whether they are of commodity or premium grades, may be implemented in a modular manner. Advanced power electronics provides the wherewithal in an unbundled business scenario to differentiate power quality levels provided to customers. The equipment may be individually customized via dynamic voltage restorers (DVR), distribution static compensators (DSTATCOM), solid state breakers (SSB), etc., depending on customer needs and resources available. Such an approach permits business strategies whereby customer retention and acquisition become possible in a competitive environment.

FRIENDS is a forward-looking type of power delivery system that takes into account deregulation, a varied and distributed power supply, and a delivery system that provides flexible, yet reliable, power to a diversified customer base. There are several possible conceptual implementations of FRIENDS. However, fundamentally the network is an integrated system with the ability to provide flexibility in reconfiguration and reliability so that uninterrupted service is obtained. To implement such a system requires advanced power electronic technologies to create the desired conditioned power and command-and-control technologies.

From the viewpoint of consumers, the characteristic of FRIENDS can be summarized as multiple menu service, which may be classified into three types: multiple rate service, multiple quality service, and multiple supplier service. Specifically, FRIENDS is directed to obtain the following technical features:

- Flexibility in reconfiguration of a power system
- Reliability of power supply
- Multimenu services to allow customers to select the type of power provided and other services offered by the electric utility
- Revenue-enhancement techniques
- Load leveling and energy conservation
- Enhancement of information services (utility/customer, and utility/utility)
- Effective demand-side management
- Flexibility in incorporating dispersed generation
- New automatic generation control methodologies
- Voltage regulation functions
- Fault current-limiting functions
- Prevention of sags, swells, and harmonics
- Instrumentation and revenue metering

In brief, the purpose of FRIENDS is to develop a desirable structure for future power delivery systems, where dispersed energy storage systems and dispersed generators are installed near the demand side, and to develop reliable and energy-conserving operation strategies of power systems, taking into account the ways of enhancing service to customers through intelligent functions. It will be necessary for the power industry to create technical product differentiation that provides for the effective unbundling of power quality services, of readily calculable value, as the needs of the customer evolve [2].

Quality Control Centers

FRIENDS can realize the most efficient use of the flow of electric energy generated by remote generators, dispersed generators, and dispersed storage devices in electric power networks. One of the most important features of FRIENDS is that new power improvement facilities referred to as quality control centers (QCCs) are installed very closely to the customers. A desirable operating algorithm of DGs and DESSs in QCCs have been investigated and the capacity required for the multiquality power supply have been evaluated [3–9]. QCCs are developed to cope with providing flexible services to customers in an uncertain electric utility business in near future delivery systems, with which multimenu electrical power quality services are realized in FRIENDS. A QCC is much like a switching facility with the capability to change flexibly the system configuration depending on the system states. The QCCs play a vital role in the operation of FRIENDS, such as:

- Flexible change in system configuration
- Multiple menu services for customers (unbundled services)
- Information management (information processing and data exchange centers)
- Monitoring and controlling power flow by interchange of information between QCCs so that the system can operate in the most effective and economical way

A QCC can be supplied with electrical power from several distribution substations through several power lines to enhance the supply reliability as shown in Fig. 19.2. It may cover a wide area or may be local and located at a section of the current distribution system, an underground floor of a large building, inside the area of a factory, and so forth, depending on its role. In a QCC, it is expected that electric

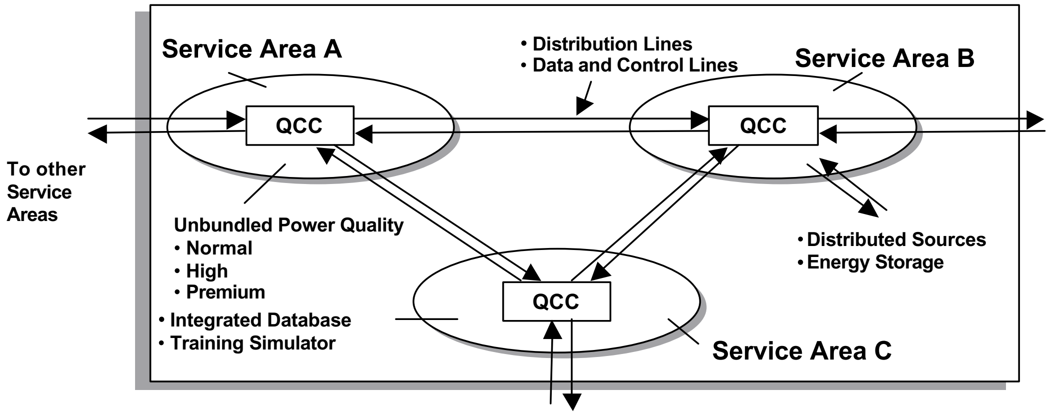

FIGURE 19.2 A FRIENDS network with quality control centers.

