The Future-Oriented Grid-Smart Grid

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***Abstract*— Since its emergence, smart grid has been given increasingly widespread attentions. Basically, smart grid combines a various modern technologies like network communication, information processing and distributed control to provide a more secure, reliable and intelligent grid, thus meeting the requirements of future social and economic development. As a new paradigm in the power grid, smart grid undoubtedly represents the mainstream trend of future electric industry. As a result, it also brings some new technical challenges to researchers and engineering practioners. To support researchers and engineering practioners constructing a modern and intelligent grid, research in the field of smart grid has proliferated. In this paper, we look deeper into some key issues of smart grid, such as distributed cooperation and control, data and application integration, and knowledge-based comprehensive decision. Still, we give some solutions to resolve these challenges. In addition, we also introduce the concept of smart grid and define its key characteristics. Finally, we outline future directions of research and conclude the paper.**

***Index Terms*—smart grid, informationization, digitalization, automation, interaction, agent, multi-agent, distributed cooperation and control, EAI, middleware, message bus, SOA, SOM, web services, SOAP, WSDL, BPEL, XML, data warehouse, OLAP, data mining, knowledge-based comprehensive decision**

I. Introduction

With the advent of digital economy and information era, electric power industry is confronted with new challenges. Some problems [1] [2] relevant to climate change, environmental protection and sustainable development are becoming increasingly acute. Meanwhile, users' demand for higher supply reliability, excellent power quality and satisfactory services has emerged. Although traditional electric power technologies can alleviate these problems, they have proved to be inappropriate. As a result, a new technology should be used to help us to resolve these challenges.

In recent years, smart grid has received considerable attentions and is active subject of research. Smart grid utilizes the latest information and communication technologies to accommodate renewable energy generation and to construct smart measurement system, demand-side response, distribution automation to transmission grid intelligence [3] [4]. The main purpose of smart grid is to meet the future power demands. Nowadays smart grid has been one of major trends in the electric power industry and has gained popularity in different application domains.

Although the rapid development of society and economy has brought about great changes to the electric power industry, there still remain three major limitations for today's grid. First of all, in many real grid control systems, the control capability is quite limited. Vertical and multi-level control mechanisms can not immediately react in response to the dynamic changes in grid facilities. Therefore it is hard for conventional grid to construct real-time and reconfigurable control systems. Secondly, traditional grid mainly employs entity redundancy to improve the capability of system self-healing and self-recovery. Obviously, it is not appropriate for the future grid. Last but not least, in numerous electric utilities, there exist a number of islands of information [5]. With the explosive growth of information and data, current these systems suffer serious sharing problem and need an integration solution that allow applications to share information and make the comprehensive decisions based on the knowledge.

To address these limitations, a variety of research efforts have focused on designing new grid systems capable of supporting the requirements imposed by new generation grid applications. As a result of these efforts, smart grid has been produced to enhance the intelligence of electric power systems. Although smart grid brings great benefits to electric power industry, such a new grid presents new technical challenges to researchers and engineering practioners. They have to deal with new kinds of problems, such as distributed cooperation and control, data and application integration, and knowledge-based comprehensive decision, and the like. These problems leave much work to be done before smart grid is fully enabled.

In this paper, we attempt to give a view on the present and future smart grid. As part of this view, we first introduce the basic concept and its main characteristics of smart grid. Subsequently, we look deeper into the major

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challenges in today's grid and present some solutions to resolve some typical problems relevant to smart grid. In addition, we also point out the future direction in the research field of smart grid.

The remainder of this paper is organized as follows: Section Ⅱ introduces the basic concept of smart grid and its major characteristics. Section Ⅲ identifies key challenges of smart grid and presents some solutions to resolve these limitations. Finally, in Section Ⅳ, we conclude the paper and outline the future work.

