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Challenges and Opportunities in Future Grid

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***Abstract*—**Future grid is an emerging solution to the aging power grid with increasing electricity power demand. Future grid takes advantages of two-way communications and the technologies in sensing, computing, and control. A future grid system is built from the aspects of reliability, efficiency, economics, environment and interaction. Future grid bearing in response to changing in the environment, improving energy efficiency, reducing carbon emissions. Future grid has become the new development trend and new directions of the world power grid. While Future grid has drawn the attention of research communities, power companies, as well as power consumers, it is confronted with great challenging for the deployment at the same time.

***Keywords*—** Electric grid, aging, power system, energy, distribution, loads.

I. INTRODUCTION

Today's electric grid was designed to operate as a vertical structure consisting of generation, transmission, and distribution and supported with controls and devices to maintain reliability, stability, and efficiency. However, system operators are now facing new challenges including the penetration of Renewable Energy Resources in the legacy system, rapid technological change, and different types of market players and end users. The next iteration, the Future grid, will be equipped with communication support schemes and real - time measurement techniques to enhance resiliency and forecasting as well as to protect against internal and external threats. A Future Grid is an electrical grid that uses information and communications technology together and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity. The design framework of the Future grid is based upon unbundling and restructuring the power sector and optimizing its assets. The new grid will be capable of:

*Handling uncertainties in schedules and power transfers across regions
*Accommodating renewable
*Optimizing the transfer capability of the transmission and distribution networks and meeting the demand for increased quality and reliable supply
*Managing and resolving unpredictable events and uncertainties in operations and planning more aggressively

II. FUTURE GRID

The future grid is also known as 'smart grid' which refers to an electricity transmission and distribution system that incorporates elements of traditional and cutting-edge power engineering, sophisticated sensing and monitoring technology, information technology, and communications to provide better grid performance and to support a wide range of additional services to consumers.

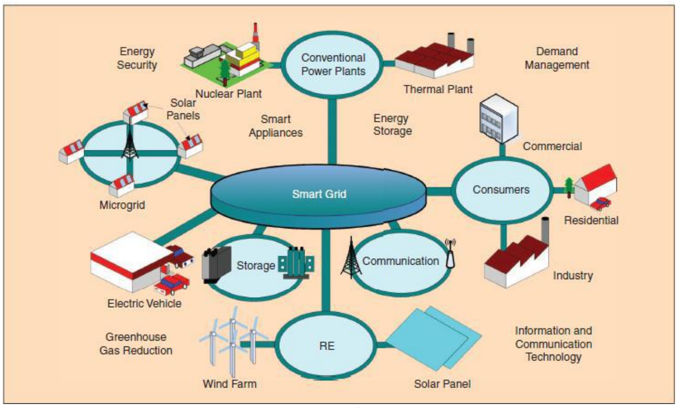


Fig. 1. Represents the future electric grid.

A. *What is the Need to Change the Present Grid?*

An electric grid consists of three main subsystems: the generation sources (various power plants); the delivery system (transmission and distribution networks); and the end customers (Residents, commercial buildings, industrial installations, and others). The electric grid is unique in that electrical supply and demand must remain tightly balanced at all times, since for most of the history of the electric grid there has been no commercial solution for large-scale storage of electricity to compensate for any excess or shortfall in power. In the past, this balancing act was performed by the vertically integrated utilities that controlled both the generation and the delivery systems.

Power grids in the industrialized countries are aging and being stressed by operational scenarios and challenges never envisioned when the majority of them were developed many decades ago. The main challenges are summarized below.

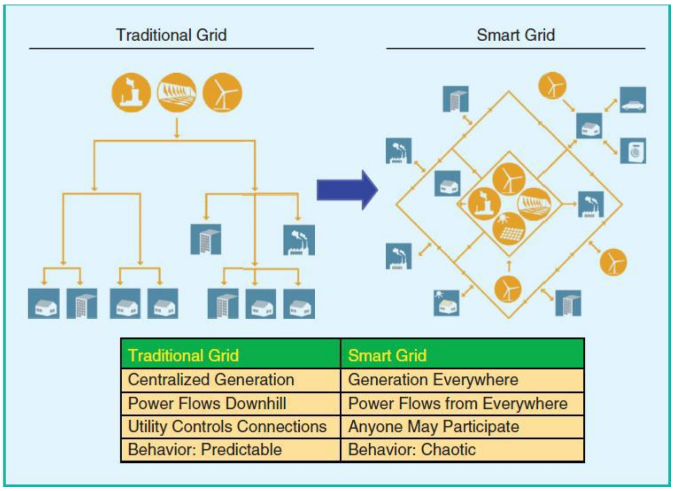
1. Deregulation unleashed unprecedented energy trading across regional power grids, presenting power flow scenarios and uncertainties the system was not designed to handle.
2.The increasing penetration of renewable energy in the system further increases the uncertainty in supply and at the same time adds stress to the existing infrastructure due to the remoteness of the geographic locations where the power is generated.
3. Our digital society depends on and demands a power supply of high quality and high availability.