power with various levels of quality is produced for multiple-menu services, and a number of static open and closed switches are equipped to establish flexibility in the configuration of the delivery system. Distributed power generation resources and energy storage systems may be incorporated into the QCC for high reliability and energy conservation. Further, the QCC has roles as an information processing center and data communication center for controlling certain apparatus in the QCC and supplying many kinds of information. The operation and control of certain apparatus in the QCC, such as open and closed switches, are implemented from a global point of view by cooperation between computers used at a distribution substation or by individual consumers.

Intelligent Function of FRIENDS

The principal computer functions of FRIENDS include not only the current distribution automation functions, but many other functions to cope with the new system. They are typically the DSM functions, power quality selection/control functions, and information services.

The most important role among the computer functions is the high-speed and flexible switching operation of the distribution network that includes protective relaying functions. This function flexibly controls the static switching facilities (such as thyristors) in the system according to the situation of the system, to minimize loss in the normal state, to provide protective relaying scheme in the emergency state, and to conduct restorative operation in the restoration state. These functions are installed on every computer according to its control level, and achieved on the basis of the distributed computers.

Other important functions are related to the control of DGs and DESSs, or multiquality power control and load leveling. These functions are mainly installed on the computers at the QCC. The DSM functions are also a remarkable feature of FRIENDS. Moreover, through communication lines, control computers are connected to an off-line computer in which the integrated database for control and maintenance, rate calculation, and mapping (see Fig. 19.2). Therefore, only one database must be maintained for the distribution systems operation and management. This database can also be used for the operator-training simulator installed within FRIENDS. Training of mapping and management as well as systems operation may be a key issue for the operators and the manager in the future automated power system.

19.3 Development of FRIENDS

In the near future, power systems may change considerably as a result of the worldwide deregulation occurring in the electric power industry. Further, various customers' requirements with regard to their power supply will increase. Therefore, it is desired to establish new power distribution systems [10]. On the other hand, automatic operation technologies in power distribution systems such as SCADA, AM/FM-GIS

(Automatic Mapping/Facility Management Geographic Information Systems) have been developing rapidly. Meanwhile, power electronic technologies, communication technologies, DSM technologies, etc. have also been developing. Some DGs and energy storage systems have been installed in distribution systems. The complexity of the existing systems as well as the specific quality requirements of each customer are expected to increase, and will consequently require more advanced electric power delivery systems and advanced technologies. Therefore, it is possible to build new distribution systems that have many excellent functions with these new technologies.

The advantages of FRIENDS are increasingly apparent by progress made via international collaboration in recent years. They are as follows: multiquality electric power, multimenu services and rate information to customers, energy conservation effect with the full use of flexibility of the system configuration and advanced DSM, and powerful intelligent communication networks along with QCCs. So far, research in the following aspects of this field has attracted much attention:

- Optimal FRIENDS configuration for reliable power supply
- Concepts and configurations of QCCs for unbundled power quality services
- Optimal allocation of DGs
- Autonomous decentralized power distribution system (ADPDS)
- Utility and customer interface

It is necessary to develop an optimal configuration of FRIENDS from the viewpoint of power supply reliability, to realize the unbundled power quality services through DGs and DESSs. Network connection of FRIENDS must be flexibly changed to minimize distribution loss in a normal state, and to supply power without interruption to customers by utilizing DGs and DESSs in a fault state, through ON/OFF status of solid-state transfer switches (SSTS). To solve the network configuration problem in FRIENDS, from the viewpoint of power supply reliability, an effort has been made to determine power lines and DG installations, to minimize total installation cost under constraints of the maximum capacity of DGs, line current capacity, and uninterrupted power supply. Special algorithms have been employed to solve this problem and numerical results have been obtained [3–9]. It is expected that system configurations can be changed flexibly, to minimize distribution losses in normal states, to restore the system swiftly in an emergency state, and to repair facilities without power interruption in a maintenance state.