Ⅱ. BASIC CONCEPT AND MAJOR CHARACTERISTICS

Smart grid is considered the most promising grid technology to date and is gaining wide-spread popularity in electric utilities, research institutes and communication companies. However, the concept of smart grid in the field lacks universally accepted definitions.

As stated by DOE, smart grid is defined as the grid that uses digital technology to improve reliability, security, and efficiency of the electric system: from large generation, through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources [6].

In general terms, smart grid is referred to as the modern grid technology that covers all the part of electric power industry from power production to transmission to consumption and implements the convergence of electric flow, and information flow and business flow on the basis of information technology, communication technology and computer technology.

In reality, smart grid aims to render a brand-new electric power grid framework that allows to add new technologies or to change an existing one in a simple manner. The concept of smart grid has been increasingly recognized as a means to improve the energy efficiency of generating and consuming electricity in homes, businesses, and public institutions.

In the next few decades, smart grid will form the critical basis for the new generation grid [7]. By applying information technologies and communication technologies as well as computing technologies in the conventional power grid, smart grid will greatly enhance the utilization rate of energy and power asset management, achieve flexible accessing of diversified supplies and power users with different characteristics, optimize the allocation of resources, and further improve the service capability[3][8].

From the electric power system perspective, a smart or modern grid should have the following four major characteristics [9]:

1) Informationization, which means that the smart grid should be able to integrate, share and exploit the real-time and non-real-time information in electric power systems. When needed, it also can use this information to improve the QoS of the grid.

2) Digitalization, which makes it possible that the grid objects, structs and states can be quantitatively described. Also, digitalized smart grid can realize the efficient collection and transmission of a variety of information in power systems.

3) Automation, which will require more advanced control systems that construct elastic and flexible grid. Conventional grid is, to a large extent, rigid, which lacks of elasticity and flexibility, and thus fails to properly meet those requirements. In smart grid, traditional vertical and multi-level control mechanisms may need to be altered due to the dynamic changes in grid facilities. As consequence, dynamic reconfigurability is required in the control systems and can be achieved by adding a new mechanism or changing an existing one at system runtime. In addition, smart grid should be able to automatically monitor the operation of it, detect, analyze and solve the problems and identify the potential problems to prevent the system collapse [4].

4) Interaction, which will bring benefits to electric generation systems, transmission systems and consumers. In a smart grid, electric generation, transmission systems and customers need to interact with each other and coordinated operate. Meanwhile, the consumers should be well informed of the prices and the load situations by means of the intelligent components [4]. As a result, the consumers must strike the balance between their own demands and the power system's needs. Accordingly, the demand management, decision support, real-time pricing may be considered to realize this function in the smart grid [4].

Ⅲ. THE KEY ISSUES

A. Distributed Cooperation and Control

In conventional grid, the control mode of power systems mainly adopts the central architecture that consists of a collection of autonomous components such as relay protection, stable compensator, field force control, var compensator and other intelligent control devices. These applications and components are autonomously responsible for their tasks and achieve their own functions. Applications and devices seldom need to communication with each other to adapt to changes in the power systems and achieve advanced functions of distributed cooperation and control. As a result, more advanced cooperation and control mechanisms need to be considered to meet the requirements imposed by advanced distributed control systems of smart grid.

Agents and multi-agent systems render a new way of analyzing, designing, and implementing complex distributed cooperation and control systems[10][11]. The agent-based view offers a powerful pool of tools, techniques, and metaphors that have the potential to considerably improve the way in which researchers and practioners conceptualize and implement various types of distributed control software of smart grid[10][11]. As a result, Agents are drawing much attention from the research community of smart grid and are being used in an increasingly wide variety of power systems.

An agent is a component of software or hardware situated in some environment, which is capable of flexible autonomous action in order to meet its design objectives and accomplish tasks on behalf of its user[10][11][12]. There are thus three key concepts in its definition: situatedness, autonomy, and flexibility.

