补充阅读材料

Smart Grid

The basic architecture of power grid has not changed much since its development over 100 years ago: it is designed to move power from controllable centrally-generated sources[1] through the transmission and distribution network to end users, supplying power needed to satisfy demand. About 68% of the world's power is generated from combustion of fossil fuels, and is a major source of emissions. Additionally, the need to provide enough generation capacity to meet relatively short intervals of peak demand results in a very inefficient system.

The term "smart grid"[2] refers to a kind of power transmission and distribution system that incorporates elements of traditional and cutting-edge[3] power engineering technology, sophisticated sensing and monitoring technology, information technology, and communications to provide better grid performance and to support a wide array of additional "digital age" services to consumers. The potential benefits of a smart grid are substantial. An upgraded grid could boost the economy, reduce the impact of energy production and consumption on the environment, and enhance the security of the network.

A smart grid could be defined by what it can do:

1) A smart grid would be "self healing"[4] and more secure from physical and cyber threats[5]. A nation's power transmission and distribution system is a critical element of the nation's infrastructure. Yet we have allowed a lack of critical investment and surging demand for highquality digital-grade power[6] to stress the electrical infrastructure.

2) Technology upgrades in the areas of transmission system monitors, information systems and power flow controls would enable the grid to be "self healing" by permitting grid controllers to anticipate and instantly respond to system problems in order to avoid or mitigate power outages, power quality problems and system damage. This would benefit high-tech consumers and others who require a stable and reliable power supply.

3) A smart grid would facilitate the use of new energy technologies such as solar power and fuel cells. Distributed energy resources[7], fuel cells, microturbines[8] and renewable energy generation are emerging options for homes, offices and factories, but the grid does not accommodate them easily. Enabling such use of distributed generation will lead to improved reliability and power quality, reduced costs, and less pollution. The use of these technologies can be encouraged through the development of "plug and play"[9] interfaces that will enable customers to use distributed generation with a minimum of technical or regulatory difficulty.

4) A smart grid would give consumers greater control of the power use in their

homes and businesses. Simple, effective interfaces between the grid and the energy management systems of buildings and other loads will enable residential, commercial, and industrial consumers to manage power use in a manner that improves efficiency and reduces consumer costs. Grid upgrades that increase the amount of power, that can be moved through the transmission grid and that optimize those power flows will reduce waste and maximize the use of the lowest-cost generation resources.

While definitions and terminology vary somewhat, all notions of an advanced power grid for the 21st century hinge on the integration of advanced information technology, digital communications, sensing, measurement and control into the power system. The smart grid evolves the architecture of the legacy grid[10], which can be characterized as providing a one-way flow of centrally-generated power to end users into a more distributed, dynamic system characterized by two-way flow of power[11] (centralized and distributed) and information. Bidirectional flows of information will enable an array of new functionalities and applications that go well beyond "smart" meters for homes and businesses.

Figure 1 shows a conceptual model of the smart grid that is comprised of seven interconnected domains. Four domains (bulk generation, transmission, distribution and the customer) are linked together to provide a bidirectional flow of both electricity and information from the point of generation to end use. Three domains (markets, operations, and service provider) provide operations and information that deal with the buying and selling of electricity, operation of the system, and provision of retail and value-added services[12] to customers.

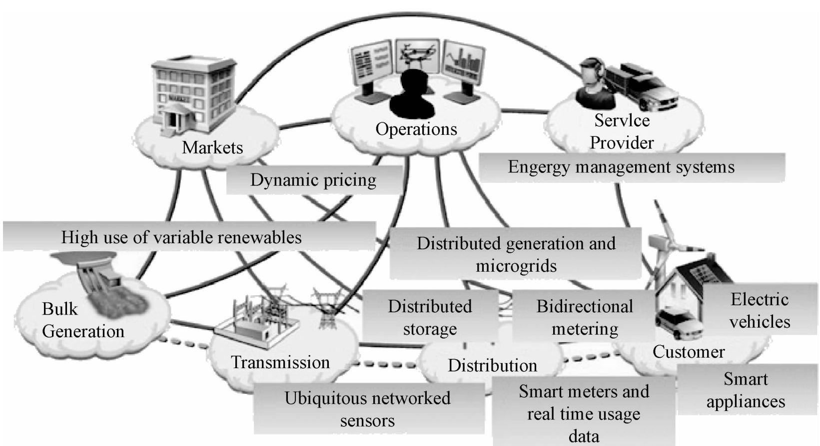

Figure 1 Conceptual model of the smart grid

Following are key technologies and capabilities that enable the operation of a smart grid:

1) High penetration of renewable energy sources: 20%—35% or more in some areas.

2) Distributed generation and microgrids[13].

3) Bidirectional metering-enabling locally-generated power to be fed into the grid.

4) Distributed storage to buffer variability and intermittency of renewable generation[14].

5) Smart meters that provide near-real time usage data.

6) Time of use[15] and dynamic pricing to encourage smoother demand on the system.

7) Ubiquitous smart appliances communicating with the grid.

8) Energy management systems in homes as well as commercial and industrial facilities linked to the grid.

9) Growing use of plug-in electric vehicles[16].

10) Networked sensors and automated controls throughout the grid.

Maintaining cost effective and electric service reliable while modernizing the grid is a paramount concern. The new technologies and operating principles of the smart grid will not simply appear all at once. The legacy grid will undergo a transformation into the envisioned smart grid in an evolutionary way. These technologies and capabilities will be introduced over the course in several decades.