A QCC is a new facility that can improve the quality of power according to customers' requests and provide multiquality power to customers. A QCC may be connected to multiple power lines and can be supplied with commodity quality power from several substations. The connection of many QCCs will lead to the development of a new type of high-voltage power distribution network such that QCCs can provide power with various qualities to customers in a multimenu manner. To realize FRIENDS, detailed interior structures of QCCs for accomplishing its functions and algorithms for optimal selection of power quality and power provider are needed. The problems for development of a structure of QCCs are mainly focused on (1) a circuit configuration that makes it possible to deliver electric power with different power quality levels and (2) the control of the static switches that are the most fundamental components of a QCC. In general, QCCs will take various kinds of interior structures according to the features of customers connected to the QCC, conditions in the neighborhood of the QCC, location of the QCC, and installation cost of the QCC, and so on. Progress has been made on development of concepts and physical configurations of the QCC. The configuration of a QCC, which will be located between distribution substations and loads, has been investigated and a prototype model of generating end-use power demand proposed [11, 12]. This model can simulate the activity of a customer and the usage patterns of energy using appliances in the household. Three structures for industrial, business, and commercial, and residential areas have been proposed [13, 14], where the control scheme of solid-state switches used for changing network configuration and cutting off a line when abnormal voltage occurs. Further, the initial structural design of a QCC has been proposed, and the interior structures of the QCC in the scheme of FRIENDS, together with qualitative explanations for various characteristics of the proposed structures, have been provided [15–21]. Two types of QCC models that can execute unbundled power quality services to customers, along with simulation of transient behavior of the proposed model, have been investigated. Uninterruptible power supply (UPS) system, DGs, and solid-state breakers (SSB) can be incorporated into the proposed QCC models. It is expected in a QCC that electric power with various levels of quality is produced by using various types of equipment, e.g., UPS, DVR, SVC, AF (active filter), AVR (automatic voltage regulator), FCL (fault current limiter), etc., with intelligent features. A number of solid-state open/close switches, DGs, and DESSs are also important facilities for realizing many of the functions to be incorporated within a QCC. Small consumers, who are usually considered as captured consumers and cannot select their suppliers, may enjoy the multiple supplier service through the service of QCCs. This service will undoubtedly encourage competition in the electric power market. In addition, a QCC can also be considered a virtual consumer. It may choose the supplier to minimize the electricity cost.

ADPDS has been introduced as a concept of FRIENDS [22]. The major purpose in this area is to develop a method to find the realizable configuration and operation of ADPDS from a viewpoint of power quality and supply reliability under global deregulation and competition, such that the unbundled power quality services can be applied to traditional power distribution systems. In this concept, among many kinds of power qualities, power interruption or power supply reliability is the most important function of unbundled power quality services. A concept for real-time voltage regulation and a modeling method for distribution systems integrated with DGs have been recently developed [23]. It is expected that this modeling method could be widely applied to design and operation of distribution systems with many DGs.

The distribution system envisioned by FRIENDS will need to be able to operate with an array of lines, QCCs, DGs, and storage elements—all digitally controlled so that resources are allocated flexibly, yet reliably. Similarly, the transmission system must also be controlled effectively to handle the transaction increases expected. Both on the distribution and transmission sides this may be accomplished via a multilevel hierarchical control structure [24–26], which incorporates FRIENDS, FACTS, Custom Power, and wide-area communication technologies. Both a power supply and delivery technology (one that is flexible, robust, and efficient) are required to sustain the expected use of energy. FRIENDS is the key for such a successful delivery system. However, FRIENDS technology must be implemented on a value-added basis; otherwise, one risks returns on investment not well optimized with respect to the cost of capital. What is needed is a sensible roadmap of value-added innovation that fits within anticipated options available to customers. Research on other areas such as security constrained power planning and operations in competitive market [27], DSM, and computer technologies in FRIENDS [28] are under way.

19.4 The Advanced Power Electronic Technologies within QCCs

Power quality for unbundled power quality services may be considered on three levels—normal quality, high quality, and premium quality—depending on demand characteristics of customers. In the concept of FRIENDS, QCCs have transfer switches to reduce distribution losses, voltage sags, swells, flickers, interruptions, three-phase voltage unbalance, and voltage harmonics, by using advanced power electronics devices such as DSTATCOM, DVR, UPS, and SSB or SSTS.