In this context, situatedness means that the agent can receive sensory information from its execution environment and that it can perform actions which bring modifications to the environment in some way [11]. Examples of environments in which agents may be situated include the physical world and control systems or the Internet [11]. In a real system, an agent may not interact directly with any environment. It is in charge of receiving information not via sensors, but through a user acting as an intermediary. In the same way, it need not act on any environment, but rather it can give feedback or suggestion to a third party [11].

Autonomy is a difficult concept to define precisely. In a simple sense, it means that the system should be able to act without the direct intervention of humans or other agents, and that it should have control over its own behaviors and internal state [11]. Other researchers also use it in a stronger sense, to mean systems that are capable of learning from experience [11].

By flexible, it denotes that the system is[11] : 1)responsive: agents should perceive their environment and respond in a timely manner to dynamic changes that occur in it; 2) pro-active: agents should not simply act in response to their environment, they should be able to exhibit opportunistic, goal-directed behavior and take the initiative where appropriate; 3) social: agents should be able to interact, when appropriate, with other agents or humans in order to achieve their own tasks and to assist others with their activities.

Although some agents will have additional features, and for certain types of applications, some attributes will be more important than others; these four properties stated above are the essence of agenthood. Furthermore, it is the presence of all the four attributes in a single software entity that renders the power of the agent paradigm and which distinguishes agent systems from other related software paradigms [11].

In reality, agent is a meta-term or class, which covers a range of other more specific agent types. In essence, agents exist in a truly multi-dimensional space, which can use a two or three-dimensional matrix to classify them. Specifically, there are several dimensions to classify existing agents [12]. First of all, agent may be classified by its mobility, i.e. by its ability to move around some network. This yields the classes of static or mobile agents [12]. Secondly, agent can be categorized as either deliberative or reactive. Deliberative agent derives from the deliberative thinking paradigm: the class of agents owns an internal symbolic, reasoning model and they engage in planning and negotiation in order to achieve coordination with other agents [12]. In contrast, reactive agent does not possess any internal, symbolic models of its environment, and it acts using a stimulus or response type of behavior in response to the present state of the environment in which they are executed [12]. Fourthly, agent may sometimes be classified by its roles (preferably, if the role is major one). The agent based on its role may be static, mobile or deliberative [12]. Lat but not least, some agents can also be included the category of hybrid agents which combine of two or more agent philosophies in a single agent [12].

By an agent-based system, it refers to one in which the key abstraction used is that of an agent. In principle, an agent-based system might be conceptualized in terms of agents, but implemented without any software structures corresponding to agents at all [11]. An agent-based system may contain one or more agents.

In general terms, Multi-Agent Systems (MAS) is referred to as all types of systems composed of multiple autonomous or semi-autonomous agents [11]. A MA is relevant to the behavior of a collection of possibly pre-existing autonomous agents aiming at solving a given problem or achieving a specific task [11]. A multi-agent system can be described as a loosely coupled network of agents that cooperate to solve problems that are beyond the individual capabilities or knowledge of each agent [11]. These agents are autonomous and may be heterogeneous in nature [11].

The multi-agent system is generally designed and implemented as several interacting agents in various application domains. Ideally, multi-agent systems suit well those problems that have multiple problem solving methods, multiple perspectives or multiple problem solving entities [11]. Such systems have the intrinsic advantages of distributed and concurrent problem solving. In reality, multi-agent can also be used to resolve other sophisticated patterns of interactions. Examples of common types of interactions include: cooperation (working together to achieve a common objective); coordination (organizing problem solving activity so that harmful or malicious interactions can be avoided or beneficial interactions can be fully exploited); and negotiation (coming to an agreement which is acceptable to all the parties involved) [11]. Undoubtedly, it is the flexibility and high-level nature of these interactions which distinguishes multi-agent systems from other forms of software paradigm like object-oriented systems, distributed systems, and expert systems and which provides the underlying power of the paradigm [11].