Notes

1. controllable centrally-generated sources　可控的集中式发电
2. smart grid　智能电网
3. cutting-edge　前沿的
4. self healing　自愈
5. physical and cyber threats　物理和网络攻击
6. surging demand for high quality, digital-grade power
   对优质（数字等级）的电力需求的爆发式增长
7. Distributed energy resources　分布式电源
8. Microturbines　微型燃气轮机
9. plug and play　即插即用
10. legacy grid　现有电网
11. two-way flow of power　双向潮流
12. value-added services　辅助服务
13. microgrids　微电网，微网
14. buffer variability and intermittency of renewable generation
    减缓可再生能源发电的波动性及间隙性
15. time of use　用电时段（记载）
16. plug-in electric vehicles　即插（充电）电动车

Technical Challenges Brought About By Smart Grid

The smart grid involves many new technologies and new operating paradigms that need to be integrated into the existing grid as it evolves while maintaining safe and reliable operation. This poses many significant technical challenges.

Phasor Measurement Units[1], which are now being widely deployed will provide time-stamped real time voltage[2] and current phasor measurements at points throughout the grid. The widespread use of these measurements will significantly improve reliability, power quality, grid robustness and resilience[3]. Significant technical challenges need to be addressed to create a data measurement infrastructure to enable the effective use of this technology. Ensuring the accuracy of measurements from different vendors' synchrophasors[4] and precise time synchronization is critical to ensuring accurate system-wide measurement.

Achieving a high penetration of renewable and distributed generation resources in the grid presents a different set of challenges. Unlike the conventional generation, wind and solar resources have variable output that can change quickly and cannot be controlled. New technologies for cost-effective electrical storage and demand management will be needed to accommodate growing use of renewable generation if we wish to avoid underutilized backup conventional generation for periods when the wind does not blow or clouds obscure the sun. Electricity storage could be used in place of backup conventional generation to buffer short-term imbalances between generation and demand.

The ability to achieve high penetration levels of renewable resources and incorporate electricity storage technologies into the grid while ensuring stable system operation also requires enhanced interfaces to renewable generators and storage devices. These enhanced interfaces must be capable of providing dispatchable power levels, voltage and reactive power regulation, controllable ramp rates[5], grid disturbance ride-through[6], microgrid capability, etc.

In many respects, today's grid operates as a deterministic system. Generation capacity is planned to meet peak load and is dispatched as needed to meet real-time demand. Demand can be forecasted with a high degree of accuracy based on historical patterns and weather conditions. However, demand has not been treated as a controllable resource in the way as generation. In the future the grid will require more stochastic[7] control, in which variable generation output can be balanced by dynamically managing demand using smart grid technologies. For example, smart appliances will be able to adjust energy usage dynamically in response to price or congestion signals. Building energy management systems can dynamically shift usage patterns by, for example, pre-cooling the building or generating hot water when electricity demand is low. Maintaining reliable operation in such a dynamic system requires the development of new models to characterize performance at component and system levels and control strategies to maintain balance between generation and demand.

Eventual large-scale deployment of electric vehicles represents both a challenge and an opportunity for the grid. A challenge that must be addressed is managing the additional load that vehicle charging will place on the grid. Generation and transmission resources do not present a problem because their idle capacity can be utilized to provide that vehicle-to-grid communication and control protocols ensure that most charging occurs outside of peak periods. However, local distribution grids could become overloaded, an electric vehicle draws as much power as a typical house while it is charging. Utilities will have to monitor patterns in electric vehicle deployment and plan for distribution system upgrades where needed. The batteries in electric vehicles represent an opportunity to provide distributed storage resources for the grid, since vehicles generally sit idle at most of the time. Electric vehicle batteries could be helpful in providing regulation service for the grid without requiring deep cycling that shortens battery life. However, the automotive industry is reluctant to support the use of electric vehicle batteries for this purpose because little if any data[8] is available to characterize the impact of such use on battery life. Research on measurement and characterization of battery performance in grid storage applications is needed to determine the potential role of electric vehicles as a support to the grid.

A great deal of attention is being placed on vulnerabilities and threats to the grid resulting from the application of information and communications technology to control system operation. A large array of cybersecurity tools[9], standards, and practices have been developed and applied to other critical commercial infrastructures, such as financial systems. These tools are being adapted and applied to the electric grid. However research on cybersecurity threats and mitigation techniques for the electric grid will be an ongoing critical priority as threats and vulnerabilities will continue to evolve.

Notes

1. Phasor Measurement Units	同步相量测量单元
2. time-stamped real time voltage	标注时间的实时电压
3. grid robustness and resilience	电网鲁棒性和适应性
4. vendors' synchrophasors	不同电厂处的相位同步器
5. ramp rates	斜率
6. grid disturbance ride-through	电网故障低电压穿越功能
7. stochastic	随机的
8. because little if any data	几乎完全没有或很少量的
9. cybersecurity tools	网络安全工具

Microgrid

Restrictions on expansion of traditional centralized generating and delivery systems may be becoming so tight in the industrialized countries that they cannot reasonably be expected to meet future power demand growth at acceptable cost. Meanwhile, technological advance, notably improved power electronics that permit grid interconnection of asynchronous generation sources, is tilting the economics of power generation back towards smaller scales[1], thereby reversing a century long trend towards the central control paradigm. Special power quality requirements or opportunities for combined heat and power applications make on-site generation[2] an even more attractive option for customers. The existence of a significant amount of power sources dispersed throughout the low voltage distribution system could create a power system quite different from the one[3] we are familiar with. Moreover, the electrical and economic relationships[4] between customers and the distribution utility and among customers may take forms quite distinct from those we know today. For example, they may be grouped with loads in a semi-autonomous neighborhood that could be termed a microgrid, rather than devices being individually interconnected in parallel[5] with the grid.