Distribution Static Compensator

As a fast, flexible, and effective power quality mitigation tool, DTSATCOM is designed to protect the upstream system from "dirty" loads, surges, or harmonics caused by other users on the distribution system. The use of DSTATCOM devices (whose capabilities may include active filtering, reactive power supply, and flicker correction) is becoming quite attractive for customers and distributors, partly because of its direct connection to the network (just as any other load element) and mainly because the same power electronics configuration can be used, modifying the control structure, to provide the different services. The parallel-connected DSTATCOM with the load provides dynamic, subcycle voltage support and regulation of reactive power flow. It is capable of generating continuously adjustable reactive or capacitive compensation at a level up to the maximum MVA rating of the DSTATCOM inverter. Accordingly, it has better dynamic response than have conventional voltage and VAR control elements.

By varying the amplitude and phase angle of this solid-state synchronous voltage source, the dynamic subcycle response of a DSTATCOM system mitigates the terminal voltage disturbances and improves the system power factor by variable parallel-connected reactive compensation. Yet the DSTATCOM can reduce and totally eliminate voltage flicker resulting from rapid variations in load currents by dynamic nonlinear loads. By eliminating the flicker at the load, the DSTATCOM enables these loads to coexist on the same feeder as more sensitive loads, eliminating the need for separate feeders. The DSTATCOM can increase the capacity of distribution feeders by as much as 50% through power factor improvement and real-time voltage support, thereby alleviating thermal overload conditions and improving power quality for remote energy users.

Dynamic Voltage Restorer

A DVR is a custom power element for series connection into a distribution feeder. As an IGBT DC-to-AC switching inverter that injects three single-phase AC output voltages in series with a distribution line and in synchronism with the voltage of the distribution system, it provides the entire downstream load with protection from voltage sags and transients. By injecting voltages of controllable amplitude, phase angle, and frequency into the distribution feeder via a series injection transformer, the DVR can restore or supplement the voltage quality at its load-side terminals, when the quality of the source-side terminal voltage is significantly out of specification for sensitive load equipment. For example, DVR can restore the voltage quality delivered to an end-use customer when the source-side voltage deviates. During a voltage sag, the subcycle response of the DVR technology supplies what is missing in the voltage waveform, so the customer's sensitive load sees a restored nominal voltage, i.e., no sag. A DVR can supply partial power to the load from a rechargeable energy source attached to the internal DVR DC-link to keep the voltage within the requirements. During the normal line voltage conditions, the energy storage device is recharged from the AC system. Even without stored energy, the DVR can compensate for voltage fluctuations by inserting a voltage that lags or leads the line current by 90 electrical degrees, thus providing continuously variable line compensation.

A DVR (designed by Siemens, for example) is typically composed of several 2 MVA inverter modules connected in parallel at the injection transformer. Its ability to maintain maximum voltage injection depends on the kilojoules available in the energy storage subsystem (capacitors, flywheels, and SMES). The per-unit rating of a DVR can be determined by the per-unit voltage injections multiplied by the rated load current.

Solid-State Breaker

The SSB, based on GTO switch technology, is a fast-acting, subcycle breaker that can instantaneously operate to clear an electrical fault from the power system. It also can be used in combination with other power electronic devices to improve power quality performance to customers, as well as prevent excessive fault currents from developing. An SSB can be applied in a single switch, a transfer switch, a tiebreaker, or a low-level fault interrupter. An SSB may consist of two parallel-connected circuit branches: a solid-state switch composed of GTOs and another using SCRs. The capacity of the semiconductor devices used in the breaker primarily determines the operating characteristics of the SSB. Voltage and current ratings of the breaker define the number of power semiconductors required, and consequently the cost and the operating losses of the breaker. GTO breakers are used to provide rapid, subcycle current interruption and SCR breaker to provide fault current conduction for protection coordination in conventional distribution system applications.

The SSB is able to provide power quality improvements through near-instantaneous current interruption at utility distribution voltages (4 kA at 4.5 kV), an action which provides protection for sensitive loads from disturbances that conventional electromechanical breakers cannot eliminate. The SSB is designed to conduct in-rush and fault currents for several cycles, and to disconnect faulty source-side feeders in less than one half a cycle.

A high-voltage SSTS can provide nearly uninterruptible power to critical distribution-served customers who have two independent power sources. Fast-acting solid-state switches can rapidly transfer sensitive loads from a normal or preferred supply that experiences a disturbance to an alternate or backup supply such as another utility primary distribution feeder or a standby power supply operated from an integral energy storage system.