The field of agents and multi-agent systems is an active and rapidly expanding area of research. It melts some ideas originating from such research areas as distributed computing, object-oriented systems, software engineering, artificial intelligence, and so on. Its metaphor is the concept of autonomous agents interacting with one another for their individual or collective objectives [11]. And also, autonomous agents and multi-agent systems offer a natural and powerful means of analyzing, designing, and implementing a diverse range of software systems [11].

Future control system will need to monitor a grid operating environment and perform actions to modify its own behaviors to adapt to conditions change in a real-time fashion. As multi-agent system is widespread applied in smart grid, those power system with naturally distributed control mode, such as EMS, DMS, plant and substation automation, watches and the like, will exploit more open, flexible and efficient distributed cooperation and control mechanisms, make each system component and devices more autonomous, and achieve more advanced and complicated application functions.

B. Data and Application Integration

Within the last decade, Electric utilities have invested considerable time and effort in automating complex or repetitious business and operational processes to handle various aspects of their operational and management requirements. For instance, many utilities have constructed individual systems such as supply chain management(SCM, for managing inventory and shipping), customer relationship management(CRM, for managing current and potential customers), business intelligent(BI, for finding patterns from existing data from operations), and other types of systems (for managing data such as human resources data, operational data, management data, etc).

However, these systems often reflect the needs of a particular division or department without considering how this functionality suits within the whole organization [5]. In order to achieve their specific objectives, these systems often require information that is stored in some other systems and cannot be easily shared with the system that needs it [5]. They cannot communicate with one another in order to share data or business rules in multiple locations. As consequence, these business systems often occur in isolation from the rest of the organization. This process of application isolation gives rise to islands of information.

As a result of islands of information, these systems can only meet specific functional needs [5]. Data is often only available to an individual division or a part of the electric utility [5]. Other divisions within the enterprise are not even aware that the data used to enhance their operation and management is available within the electric utility [5]. And also, isolated islands of information lead to the problem of the duplication of data and the need to maintain data in multiple systems or applications [5]. Identical data is resident in multiple locations, or straightforward processes are unable to be automated. Each application must populate and maintain separately [5]. This is extremely inefficient and time consuming and increases the probability for errors to be introduced [5].

In order to cope with these limitations, electric utilities must provide a platform under the framework of smart grid to integrate and coordinate their system activities and processes and improve their responsiveness to customers, thus streamlining workflows and business processes. Meanwhile, integration of the various islands of information will provide information to decision makers and achieve more efficient operations and management [5].

Enterprise Application Integration (EAI) is a technique of integrating a variety of applications and data sources, thus minimizing duplication of data, and reducing maintenance cost [5]. EAI offers an integration framework which consists of a collection of technologies and services which form a generic platform to enable integration of systems and applications across the enterprise. EAI can implement data or information integration, and make sure that data or information stored in multiple locations is kept consistent. In the meantime, by extracting business rules from different applications and implementing them, EAI system can achieve functional independence. Even if one of the business policies is replaced with a different application, the business rules do not have to be re-writed. In addition, EAI also provides a common facade to different applications and hides users from the details of interaction with different software systems.

The core of EAI architecture is the concept of message bus. Message bus facilitates the communication and allows to interoperate without imposing a strict structure on data or the application environment [5]. Message bus supports asynchronous communication in a very natural way, achieving de-coupling of applications and communication details [5] [13]. The application is able to continue processing as soon as the communication facility has accepted the message; eventually the message receiver will send a reply message and this application will be able to collect it at a convenient time [13].

Message bus can be further classified in two categories according to the message selection mechanism: Queue-based and Publish/Subscribe [14] [15]. In queue-base mode, messages are selected by means of queue membership. Publish/Subscribe mode on the contrary selects messages by means of predicates. Applications can publish messages, while other applications submit predicates for defining a message topic or specific message content they are interested in. The messaging bus is responsible for selecting those messages that satisfy the predicates, and for delivering them to a list of clients who have subscribed to that topic. Message bus renders functionality to publish, subscribe and deliver messages with properties such as persistence, replication, real-time performance as well as scalability and security [15].