4. The threat of terrorist attacks on either the physical or the cyber assets of the power grid introduces further uncertainty.

The objective of transforming the current power grid into a Future grid is to provide reliable, high-quality electric power to digital societies in an environmentally friendly and sustainable way. This objective will be achieved through the application of a combination of existing and emerging technologies for energy efficiency, renewable energy integration, demand response, wide-area monitoring and control, self-healing, HVDC, flexible ac transmission systems (FACTS) etc.

III. TRANSITION FROM THE PRESENT GRID TO A SMART GRID

The transition from the present grid to a smart grid and the key differences between the two can be illustrated by Figure 2 One can see there is a fundamental shift in the design and operational paradigm of the grid: from central to distributed resources, from predictable power flow directions to unpredictable directions, from a passive grid to an active grid. In short, the grid will be more dynamic in its configuration and its operational condition, which will present many opportunities for optimization.



Traditional Grid	Smart Grid
Centralized Generation	Generation Everywhere
Power Flows Downhill	Power Flows from Everywhere
Utility Controls Connections	Anyone May Participate
Behavior: Predictable	Behavior: Chaotic

Fig. 2. Shows comparison between traditional grid and smart grid.

IV. FEATURES OF THE SMART GRID

1. Tightly Integrated Renewable Energy

In the smart grid, energy from diverse sources is combined to serve customer needs while minimizing the impact on the environment and maximizing sustainability. In addition to nuclear, coal-, hydroelectric-, oil-, and gas-based generation, energy will come from solar, wind, biomass, tidal, and other renewable sources. The smart grid will support not only centralized, large-scale power plants and energy farms but residential-scale dispersed distributed energy sources. These renewable and green sources will be seamlessly integrated into the main grid

2. Proliferation of Energy Storage

A smart grid has numerous energy storage centers, large and small, stationary and mobile, that it can use to buffer the impact of sudden load changes and fluctuations in wind and solar generation, as well as to shift energy consumption away from peak hours by providing energy balancing, load following, and dynamic compensation of both reactive and real power. The recent development of quick-response battery energy storage systems (BESSs) with voltage source converters (VSCs) has demonstrated the promise and potential benefits of energy storage.

3. Growing Mobile Loads and Resources

Many loads and resources connected to the future smart grid will no longer be stationary. Breakthroughs in battery technology are making plug-in electric vehicles (EVs) commercially viable. At all times of day, tens of millions of EVs will be connected to the future grid at parking lots near homes, workplaces, and shopping malls. These EVs will represent both mobile loads and potential sources of power. The battery systems in these vehicles will be charged or discharged via sophisticated coordination protocols in order to smooth out fluctuations in power demand in different parts of the grid, avoid power transmission bottlenecks, and render the grid more stable. Controllers will be able to respond to power system condition signals such as voltages and frequencies as well as market signals such as real-time electricity prices.

4. Distribution of Production

DG (from solar, fuel cell, small wind turbine, and other sources) and energy storage (battery, thermal, and hydrogen) are everywhere in a smart grid. They are not marginal players but highly influential and integrated parts of the energy web. They provide energy diversity, reduce demand for central fossil-fuel power plants, and increase supply redundancy and system reliability. The distribution of energy production from renewable sources also increases the resilience of the grid in the face of widespread disturbances (e.g., blackouts).

5. A New Level of Controllability

In the future smart grid, a new generation of power transport and control technologies will have become mature and widely adopted. Current-limiting and current-breaking devices based on solid-state technology will help protect valuable grid assets and isolate faults. Power electronics–based transformers will be common. FACTS technology will enable system operators to route power flows along the most efficient paths and find the best power production mixes and schedules. Advanced applications in the control center will continuously check the state of the grid and determine the best control strategies from among billions of possibilities in real time.

6. Real-Time Grid Awareness

Massively deployed sensors will continuously collect end-users energy consumption data, weather data, and equipment condition and operational status and perform real-time rating in the context of actual distribution and transmission line flows. The information will be disseminated through highly available, flexible, open (but secure) two-way communication infrastructures to any point in the grid where it can be used to monitor the status of the grid, predict what will happen next, and develop optimal control strategies.