19.5 Significance of FRIENDS

FRIENDS will give consumers the ability to take advantage of multiple menu services, and utilities the ability to provide flexible, reliable, and intelligent electricity services. Since consumers are given a choice with a multiple menu service, they may have greater influence on the overall system operations. The necessary condition for the existence of FRIENDS is consumer satisfaction and improved operations for the utility. Because of deregulation and competition, it becomes important to provide reliability and tailored services and its realization will make it economically possible to create the system. From this standpoint, the reliability of the high-voltage side, such as the generation and/or transmission systems, of power networks can be less important, and the investment in it may be reduced. Therefore, a part of the investment on the high-voltage side may be diverted to the distribution side without a change in the total investment. However, implementation costs for QCCs will be high because of the SSBs in its configuration. More cost reduction is necessary to make the concept of FRIENDS realizable. FRIENDS will be developed through several items, the important of which are (1) powerful intelligent communication networks; (2) QCCs; and (3) advanced power quality enhancement systems. These items are interrelated and may be enhanced if considered together. The QCC will also have dispersed generation and storage in its configuration to achieve load leveling and to supply uninterrupted power to the loads. The QCC will change the system configuration flexibly depending on the system states, data of which are exchanged through intelligent communication networks.

As mentioned in previous sections, FRIENDS integrates a number of research concepts that have been developed individually, by adding more reliable and flexible functions. Distributed generation resources and energy storage systems, demand-side control, advanced power electronics technologies, and distributed intelligent facilities can be combined into FRIENDS systems. Generally, a FRIENDS system with QCCs will play an important role in the following ways (Fig. 19.3).

Flexibility in reconfiguration of the system. With solid-state switches in a properly used QCC, the distribution system configuration can be frequently changed according to the state and load patterns of the system to reduce distribution losses and load leveling and to avoid power interruption. QCCs may permit a reverse flow of power and have the ability to bypass selected QCCs. Power electronics switches, together with computerized relaying schemes, will be utilized to make switching operations much easier and more flexible.

Reliability in power supply. In principle, power interruption never occurs in FRIENDS. To realize an uninterrupted power supply, DESS and DGs installed at the demand side are fully used under the control of the QCC, providing flexibility in reconfiguration. A computer installed at the QCC has functions related to the control of DESS and DGs, multiquality power control, and load leveling. With consideration of power interchange between QCCs, an effective operational scheme of DESSs and DGs can be attained. It is found that there might be a trade-off between the system configuration and the capacity of DESSs and DGs.

Multimenu service for customers. A QCC produces multiquality power by using DESSs and DGs. The customers can select the supplier according to the power cost by automatically selecting the supplier and accounting for the cost of energy. For providing a multiquality power supply, the QCC can control and operate customer's switching facilities flexibly with a priority order decided by the customer's power supply reliability, such as a customer's switchboard, panel-board, and/or electric apparatus, via a powerful communication network and intelligent computers.