Service-oriented architecture is an new-generation integration framework that supports the development of distributed software systems in terms of loosely coupled networked services [15]. SOA exploits services as the basic constructs to render the intrinsic support for the development of rapid, low-cost and easy composition of applications. SOA also presents a logical view of designing a software system to provide services to either end-user applications or to other services distributed in a network. A well-defined, standards-based SOA can empower distributed applications with a flexible infrastructure and execution environment. In order to achieve this objective, SOA provision independent, reusable and automated business policies or rules as services and provide a robust and secure foundation for leveraging these services [14][16][17][18].

Major feature of SOA is that services are autonomous, platform-independent computational entities, with well defined interfaces, which can be invoked in a platform independent way, without requiring the application to have knowledge about how the service actually performs its tasks[14][15].

In SOA-based integration architecture, services can be described, published, discovered, and dynamically assembled for constructing interoperable and evolvable applications. Any piece of code or business component can be reused and transformed into a network-available service [14] [16] [17] [18]. Services reflect the philosophy of service-oriented programming and adhere to the approach of composing applications by discovering and invoking network-available services rather than developing new applications or by invoking available applications to accomplish some tasks[14][16][17][18]. Services are most often built in a way that is independent of the context in which they are used. As a result, the service providers and the consumers are loosely coupled. This service-oriented approach is independent of specific programming languages or operating systems. It allows application developers to expose their core competencies, programmatically over the Internet or a variety of networks, using standard languages and protocols, and implementing a self-describing interface [14] [16] [17] [18].

Specifically, the SOA architecture is structured around three key architectural components: (i) service provider, (ii) service consumer, and (iii) service registry [15]. The service provider creates a service and publishes its interface and accesses information to the service registry. Each provider must decide which services to expose, how to make trade-offs between security and availability, how to exploit them for other applications [14] [15] [19]. The provider also has to decide what category the service should be listed in for a given service registry. It registers what services are available within it, and lists all the potential service recipients. The service consumer locates entries in the service registry using various find operations and then binds to the service provider in order to invoke one of its services[14] [15][19]. Which service the service consumers need, they have to take it into the service registry, then bind it with respective service and then use it. They can access multiple services, if the service provides multiple services [14] [15] [19].

Web services are the ideal implementation for SOA. Web services provide the basic blocks for the development and execution of business policies or business rules that are distributed over the network and can be invoked via standard interfaces and protocols [14] [16] [17] [18]. Web services may use the Internet as the communication medium (as well as other transport protocols) and open Internet-based standards, such as the Simple Object Access Protocol (SOAP) as transmission medium, the Web Services Description Language (WSDL) for service definition and the Business Process Execution Language (BPEL) for orchestrating services[14][16][17][18].

In reality, a web service is a unit of functionality that exposes an XML interface, describes a WS in terms of the messages it receives and sends. And also, it is a self-describing, self-contained entity that can be registered with a registry and located by the potential users [14] [19]. WSs can be combined in any way to provide a more complex, functional entity, which can in turn be exposed as a Web service. Access to and communication between WSs is achieved in terms of messages [14] [19]. The messages are based on a single protocol over the Web, thus Web services exploit the characteristics of the Internet, namely simplicity and ubiquity [14] [19]. From a technical perspective, web services have dual nature. For one thing, WSs are single units of functionality. For another, they are represented by a set of protocols (SOAP, WSDL, and UDDI) to combine any piece of functionality work and interoperate independent of the hardware and software platform, with any other piece of application over the Internet[14][19].

