Evolution of Smart Grid and Some Pertinent Issues

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ABSTRACT

At present there is a universal anxiety about the economic decline and a greener globe which is correlated to an improved and efficient system to generate and transmit electric power. With the initiation of the plug-in electric vehicles and renewable energy generators, a smarter, more efficient and customer-friendly power grid is indispensable that is "Smart Grid". This paper depicts the importance, characteristics and evolution of smart grid. The allied new concerns, environmental impacts and benefits of smart grid are illustrated here. In brief platform for smart grid R&D is also portrayed It is highlighted that though the smart grid implementation is promising, it faces mammoth challenges. The voyage to smart grid is an extensive when diverse technologies will coexist. Finally the future key challenges are enlisted as a guideline for the successful implementation of Smart Grid for the sustainable future.

Keywords: Smart Grid; Distributed generations; Demand Response; Automated Meter Reading (AMR); Advanced Metering Infrastructure (AMI); CO_2 emissions.

1 INTRODUCTION

Smart Grid refers to an improved electricity supply chain that runs from a major power plant all the way inside our home. In short, there are thousands of power plants that generate electricity using wind energy, nuclear energy, coal, hydro, natural gas, and a variety of other resources. These generating stations produce electricity at a certain electrical voltage. This voltage is then "stepped-up" (increased) to very high voltages, such as 500,000 volts, to increase the efficiency of power transmission over long distances. Once this electrical power gets near our town or city, the electrical voltage is "stepped-down" (decreased) in a utility substation to a lower voltage for distribution around our town or city. As this electrical power gets closer to our home, it is stepped-down by another transformer to the voltage we use in our home. This power enters our home through our electrical meter.

In many areas of the world, the electricity delivery system described above is getting aged and worn out. In addition, population growth in some areas has caused the entire transmission system to be over used and fragile. At the same time, we have probably added more electronic devices to our home, such as computers, high-definition TV's, microwave ovens, wireless telephones, and even electronic controls on refrigerators, ovens, and dishwashers. These new appliances are more sensitive to variations in electric voltage than old appliances, motors, and incandescent light bulbs. Unfortunately, the entire electrical grid is becoming more fragile at the same time the appliances in our home are getting more sensitive to electrical variations. In short, the reliability of electrical power in the world will decline unless we do something about it now.

Adding new transmission lines will help the utilities get more power from the power plants to our home. However, many communities don't want new power lines in their areas. In addition, adding new capacity, although needed, will not increase the reliability of all the old electrical equipment reaching the end of its useful life. What is needed is a new approach that significantly increases the efficiency of the entire electrical delivery system. This approach will not only increase reliability, but will also reduce energy in the delivery process and thereby reduce greenhouse house emissions. We call this new approach Smart Grid.

The basic concept of Smart Grid is to add monitoring, analysis, control, and communication capabilities to the national electrical delivery system to maximize the throughput of the system while reducing the energy consumption. The Smart Grid will allow utilities to move electricity around the system as efficiency and economically as possible. It will also allow the home owner and business to use electricity as economically as possible. We may want to keep our house set at 23.88 degrees C in the summer time when prices are low, but we may be willing to increase our thermostat to 25.55 degrees C if prices are high. Similarly, we may want to dry our clothes for 5 cents per kilowatt-hour at 9:00 pm in stead of 15 cents per kilowatt-hour at 2:00 pm in the afternoon. We will have the choice and flexibility to manage our electrical use while minimizing our costs.

Smart Grid builds on many of the technologies already used by electric utilities but adds communication and control capabilities that will optimize the operation of the entire electrical grid. Smart Grid is also positioned to take advantage of new technologies, such as plug-in hybrid electric vehicles, various forms of distributed generation, solar energy, smart metering, lighting management systems, distribution automation, and many more.