The microgrid concept assumes a cluster of loads and micro sources operating as a single controllable system that provides both power and heat to its local area. This concept provides a new paradigm for defining the operation of distributed generation. To the utility the microgrid can be thought of as a controlled cell of the power system. For example, this cell could be controlled as a single dispatchable load, which can respond in seconds to meet the needs of the transmission system. To the customer the microgrid can be designed to meet their special needs such as enhancing local reliability, reducing feeder losses, supporting local voltages, providing increased efficiency by the use of waste heat, providing voltage sag correction[6] or uninterruptible power supply[7] functions .

The micro sources of special interest for microgrid are small units (<100kW) with power electronic interfaces. These sources (typically microturbine generator units, photovoltaic panels, and fuel cells) are placed at customers' site. They are low cost, low voltage and high reliablity with few emissions. Power electronics provide the control and flexibility required by the microgrid concept. Correctly designed power electronics and controls insure that the microgrid can meet its customers as well as the utilities' needs. The above characteristics can be achieved by using a system architecture with three critical components: local micro source controllers, system optimizer[8] and distributed protection.

Figure 2 illustrates the basic microgrid architecture. In this example the electrical system is assumed to be radial with three feeders[9] (feeders A, B and C) and a collection of loads. The radial system is connected to the distribution system through a separation device, usually a static switch[10]. The feeder voltages at the loads are usually 480 volts or less. Feeder A indicates the present of several micro sources with one providing both power and heat. Each feeder has circuit breakers and power flow controllers. If we consider the power flow controller near the heat load[11] in feeder A, the controller regulates feeder power flow at a level prescribed by the Energy Manager[12]. As loads down stream[13] change the local micro sources increase or decrease their power output to hold the power flow constant. In this figure feeders A and C are assumed to have critical loads[14] and include micro sources, while feeder B is assumed to have non-critical loads that can be shed[15] when necessary. For example, when there are power quality problems on the distribution system the microgrid can become an isolated island[16] by using the separation device shown in the figure. The non-critical feeder can also be dropped using the breaker at B.

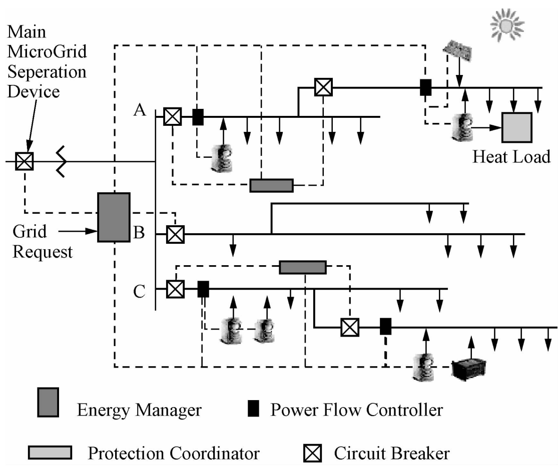

Figure 2 Microgrid Architecture

A key distinction between microgrid and our familiar arrangements is the expanded role of end power users[17] in determining the pattern of development of the overall power system, which must not only accommodate purchases and sales of electrical energy and ancillary services[18] to and from established markets but also contractual agreements between microgrids. Fundamentally, the characteristics and capabilities of the microgrid will be determined by its internal requirements together with technical, economic, and regulatory opportunities and constraints it faces, and not by established objectives for capacity expansion and reliability of the macrogrid[19].

Micro source controller is also an important component of the microgrid infrastructure. This controller responds in milliseconds and uses local information to control the micro source during all events[20]. A key element is that communications among micro sources are unnecessary for basic operation. Each inverter is able to respond to load changes in a predetermined manner[21] without communication of data from other sources or locations, which enables "plug and play" capabilities. "Plug and play" implies that a micro source can be added to the microgrid without changes to the control and protection of units that are already part of the system. The basic inputs to this controller are steady state set points for output power P and local bus voltage V[22].

There are two basic classes of micro sources: one is DC source, such as fuel cells, photovoltaic cells and battery storage; the other is high frequency AC source, such as microturbine generator, the output of which needs to be rectified. In both cases the resulting DC voltage is converted to an acceptable AC voltage using a voltage source inverter[23]. The voltage source inverter provides control of both the magnitude and phase of its output voltage V. The vector relationship between the inverter voltage V and the system voltage E along with the inductive reactance X determine the flow of real and reactive power (P & Q) from the micro source to the system.