The SOA-based EAI approach relies on service-oriented middleware (SOM). Middleware is a layer of software that shields the heterogeneity of hardware and operating systems and homogenizes the distributed infrastructure's diversities by means of a well-defined and structured distributed programming model[13][14][15][20]. Middleware addresses the ever increasing complexity of distributed systems in a reusable way. Moreover, middleware renders building blocks to be exploited by applications for enforcing non-functional properties, such as scalability, heterogeneity, dependability, performance, resource sharing, and the like[13][14][15]. These attractive features of middleware have made it a powerful tool in the software system development practice [13] [14] [15].

SOM serves as an integration platform and communication infrastructure for all applications to share data and render uniform protocols and a single, seamless data model [5]. SOM provides infrastructure support for service providers to deploy services and further publish their presence to the registry, and for service consumers to discover and use services [15]. SOM also renders application designers with a higher level of abstraction and shield heterogeneity of the underlying environment, by introducing languages for rigorous service description and protocols for service discovery and access [15]. Like other middleware systems, SOM is also built adhering to the metaphor of the black box. The heterogeneity of the underlying distributed infrastructure is hidden from both applications and software pratcioners, so that the system appears as a single integrated computing facility. In other words, the underlying heterogeneity becomes transparent upon SOM [13[15].

One major challenge for SOA-based EAI approach is that the various legacy systems that need to be linked together often reside on heterogeneous operating systems, use heterogeneous database connections and heterogeneous programming languages. As a result, SOM must incorporate and integrate existing legacy systems as appropriate [5]. In order to integrate legacy systems, one strategy for achieving this is web services adapter. Web services adapters are implemented as a series of services for the legacy systems that are not compliant with the standards for enterprise application integration interfacing, so that the legacy systems can communicate with the other systems that conform to the standards [5].

Although SOA-based integration approach has been a very active area of research over the last few years, actually taking over most middleware technologies, SOA and SOM are still relatively emerging technologies that are evolving at a high pace [15]. In the next a few years, with the explosive growth of smart grid, SOA-based EAI technology will provide a generic platform to support other business processes within the electric utilities that have the need for information from these applications, thus eliminating islands of automation and information[5].

C. Knowledge-Based Comprehensive Decisision

With the rapid development of smart grid, data and information in future electric utilities will become more complex. In the meantime, the amount of data and information will exponentially increase, and the correlation of these data and information will become much closer. With the explosive growth of information in electric utilities, the problem of information overload is becoming increasingly acute. In order to efficiently sift all available information to find what potential and valuable knowlege to electric utilites is, some new approaches must be examined.

In future power industry, a variety of business systems will be built to form enterprise solutions that support all segments of the business. As a result, effective and timely information retrieval and knowledge management is vital for operating in future electric utilities. If data and information is frequently processed within a stand-alone application, it may take a significant amount of time before these data and information is available to other applications. Therefore, some new technologies should be used to integrate the various islands of data and information and to provide useful information and knowledge to decision makers, achieving the objectives of efficient operation and asset management and improved supply service [5].

Knowledge-based comprehensive decision technology relies on the integration of data warehouse, on-line analysis processing (OLAP), and data mining. In essence, the concept of data warehouse is intended to render an architectural model for the flow of data from operational systems to decision support environments. Data warehouse aims to cope with the various problems associated with this flow, mainly the high costs relevant to it. In the absence of data warehouse architecture, a large amount of redundancy is required to support decision support environment.

The practical reality of numerous electric utilities is that their data infrastructure is composed of a collection of heterogeneous systems. For instance, many utilities may have implemented separate systems to deal with various aspects of the utility’s requirements [5]. They might have one system that handles customer-relationship, a system that handles human resources, systems that handle sales data or operational data, yet another system for financial and budgeting data, etc. However, these systems are often poorly or not at all integrated. As a result, it is hard for them to make a comprehensive analysis and decision due to the scattered data and information in the different systems.

A data warehouse is a repository of an department or overall organization’s stored data, designed to facilitate analysis and decision support. Although data warehouse mainly focuses on the problem of data storage, the means to retrieve and analyze data, to extract, transform and load data, and to manage the data dictionary are also considered indispensable components of a data warehouse system. Therefore, an typical data warehouse system might include business intelligence tools, tools to extract, transform and load data into the repository, and tools to manage and retrieve metadata.