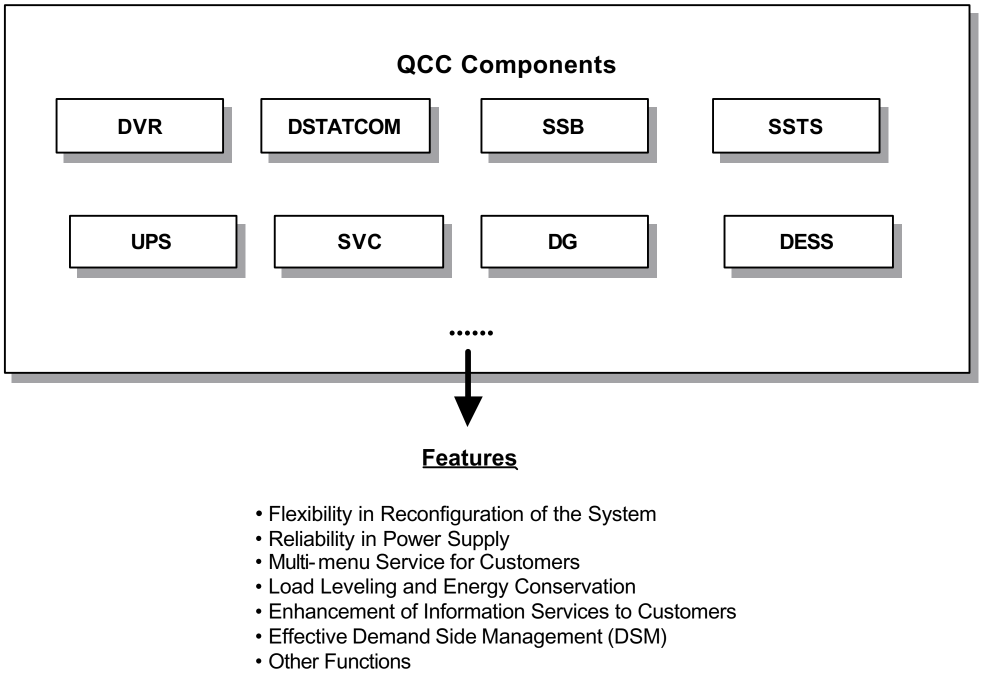

FIGURE 19.3 Features of QCCs.

Load leveling and energy conservation. Power generation in large power units can be leveled by the optimal operation of DESSs and DGs via QCC; then power plants can operate efficiently. As installation of DESSs and DGs increases, load factors at some nodes are enhanced according to the peak-cut and bottom-up approach. Further, if load factors at some nodes become 100%, it is possible to have a margin in the installation of DESSs and DGs. In FRIENDS, this margin will be effectively used to improve the total load factor by interchanging the power between QCCs.

Enhancement of information services to customers. Through the use of a powerful communication network for power system control installed along system components, much information about the power supply and other factors can be sent between a customer and a power company. For example, information of power system restoration can be sent to a customer when power interruption occurs in the system by a fault. In the view of a power supplier, this can provide a competitive edge in an open market by increasing the visibility of its company as a preferred energy provider.

Effective demand-side management. Passive and active DSM can be realized efficiently by controlling the customer's demand through the communication network and dispersed computers. The passive type of DSM uses season-of-year rates, time-of-day rates, and load control contracts. The active type of DSM uses apparatus control, voltage control, online rate system, selection of power suppliers, and so on.

Other functions. Other functions that could be accomplished by the QCC are voltage regulation, fault current limitation, prevention of momentary voltage sags, swells, and harmonics, shedding of the ordinary or low-quality loads, filter, AC-DC converters, etc. With expected progress in the study and development of FRIENDS, new ideas to further enhance the function of the QCC are expected.

In fact, FRIENDS, as a novel concept to cope with deregulation and unbundled power quality services, will impact significantly not only on the infrastructure of power delivery systems in the near future, but also on related fields such as political issues of energy policies, customer satisfaction, etc. This means that the concepts of how customers can benefit from a multiple rate service, multiple quality service, and multiple supplier service of the new systems should be well represented through multiple media.

19.6 Realization of FRIENDS

Significant progress has been achieved in several areas that form the background technologies of FRIENDS, such as information processing technologies, power electronics facilities, distributed generators and distributed energy storage systems, new communication schemes, demand-side management and deregulation, etc. Especially, ongoing development and commercial availability of high-power semiconductors will further increase opportunity and cost-effectiveness of advanced technologies as mentioned above. New system control technologies are needed to integrate safely small modular generation and storage technologies such as fuel cells, microturbines, photovoltaic, wind, batteries, flywheels, and so forth into the distributed system. The custom power/premium power pak concept is one that can integrate these state-of-the-art technologies to improve power quality, which can then be incorporated into the QCCs of FRIENDS. Related technology development in power quality monitoring, metering, and communications will also need to keep pace to support the large number of "differentiated" users that unbundling creates. Directions of development are anticipated as follows:

- Development of technologies, such as FRIENDS, premium power pak, etc., to catch up with new challenges in future electric utilities;
- Development of decision-making models to include the complexity of the present or future price structure, taking into account the technical, financial, and social issues;
- Development of new control technologies for distribution systems in a competitive power market;
- Development of technologies for revenue enhancement, instrumentation, and real-time pricing;
- Development of new rules for unbundled power quality services in energy supply systems.