Notes

1. tilting the economics of power generation back towards smaller scales
   使得发电的经济性考量重新向小规模发电方向倾斜
2. on-site generation　就地发电，分布式发电
3. the one　此处指电力系统 power system
4. electrical and economic relationships
   电力用户与配电网之间及电力用户之间的电力与经济关系
5. being individually interconnected in parallel　被分别并联于
6. voltage sag correction　电压跌落补偿
7. uninterruptible power supply　不中断供电服务
8. system optimizer　系统优化
9. be radial with three feeders　呈辐射状，有三条支路
10. static switch　静态开关
11. heat load　供热负荷
12. Energy Manager　能源管理（系统）
13. loads down stream　负荷功率需求
14. critical loads　重要负荷
15. shed　甩去，切除（负荷）
16. isolated island　孤岛，即与外部电力系统无任何连接
17. end power user　电力终端用户
18. electrical energy and ancillary services　电能及辅助服务
19. macrogrid　大电网
20. during all events　在所有的工作状态下
21. predetermined manner　预定方式
22. are steady state set points for output power P and local bus voltage V
    是输出功率及出口母线电压的恒设置点
23. voltage source inverter　电压（源）型逆变器

The Operation Stability of Microgrid

The power demand continues to grow globally and the formation of microgrids is becoming a potentially attractive option to meet the expanding energy demands. It is expected that a microgrid would operate in two modes: connected to the main grid under normal conditions (grid connected mode) and as an island system during a fault on the main distribution network (islanded mode). The micro sources and the energy storage system are not suitable for supplying energy to the grid directly. They each have to be interfaced with the network through inverters. The use of power electronic interfaces leads to a series of challenges in the design and operation of the microgrid, i. e. protection design of the microgrid, and the safety and stability of the microgrid during both grid-connected mode and islanded mode.

The major factors influencing the stability of the microgrid are the control strategies of micro sources and energy storage system, the types of load in the microgrid, the location of fault and the inertia constants of motors. Depending on the type of microgrid, the control topology[1], network parameters, micro sources etc. vary and so does the stability aspect. With more and more voltage source converter (VSC) interfaced source integration, the stability in a microgrid largely depends on the control topology of the VSCs. However, other micro sources, energy storage, protection, compensation etc. also play a significant role in the system stability.

A microgrid can be represented with different micro sources and loads. However, the remote microgrids do not have the utility connections. The utility microgrids span geographically a larger area compared to the facility microgrids. In general the microgrid is defined as an integrated energy system consisting of distributed energy resources (DERs) and multiple electrical loads operating as a single, autonomous grid either in parallel to or "islanded" from the existing utility power grid.

From the stability aspect, the major differences can be described as:

1) A utility microgrid connected to the utility at one point (there could also be multiple connection points for grid connected reliability) of common coupling can operate in island, spaning over a large area (compared to a facility microgrid) and containing different types of micro sources and loads.

2) A remote microgrid is never connected to the utility and operates mostly with decentralized control methods. The maximum power use is limited for the customers and the power quality requirements are much relaxed compared to a facility microgrid.

3) A facility microgrid is normally connected with the host utility and is commonly a single business-entity microgrid. A facility microgrid can continue to operate in an intentional or an unintentional island. A facility microgrids can be for an industrial or an institutional microgrid.

Similar to a large power system, the stability issues in a microgrid can be divided into small signal, transient and voltage stability. The recurring reasons of each stability problem are shown in Figure3 Small signal stability[3] in a microgrid is related to feedback controller, continuous load switching, power limit of the micro sources, etc. A fault with subsequent island[2] poses most of the transient stability problems in a microgrid.

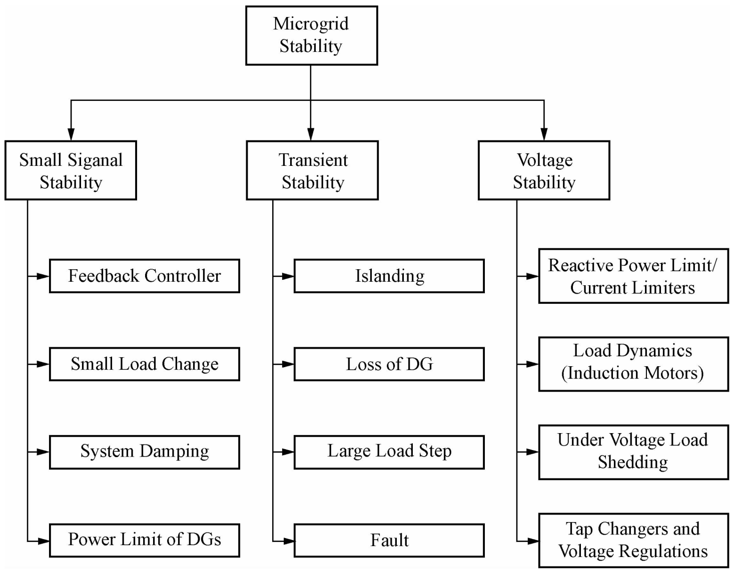

Figure 3 Different stability issues in microgrid and the usual reasons

Reactive power limits, load dynamics and tap changers create most of the voltage stability problems in a microgrid. While supplementary control loops[4], stabilizers, coordinated control of the micro sources can improve the small signal stability, the transient stability improvement is achieved through the use of storage, load shedding and adaptive protection devices. On the other hand, voltage regulation with distributed generations (DGs), reactive compensation, advanced load controller and modified current limiters of the micro sources can ensure the voltage stability in a microgrid.

Depending on the microgrid type, different stability issues can be related to most frequent problems. The DG feedback controller with decentralized control methods creates most of the small signal stability issues in a remote microgrid, while in a utility microgrid the most common reason is the current limiters. In a facility microgrid, the frequent load switching within a small area often creates small signal stability problems.

Faults produce the obvious transient stability issues in all types of microgrids. While a fault and subsequent islanding in a utility or facility microgrid demonstrates the typical transient stability aspect, in a remote microgrid, a fault within the microgrid and isolating the faulty part of the network creates the transient stability problems.