For electric utilities, data warehouse can provide a common data model for the overall organization regardless of the data's source. This makes it easier for decision-makers to report and analyze information than it would be if multiple data models were used to retrieve information such as employees, sales figures, operational information, and financial data, etc. Meanwhile, prior to loading data into the data warehouse, inconsistencies can be identified and resolved. This greatly simplifies the utilities’ reporting and analysis. Furthermore, data ware house wholly separates from operational systems, and thus data warehouse provides retrieval of data without slowing down operational systems. In addition, data warehouse also renders a knowledge pool to facilitate decision support system applications.

OLAP is a technique to swiftly perform multi-dimensional analysis. In practice, OLAP is essential part of the broader category of business intelligence, which also includes data mining and relational reporting. With the help of OLAP, electric utilities can utilize a multidimensional data model, allowing for complex analytical and ad-hoc queries with a rapid response time. Furthermore, they can obtain historical, current, and predictive views of business operations and make better comprehensive decision.

With the increasing volume of data and information in smart grid, electric utilities have called for more automated approaches to make comprehensive decision. Data mining is the process of applying analytical methods to data with the intention of uncovering hidden patterns. This reason for using data mining is to assist in the analysis of collections of observations of behavior. Electric utilities can use data mining to analyze data from different perspectives and summarizing it into useful information.

In the future grid industry, electric utilities will accumulate vast and growing amounts of data in different formats and different databases. This includes: 1) operational data, such as sales, cost, inventory, budgeting and accounting; 2) nonoperational data, such as industry sales, predictive data, and macro economic data; 3)meta data - data about the data itself, such as logical database design or data dictionary definitions. For electric utilities, data mining is an increasingly important approach to transform this data to information. Further, the patterns, associations, or relationships among all this data can provide information. And furthermore, this information can be converted into knowledge about historical patterns and future trends for analyzing data.

As for these utilities, data mining allows to analyze data from many different dimensions or angles, categorize it, summarize the relationships identified, find correlations or patterns in data and information, and obtain related knowledge. Through data mining, electric utilities can establish the link between separate business and analytical systems, achieving the objective of knowledge-based comprehensive decision.

Ⅳ. CONCLUSION AND FUTURE WORK

Since its emergence, smart grid has been given increasingly widespread attentions. Basically, smart grid combines a various modern technologies like network communication, information processing and distributed control to provide a more secure, reliable and intelligent grid, thus meeting the requirements of future social and economic development [4]. As a new paradigm in the power grid, smart grid undoubtedly represents the mainstream trend of future electric industry [4]. As a result, it also brings some new technical challenges to researchers and engineering practioners.

In this paper, we attempt to examine some key issues related to the future grid. In particular, we focus on the major challenges such as distributed cooperation and control, data and application integration and knowledge-based comprehensive decision, for which the future grid must provide adequate support, and go into deeper analysis of the these problems. Still, we give some solutions to resolve these challenges. In addition, we also introduce the concept of smart grid and define its key characteristics.

Although many research efforts have dealt with one aspect or the other of smart grid, there still remain some open issues that require further investigation. A first issue that needs to be addressed is how to adjust the scope of changes when dynamically reconfiguring the control systems. Another direction of research concerns information security. Intelligent components and devices in smart grid are particularly exposed to security attacks as they are so easy to connect to a communication network. These components and devices could cause security problems if malicious programs break the protection mechanism and use the capability to disclose, modify or delete data. Information security is a major issue for some smart grid application and therefore proper measures need to be included in the design of some software system of smart grid. Other open issues include combining real time and dependability, combining entity redundancy and control mechanism, combining security and fault tolerance, combining wireless sensor network (WSN) and intelligent electronic devices (IED), management of network devices, etc…

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