To achieve the goal of realizing FRIENDS, the following technologies are being developed:

- Optimal FRIENDS configuration for reliable power supply from the viewpoints of installation and operational cost, reliability, and system operation.
- Behavior investigation and coordination of the main components in FRIENDS—Emphases will be on control coordination of fast switching actions and parameter optimization of components, determination method of optimal switching operation in normal, emergency, and restorative states, together with protection schemes to make the system reconfiguration more flexible and the power supply more reliable.
- Development of distributed generation and distributed energy storage systems—Algorithm for optimal planning and operation of DGs and DESSs, behaviors of DGs and DESSs in normal and fault states, optimal deployment, allocation, and capacity of DGs and DESS into distribution systems will be secured.
- Structure design of QCCs for unbundled power services—This task may include development of the concepts and configuration of interior structures of the QCCs, optimal selection of the power quality and power suppliers, indices for evaluating power quality quantitatively and to analyze the performance of QCC using the indices, and a hybrid system of quality control centers and intelligent communications networks.
- Efficient demand-side prospects and energy demand monitoring of FRIENDS—The efforts in this area involve efficient demand-side management systems and their evaluation methods, options of multiple-menu services for consumers using FRIENDS, and estimation of unbundled energy demands.
- FRIENDS and power system security—Control performance, involving development of new automatic generation control methodologies that take into account new industry-defined control performance standards, needs to be investigated. Further, methodologies for security-constrained generation dispatch, transfer limits evaluation and enhancement, and open transmission access in a competitive power system market should be exploited.

- Revenue enhancement and online pricing or metering scheme consisting of economic assessment of FRIENDS systems, real-time pricing methodologies, and evaluation of power quality and detection of distortion.
- Optimal frame of customer information systems for development of quality-related electricity products.
- Instrumentation to evaluate appropriate revenue metering and power quality monitoring.
- Development of other related technologies for unbundled power quality services.

These may consist of new data requirements and an integrated database for implementation of FRIENDS (static, historical, and real time), new high-level communication procedures, and new types of training simulators.

19.7 Conclusions

- Deregulation of the power industry will cause new challenges in dealing with power quality issues.
- The deregulation issues and the power quality issues cannot be dealt with in isolation.
- Deregulation is creating the opportunity for electric utilities to offer a variety of valued-added services to customers.
- Customer choice and the types of utility services provided will be the key elements in determining the success of an electric utility.
- Commercial availability of high-power semiconductors increases the opportunity and cost-effectiveness of power quality control and improvement technologies.
- The state-of-the-art, commercially available equipment allows for the development of the FRIENDS concept, and other advanced technologies provide the means for electric utilities to add value incrementally via additions to their infrastructure.
- FRIENDS provides for useful guidance and strategic implementation schemes to improve service quality, conservation, power supply planning, and possible needs in transmission and distribution line siting.
- The quality control center (QCC) is one of the facilities of FRIENDS, and may be realized by many kinds of structures according to the roles that are performed by particular types of QCCs. QCCs should not only improve electrical waveform quality, but also provide unbundled quality power to customers.

References

1. Kazibwe, W. E. and Sendaula, M. H., *Electric Power Quality Control Techniques,* Van Nostrand Reinhold, New York, 1993, chap. 1.
2. Kessinger, J. P., Advanced power electronics as an enabler of unbundled power quality services, in *Proceedings of the NSF Conference on Unbundled Power Quality Services in the Power Industry,* Key West, FL, Nov. 1996, 114.
3. Nara, K. and Hasegawa, J., An advanced flexible and reliable power delivery system, in *Proceedings of the NSF Conference on Unbundled Power Quality Services in the Power Industry,* Key West, FL, Nov. 1996, 129.
4. Nara, K. and Hasegawa, J., Future flexible power delivery system and its intelligent functions, in *Proc. of ISAP '96,* 1996, 261.
5. Nara, K. et al., Optimal allocation of dispersed energy storage and generators for power delivery system reliability enhancement, in *Proc. of the IASTED International Conference High Technology in the Power Industry,* Orlando, FL, Oct. 1997, 47.