The voltage stability in a remote microgrid is related to the reactive compensation of the network but in a utility microgrid the main source of the voltage stability problems is the tap changers. With few sources and confined loads, limiters in the micro sources and under voltage load shedding create most of the voltage stability problems in a facility microgrid.

Notes

1. control topology　　控制结构
2. subsequent island　　（故障后）随之而来的孤岛运行状态
3. small signal stability　　小信号稳定性，静态稳定性
4. control loops　　控制回路

The Wind Turbine and Generator of Wind Power Generation

Among renewable sources wind power systems have developed to prominent suppliers of electrical energy. Since the 1980s, they have seen an exponential increase both in unit power ratings and overall capacity. While most of these systems are found on dry land, preferably in coastal regions, off-shore wind parks are expected to add significantly to wind energy conversion in the future.

The theory of modern wind turbines has not been established until the 20th century. Currently wind turbines with three blades and horizontal shaft prevail. The driven generators are of asynchronous or synchronous type, with or without interposed gearbox[1]. Modern systems are designed for variable speed operations, which make power electronic devices play an important part in wind energy conversion.

Wind turbines produce electricity by using wind power to drive a generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to a value that is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer that converts the generator voltage to an appropriate value for the power collection system.

A wind turbine extracts kinetic energy from the swept area of the blades. The power in the airflow is given by

$$P_{air}=\frac{1}{2}\rho A v^3 \tag{1}$$

where

ρ——air density

A——swept area of rotor

v——upwind free wind speed

Although Eq. (1) gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient

$$C_p=\frac{P_{wind\ turbine}}{P_{pair}} \tag{2}$$

$$P_{wind\ turbine}=C_p P_{pair}=C_p \cdot \frac{1}{2}\rho A V^3 \tag{3}$$

A maximum value of is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum values in the range 25%—45%. It is also conventional to define a tip-speed ratio[2] λ

$$\lambda=\frac{\omega R}{v} \tag{4}$$

where

ω——rotational speed of rotor

R——radius to tip of rotor

v——upwind free wind speed

The tip-speed ratio and the power coefficient are dimensionless and so can be used to describe the performance of any size of wind turbine rotor. The maximum power coefficient is only achieved at a single tip-speed ratio, and for a fixed rotational speed of the wind turbine, this only occurs at a single wind speed. Hence, one argument for operating a wind turbine at variable rotational speed is that it is possible to operate at maximum over a range of wind speeds. The power output of a wind turbine at various wind speeds is conventionally described by its power curve. The power curve gives the steady-state power output as a function of the wind speed at the hub height and is generally measured using 10 min average data.

The power curve has three key points on the velocity scale:

1) Cut-in wind speed[3] - the minimum wind speed at which the machine will deliver useful power.

2) Rated wind speed - the wind speed at which rated power is obtained (rated power is generally the maximum power output of the electrical generator).

3) Cut-out wind speed[4] - the maximum wind speed at which the turbine is allowed to deliver power (usually limited by engineering loads and safety constraints).

Modern electricity-generating wind turbines now use three-bladed upwind rotors, although two-bladed and even one-bladed rotors were used in earlier commercial turbines. Reducing the number of blades means that the rotor has to operate at a higher rotational speed in order to extract the wind energy passing through the rotor disk. Although a high rotor speed is attractive in that it reduces the gearbox ratio required, a high blade tip speed leads to increased aerodynamic noise and increased blade drag losses. Most importantly, three-bladed rotors are visually more pleasing than other designs so they are now always used on large electricity-generating turbines.

Electrically fixed-speed wind turbines are fairly simple devices consisting of an aerodynamic rotor driving a low-speed shaft, a gearbox, a high-speed shaft and an induction generator. From the electrical system viewpoint they are perhaps best considered as large fan drives with torque applied to the low-speed shaft from the wind flow.

As the size of wind turbines has become larger, the technology has switched from fixed speed to variable speed. The drivers behind these developments are mainly the ability to comply with power grid connection requirements and the reduction in mechanical loads achieved with variable-speed operation. Currently the most common variable-speed wind turbine configurations are: 1) doubly fed induction generator (DFIG) wind turbine; 2) fully rated converter (FRC) wind turbine based on a synchronous or induction generator.

A typical configuration of a DFIG wind turbine is shown in Figure 4. It uses a wound-rotor induction generator with slip rings to take current into or out of the rotor winding and variable-speed operation is obtained by injecting a controllable voltage into the rotor at slip frequency. The rotor winding is fed through a variable-frequency power converter, typically based on two AC/DC IGBT-based voltage source converters (VSCs) linked by a DC bus. The power converter decouples the network electrical frequency from the rotor mechanical frequency, enabling variable-speed operation of the wind turbine. The generator and converters are protected by voltage limits and an over-current 'crow-bar'.

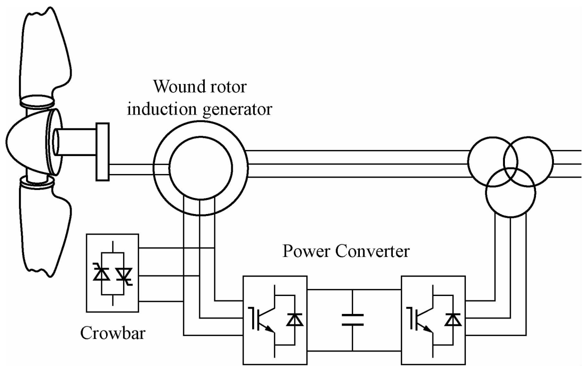

Figure 4　Typical configuration of a DFIG wind turbine

A DFIG system can deliver power to the grid through the stator and rotor, while the rotor can also absorb power. This depends on the rotational speed of the generator. If the generator operates above synchronous speed, power will be delivered from the rotor through the converters to the network; if the generator operates below synchronous speed, then the rotor will absorb power from the network through the converters.