7. The Smart Consumer and the Grid-Friendly Appliance

End-user equipment will no longer consist of dumb devices but will form interactive and intelligent nodes on the smart grid. End-user energy management systems will monitor the energy consumption situation in residences, office buildings, and shopping malls. They will know the consumption patterns and preferences of the occupants, as well as real-time conditions (e.g. market prices, grid stress). They will use the collected information to autonomously interact with the grid to determine the charging and discharging cycles of plug-in electric vehicles, schedule washer and dryer cycles, and optimize HVAC operations without sacrificing occupants comfort. Appliances will continuously monitor voltages and frequencies [3]. When the system experiences distress due to unforeseen disturbances, the appliances will modulate the power consumed to reduce the stress on the system and help prevent service disruptions.

8. The Resurgence of DC

Advancements in materials, power electronics, and sensor technologies will transform the design and operation paradigm of the smart grid. At the generation, transmission, and distribution levels, ac and dc technologies will work together harmoniously. HVDC networks embedded in ac networks will power the world's megacities but will use only a fraction of the land required for transmission a generation ago. HVDC transmissions will link clean and renewable power at remote or offshore generation sites to the main power grid. Distribution buses in office and residential buildings will supply dc power to digital appliances without the need for power adapters. Hybrid grid (ac/dc) architectures for distribution systems will make the grid more flexible and reliable.

9. Real-Time Distributed Intelligence

In the smart grid, advanced grid-monitoring, optimization, and control applications track the operating conditions of grid assets, calculate their ratings, and dynamically balance load and resources to maximize energy delivery efficiency and security in real time. The increased interactivity among producers and consumers will mean demand is dynamic rather than static; the grid's operating environment will appear chaotic, and power flow directions will change in response to market conditions. A new generation of protection and control technologies will be called on to maintain the safety and security of both the system and its personnel.

V. LAYERS OF THE SMART GRID

The four essential building blocks of the smart grid can be depicted using a layered diagram, as shown in Figure 3. An analogy can be drawn between these layers and those that make up the human body. The bottom layer is analogous to the body's muscles; the sensor/actuator layer corresponds to the body's sensory and motor nerves, which perceive the environment and control the muscles; the communication layer corresponds to the nerves that transmit perception and motor signals; and the decision intelligence layer corresponds to the human brain

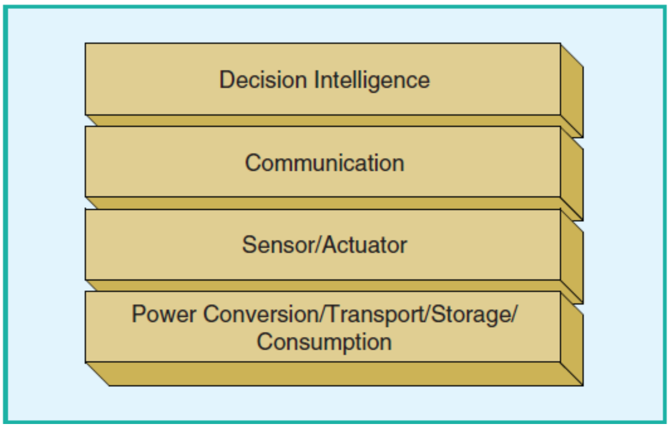


Fig. 3. Represents smart grid technology layers.

The smartness of the smart grid lies in the decision intelligence layer, which is made up of all the computer programs that run in relays, intelligent electronic devices (IEDs), substation automation systems, control centers, and enterprise back offices. These programs process the information collected from the sensors or disseminated from the communication and IT systems; they then provide control directives or support business process decisions that manifest themselves through the physical layer. For the decision intelligence layer to work, data (information) need to be propagated from the devices connected to the grid to the controllers that process the information and transmit the control directives back to the devices. The communication and IT layer performs this task. The IT layer serves to provide responsive, secure, and reliable information dissemination to any point in the grid where the information is needed by the decision intelligence layer. In most cases, this means that data are transferred from field devices back to the utility control center, which acts as the main repository for all the utility's data. Device-to-device (e.g., controller-controller or IED-to-IED) communication, however, is also common, as some real-time functionality can only be achieved through interdevice communication. Interoperability and security are essential to assure ubiquitous communication between systems of different media and topologies and to support plug-and-play for devices that can be auto configured when they are connected to the grid, without human intervention. The accelerating deployment of AMI around the world is a big step in building a two-way communication platform for enabling demand response and other advanced distribution applications. The physical layer is where the energy is converted, transmitted, stored, and consumed. Solid-state technology, power electronics–based building blocks, superconducting materials, and new battery technologies and so on all provide fertile ground for innovations.

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