6. Nara, K. et al., A study for composing flexible and reliable electrical energy delivery system, in *Proc. of International Conference on Electrical Engineering (ICEE'97),* 1997, 506.
7. Nara, K. et al., Implementation of generic algorithm for distribution system loss minimum reconfiguration, *IEEE Trans. PWRS,* 7(3), 1044, 1992.
8. Nara, K., Kin, H., Suzuki, K., and Mito, A., Study for a reliable power system structure in which dispersed power generators are installed, in *IEE of Japan Power and Energy Conference,* 1996, 155, 197.
9. Nara, K., Hayashi, Y., and Mishima, Y., Optimal network planning and operation of FRIENDS, in *Proc. of the Fourth International Meeting on Systems Technologies for Unbundled Power Quality Services,* Singapore, Jan. 28, 2000, 12.
10. Domijan, A. and Heydt, G., Eds., in *Proceedings of the NSF Conference on Unbundled Power Quality Services in the Power Industry,* Key West, FL, Nov. 1996.
11. Tsuji, K., Co-generation in urban area, *Int. J. Global Energ. Issues,* 7(3/4), 137, 1995.
12. Tsuji, K., Saeki, O., and Suetsugu, J., Estimation of daily load curves by quality level based on a bottom-up simulation model, in *Proc. of the IASTED International Conference High Technology in the Power Industry,* Orlando, FL, Oct. 1997, 181.
13. Takami, M., Ise, T., and Tsuji, K., Concepts and configuration of quality control center in a new power distribution network, presented at Japan-U.S. Seminar on Intelligent Distributed Autonomous Power Systems, Hakone, 1998.
14. Tsuji, K., Current research and future research plans at Osaka University, in *Proc. of the First International Meeting on Systems Technologies for Unbundled Power Quality Services,* Sept. 7–9, Mito, Japan, 1998, 25.
15. Nishiya, K. et al., Optimal location of dispersed energy storage systems in distribution systems from a view of economical standpoint, *Trans. IEE Jpn.,* I I 4-B(12) 1257, 1994.
16. Rho, D., Kita, H., Nishiya, K., and Hasegawa, J., Evaluation of dispersed energy storage system for its installation (from a viewpoint of the secondary battery), *Trans. ME Jpn.,* 116-B(2), 187, 1996.
17. Jung, K., Kim, H., and Rho, D., Determination of the installation site and optimal capacity of the battery energy storage system for load leveling, *IEEE Trans. Energy Conversion,* I I J(1), 162, 1996.
18. Mishima, Y., Kita, H., and Hasegawa, J., Basic study on operation of quality control center for multi-quality power supply by FRIENDS, in *Proc. of the IASTED International Conference High Technology in the Power Industry,* Orlando, FL, Oct. 1997, 175.
19. Rho, D., Kim, J., Kim, E., and Hasegawa, J., Basic studies on impacts of customer voltages by the operation of FRIENDS, in *Proc. of the IASTED International Conference High Technology in the Power Industry,* Orlando, FL, Oct. 1997, 181.
20. Rho, D., Hasegawa, J. et al., Voltage regulation methods based on an extended approach and neural networks for distribution systems interconnected with dispersed storage and generation systems, *Trans. IEE Jpn.,* 17-B(3), 298, 1997.
21. Hasegawa, J., Kita, H., Tanaka, E., Mishima, Y., Wang, G., and Hara, R., Design of quality control center for unbundled power quality services, in *Proc. of the Second International Meeting on Systems Technologies for Unbundled Power Quality Services,* Gainesville, FL, Feb. 5–7, 1999, 27.
22. Kim, J. E., Park, J. K., and Kim, J. C., Research schedule and results so far in Korea: research on configuration and operation of autonomous decentralized power distribution system, in *Proc. First International Meeting on System Technologies for Unbundled Power Quality Services,* Mito, Japan, September 1998, 41.
23. Kim, J. E., Operation technologies of power distribution system with dispersed generation systems for unbundled power quality services, in *Proc. of the Second International Meeting on Systems Technologies for Unbundled Power Quality Services,* Gainesville, FL, Feb. 5–7, 1999, 64.
24. Domijan, A. and Song, Z., Incorporation of hierarchical control with FACTS technologies in large power systems, *Int. J. Power Energ. Syst.,* 20(1), 20, 2000.
25. Domijan, A. and Song, Z., Simulation on multi-machine power system with FACTS devices by hierarchical control, *Int. J. Power Energy Syst.,* 20(2), 67, 2000.

26. Domijan, A., Song, Z., Kamoto, K., and Qiu, Q., Simulation investigation on power systems with versatile models by hierarchical control and custom power elements, in *Proc. of the Third International Meeting on Systems Technologies for Unbundled Power Quality Services,* Espoo, Finland, July 4–5, 1999, 13.
27. Chang, C. S. et al., Dynamic security constrained multi-objective generation dispatch of longitudinal interconnected power systems using bicriterion global optimization, *IEEE Trans. Power Syst.,* 11(2), 1009, 1996.
28. Glamocanin, V. and Andonov, D., Data requirements for unbundled power quality services, in *Proc. of First International Meeting on System Technologies for Unbundled Power Quality Services,* Mito, Japan, September 1998, 47.