The typical configuration of a fully rated converter wind turbine is shown in Figure 5. This type of turbine may or may not include a gearbox and a wide range of electrical generator types can be employed, for example, induction, wound-rotor synchronous or permanent magnet synchronous. As all of the power from the turbine goes through the power converters, the dynamic operation of the electrical generator is effectively isolated from the power grid. The electrical frequency of the generator may vary as the wind speed changes, while the grid frequency remains unchanged, thus, allowing variable-speed operation of the wind turbine.

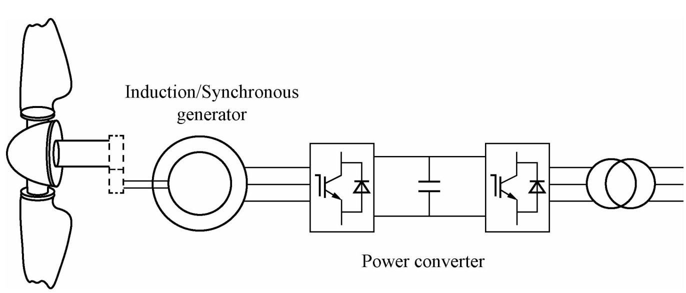

Figure 5　Typical configuration of a FRC wind turbine

Notes

1. interposed gearbox	传动齿轮箱
2. tip-speed ratio	叶尖速比
3. Cut-in wind speed	切入风速
4. Cut-out wind speed	切出风速

The Electrical Characteristics of Wind Power Generation

There are significant differences between wind power generation and conventional synchronous central generation:

1) Wind turbines employ differently, often converter-based generating systems compared with those used in conventional power plants.

2) As prime mover the wind turbine is not controllable and fluctuates stochastically.

3) The typical size of individual wind turbines is much smaller than that of a conventional utility synchronous generator.

Due to these differences, wind power generation interacts differently with the network and may have both local and system-wide impacts on the operation of the power system. Local impacts occur in the electrical vicinity of a wind turbine or wind farm, and can be attributed to a specific turbine or farm. System-wide impacts, on the other hand, affect the behavior of the power system as a whole. They are an inherent consequence of the utilization of wind power and cannot be attributed to individual turbines or farms.

Locally, wind power has an impact on the following aspects of the power system: 1) circuit power flows and bus bar voltages; 2) protection schemes, fault currents, and switchgear rating; 3) power quality-harmonic voltage distortion and voltage flicker.

The first two topics are always investigated when connecting any new generator and are not specific to wind power. Harmonic voltage distortion is of particular interest when power electronic converters are employed to interface wind generation units to the network whereas voltage flicker is more significant for large, fixed-speed wind turbines on weak distribution circuits.

In addition to the local impacts, wind power also has a number of system-wide impacts as it affects the following: 1) power system dynamics and stability; 2) reactive power and voltage support; 3) frequency support.

Squirrel-cage induction generators used in fixed-speed turbines can cause local voltage collapse after rotor speed runaway. During a fault (and consequent network voltage depression), they accelerate due to the imbalance between the mechanical power from the wind and the electrical power that can be supplied to the grid. When the fault is cleared, they absorb reactive power, depressing the network voltage. If the voltage does not recover quickly enough, the wind turbines continue to accelerate and to consume large amounts of reactive power. This eventually leads to voltage and rotor speed instability. In contrast to synchronous generators, the exciters increase reactive power output during low network voltages and thus support voltage recovery after a fault, squirrel-cage induction generators tend to impede voltage recovery.

With variable-speed wind turbines, the sensitivity of the power electronics to overcurrents caused by network voltage depressions can have serious consequences for the stability of the power system. If the penetration level of variable-speed wind turbines in the system is high and they disconnect at relatively small voltage reductions, a voltage drop over a wide geographic area can lead to a large generation deficit[1]. Such a voltage drop could be caused, for instance, by a fault in the transmission grid. To prevent this, grid companies and transmission system operators require that wind turbines have a fault ride through capability and are able to withstand voltage drops of certain magnitudes and durations without tripping. This prevents the disconnection of a large amount of wind power in the event of a remote network fault.

The voltage on a transmission network is determined mainly by the interaction of reactive power flows with the reactive inductance of the network. Fixed-speed induction generators absorb reactive power to maintain their magnetic field and have no direct control over their reactive power flow. Therefore, in the case of fixed-speed induction generators, the only way to support the voltage of the network is to reduce the reactive power drawn from the network by the use of shunt compensators.

Variable-speed wind turbines have the capability of reactive power control and may be able to support the voltage of the network to which they are connected. However, individual control of wind turbines may not be able to control the voltage at the point of connection, especially because the wind farm network is predominantly capacitive.

On many occasions, the reactive power and voltage control at the point of connection of the wind farm is achieved by using reactive power compensation equipment such as static var compensators or static synchronous compensators.

To provide frequency support from a generation unit, the generator power must increase or decrease as the system frequency changes. Hence, in order to respond to the low network frequency, it is necessary to de-load[2] the wind turbine leaving a margin for power increase. A fixed-speed wind turbine can be de-loaded if the pitch angle[3] is controlled so that a fraction of the power that could be extracted from wind will be "spilled"[4]. A variable-speed wind turbine can be de-loaded by operating it away from the maximum power extraction curve, thus leaving a margin for frequency control.

Notes

1. generation deficit	功率缺额
2. de-load	（风机）停机
3. pitch angle	桨距角
4. spilled	涌出

Renewable Energy

It is commonly accepted that the earth's fossil energy resources are limited. At the same time, there is strong political opposition against strengthening nuclear power in many parts of the world. In this scenario[1] renewable energies will have to contribute more and more to the world's ever rising need of energy in the future.

The term "renewable energy" is referred to as the energy derived from a broad spectrum of resources, all of which are based on self-renewing energy sources such as sunlight, wind, flowing water, the earth's internal heat, and biomass[2] such as energy crops, agricultural and industrial waste, and municipal waste. These resources can be used to produce electricity for all economic sectors, fuels for transportation, and heat for buildings and industrial processes.

Renewable energy is climate-friendly forms of energy, due to the absence of emissions detrimental to[3] the environment. The savings especially in carbon-dioxide and sulphur dioxide emissions are a significant advantage over fossil power stations. Hence a main role is assigned to renewable energy in the proclaimed fight against climate change.

Although the energy of the sun and wind has been used by mankind for millennia[4], modern applications of renewable energy technologies have been under development for about only 20 years. In that period of research and development investment by industry and government, dramatic improvements have occurred in the cost, performance and reliability of renewable energy systems.

Concentrating solar power, sometimes referred to as solar thermal systems, uses the sun's heat to meet a variety of needs, such as generating electricity, heating water for industrial processes, etc. Photovoltaic devices use semiconductor materials such as silicon to convert sunlight to electricity. Extremely modular photovoltaic devices can be used in small cells, panels and arrays[5]. Photovoltaic systems require little servicing or maintenance and have typical lifetimes of about 20 years. Thermo-photovoltaicis, as a new type of photovoltaics, is now emerging. It uses the energy of heat, or infrared radiation to generate electricity with the advantage that a generator can operate at night or when the sky is overcast, eliminating the need for batteries. Though it does need a fuel, such as natural gas, to provide the heat, yet using semiconductors for conversion rather than conventional diesel generators results in higher fuel-to-electricity conversion efficiencies, modularity[6], minimal pollutants, quieter operation and higher reliability.

While water power has been used in electrical power stations and pumped storage systems since many decades ago, the use of wind power conversion in larger ratings began only in the 1980s. Backed by intense technical development, unit ratings have grown fast into the MW range, and wind parks[7] have been erected in large numbers with considerable increase rates. Most commercially available wind turbines use a horizontal-axis configuration with two or three blades, a drivetrain including a gearbox and generator, and a tower to support the rotor, with electricity produced within a specific range of wind speeds.

Geothermal resources include dry steam, hot water, hot dry rock, magma[8], and ambient ground heat. Steam and water resources have been developed for power generation and ambient ground heat is used in geothermal heat pumps, reservoirs, and tapping broader resources[9]. The Geysers steam power plant in America is the oldest and largest geothermal power plant in the world, with a capacity of 2000 MW. Hot-water plants have been developed more recently and are now the major source of geothermal power in the world.

Hydrogen today can be produced from renewable sources and promises substantial contributions to global energy supplies in the long term. Hydrogen is the most abundant element in the universe and is the simplest chemical fuel that makes a highly efficient, clean-burning energy carrier. It has the potential to fuel transportation vehicles with zero emissions, provide process heat for industrial processes, supply domestic heat through cogeneration[10], help produce electricity for centralized or distributed power systems, and provide a storage medium for electricity from renewable energy sources.

Fuel cells promise to be a safe and effective way to use hydrogen for both vehicles and electricity generation. Fuel cells convert hydrogen from natural gas, alcohol fuels or some other sources directly into electrical energy with no combustion. The lack of an economical process for hydrogen production and suitable storage methods are two of the greatest obstacles to commercialization, especially in the transportation sector.

Distributed power is modular electric generation from relatively small generating systems ranging from less than a kilowatt to tens of megawatts which is located at or near consumer sites. Distributed power systems can either be grid connected or operate independent of the grid. The goal of proponents of distributed power is to reinvent[11] the power grid so that instead of producing electricity only at large, central plants and transmitting it in one direction, consumers would have some degree of energy independence and open the system to millions of small suppliers.

With distributed power, homes and businesses could produce power using technologies such as fuel cells, photovoltaic systems, wind turbines, biomass based generators, microturbines, and electric storage systems. Excess power could be sold to the grid adding to grid capacity and consumers could obtain power from the grid when needed or desired.

The benefits of distributed power systems are seen to be reliability of service and power quality. In addition, greater efficiency of energy use is realized by using the heat loss from the power generation system. One of the biggest drivers today with rolling blackouts[12] in some parts of the country is that it can serve as a standby generator or serve as an uninterruptible power supply. More and more consumers are in need of electric service 24/7[13] without interruption. Distributed power offers an approach to this need.

The industrialized world is currently undergoing rapid change in the fundamental structure of the electricity sector of our economies. The challenges and opportunities of this restructuring affect utilities，independent developers，power marketers，energy users，investors and the renewable energy community.

Notes

1. scenario	此处意为背景、条件
2. biomass	生物能源
3. detrimental to	有害于
4. millennia	千年
5. panels and arrays	以面板和阵列的形式
6. modularity	模块化，指可扩展性
7. wind parks	风电场
8. magma	岩浆
9. tapping broader resources	开发更广泛的资源
10. cogeneration	热电连供
11. reinvent	重构（电网）
12. with rolling blackouts	备用发电车
13. electric service 24/7	每周七天每天 24 小时不间断供电

Ultra-high Voltage Transmission in China

The electric power transmission with the voltages at 1000kV AC and above are known as UHV AC transmission, and the voltages at above ±600kV DC are known as UHV DC transmission. Now in China UHV AC and UHV DC transmission voltages are 1000kV and ±800kV respectively. UHV transmission lines can transmit large block of electric power over a long distance, reduce number of circuit lines and right-of-way, lower electric energy loss.

China is now at a critical point in its efforts to create an electric power structure able to sustain its emerging affluent society. China has already been the world's largest supplier of electric energy, with an installed capacity of 1122GW in 2013, with growing rate of 10% annually. At that rate, China's national economic and social development plan expects total installed capacity to reach at least 1300GW by 2020. To meet this demand, China is currently developing a network of 1000kV AC transmission facilities each having about five times more power-transmitting capacity than current 500kV ones and developing a series of ±800kV DC transmission facilities each having a capacity that is about double of a 500kV DC one. In addition to greater transmission capacity, a UHV network will also be able to extend transmission distances economically out to 2000km, reduce transmission losses by 25%, and cut line corridor[1] areas by up to 66%.

One of the major problems complicating China's efforts to distribute electric power more efficiently is the sheer vastness[2] of its electric grid system. China, the world's third largest nation, covering almost 9.6 million square miles, now divides its power system among six regional power grids: Northwest, North China, Northeast, East China, Central China, and South China. This results in energy bases that are often 800 to 3000km distant from load centers. The existing 500kV grid has proved incapable of supplying sufficient power to traverse these distances efficiently, and the power lines themselves are incapable of sustaining greater power input without short-circuiting and threatening widespread blackouts. Until recently, insufficient long-term investment in updating its power infrastructure has frustrated China's ability to overcome these drawbacks. According to planners, however, the construction of the 1000kV AC and ±800kV DC grid should effectively resolve existing problems. The increased AC transmission offers the ability to distribute higher voltages in greater bulk between regions, while the upgraded DC transmission provides the long-distance capability needed to link power bases along the grids.

Key technological concerns surrounding voltage standards, overvoltage and insulation coordination[3], electromagnetic environments, live-line working[4] and lightning shielding have already been taken into consideration. A 1000kV AC demonstration line at Jindong—nan—Nanyang—Jingmen and three ±800kV DC demonstration lines are currently being built at Yunnan-Guangdong, Sichuan- Shanghai, and Sichuan-Jiangsu. Running concurrently with design and feasibility studies, research institutions and equipment manufacturers have been developing and testing equipment specially designed to support the projected new high-power grid. The newly designed equipment includes transformers, reactors, circuit breakers, switches, insulators, and arresters.

Although considerable progress has been made, further tests at demonstration facilities will be needed to resolve remaining technological issues before China's new electric power system becomes fully operational. For this purpose, a UHV AC test base and a UHV DC test base are also being built. In addition, in 2006, the State Grid Corporation of China sponsored construction of a grid simulation center covering an area of some $61km^2$. The simulation center, with headquarters located at the China Electric Power Research Institute in Beijing, consists of three laboratories. They are dedicated to digital and analog hybrid simulation, power system dynamic simulation, and power system operation simulation and security monitoring respectively.

The UHV AC test base has a single-circuit 1000kV AC test line and a double-circuit on the same tower 1000kV AC test line, both of the lines are 1000m long. Test lines include the tower configuration with single-circuit horizontally and double-circuit vertically. The UHV AC test base has capability of research on corona performance, electromagnetic environmental effect, live line working and characteristics of insulators pollution for UHV lines.

The 1000kV single-circuit test line section was energized on February 13th, 2007. Then, the electromagnetic environment parameters of single-circuit test line section and inside substation under light rain were measured. The measured data indicate that radio interference[5] level is in the range of 54—55dB (μV/m) in fine weather, and audible noise[6] is in the range of 39—41dB (A) at 20m far away from the single-circuit line outer phase projection; and that is 65—67dB (μV/m) and 53dB (A) in rain weather respectively. These are approximately the same as the research results of UHV AC prophase scientific research .

The 1000kV double-circuit test line section was energized on June 15th, 2007. The research of UHV base substation noise level and the improved measures was carried out. Scientific researchers preliminarily achieved the practical level of UHV transmission and transformation electromagnetic environment. The selection of line conductors, substation bus bar and the connection type were confirmed.

China also recognizes the broader import of its efforts toward developing a UHV power grid. In 2006, China hosted a conference in Beijing, attended by 350 participants from 19 countries, to promote the rapid development of UHV transmission technology worldwide. In the following year, China held another international symposium to address the specific issue of developing international standards for the introduction and use of UHV power systems. These meetings underscore China's conviction that the electric power industry faces common problems that are best resolved through global cooperation, including the mutual exchange of best practices and the sharing of practical experiences.

Notes

1. line corridor	线路走廊
2. sheer vastness	广阔无际
3. insulation coordination	绝缘配合
4. live-line working	带电作业
5. radio interference	无线电干扰
6. audible noise	可听噪声