2 CHARACTERISTICS OF SMART GRID

In short, a Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to:

- better facilitate the connection and operation of generators of all sizes and technologies [1]
- allow consumers to play a part in optimising the operation of the system [1]
- accommodates intermittent generation and storage options
- enables new products, services, and markets
- integrates electric vehicles into the distribution network
- provides power quality for the needs of a digital economy [1]
- anticipates and responds in a self-healing manner
- operates resiliently in disasters, physical or cyber attacks
- provide consumers with greater information and choice of supply
- significantly reduce the environmental impact of the whole electricity supply system [1]
- deliver enhanced levels of reliability and security of supply& energy magazine

3 EVOLUTION OF SMART GRID

Continued economic growth and fulfillment of high standards in human life depends on reliable and affordable access to electricity. Over the past few decades, there has been a paradigm shift in the way electricity is generated, transmitted, and consumed. However, fossil fuels continue to form a dominant initial source of energy in the industrialized countries. The steady economic growth of some of those industrialized countries gradually exposed the unsustainable nature of the energy policy that is highly dependent on foreign fossil fuels. On the other hand, an aging power grid that faces new challenges posed by higher demands and increasing digital and nonlinear loads has placed new reliability concerns as observed with frequent outages in the recent years. Sensitivity of digital equipments, such as data centers, and consumer electronics, into intermittent outages has redefined the concept of reliability. As a result, power generation, transmission, and consumption has been the focus of investigations as to see what remedies will address the above challenges thereby transforming the power grid into a more efficient, reliable, and communication-rich system. Smart power grid is a host of solutions that is aimed to realize these lofty goals by empowering customers, improving the capacity of the transmission lines and distribution systems, providing information and real time pricing between the utility and clients, and higher levels of utilization for renewable energy sources to name a few.

3.1 THE EXISTING GRID

The existing electricity grid is a product of rapid urbanization and infrastructure developments in various parts of the world in the past century. Though they exist in many differing geographies, the utility companies have generally adopted similar technologies. The growth of the electrical power system, however, has been influenced by economic, political, and geographic factors that are unique to each utility company [2]. Despite such differences, the basic topology of the existing electrical power system has remained unchanged. Since its inception, the power industry has operated with clear demarcations between its generation, transmission, and distribution subsystems and thus has shaped different levels of automation, evolution, and transformation in each silo.

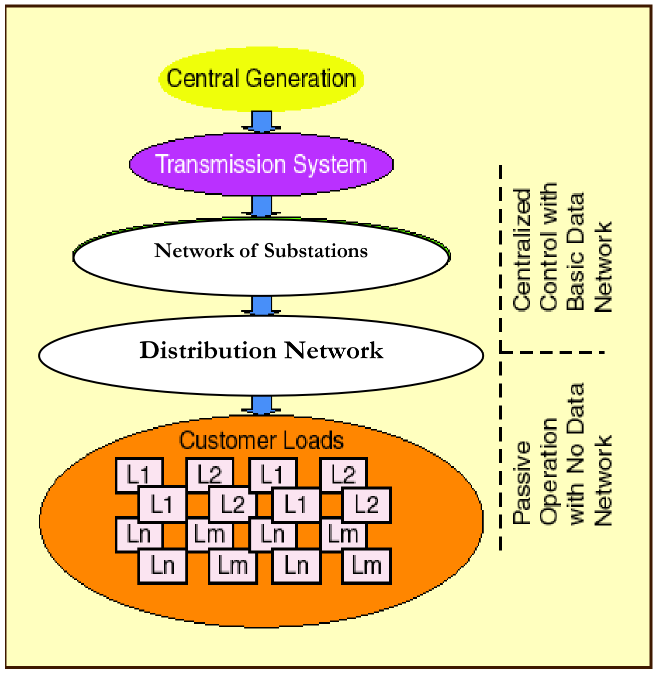


Figure 1: The Existing Grid [2]

As Figure 1 demonstrates, the existing electricity grid is a strictly hierarchical system in which power plants at the top of the chain ensure power delivery to customers' loads at the bottom of the chain. The system is essentially a one way pipeline where the source has no real-time information about the service parameters of the termination points. The grid is therefore over engineered to withstand maximum anticipated peak demand across its aggregated load. And since this peak demand is an infrequent occurrence, the system is inherently inefficient. Moreover, an unprecedented rise in demand for electrical power, coupled with lagging investments in the electrical power infrastructure, has decreased system stability. With the safe margins exhausted, any unforeseen surge in demand or anomalies across the distribution network causing component failures can trigger catastrophic blackouts. To facilitate troubleshooting and upkeep of the expensive upstream assets, the utility companies have introduced various levels of command-and-control functions. A typical example is the widely deployed system known as supervisory control and data acquisition (SCADA).

3.2 SMART GRID EVOLUTION

Given the fact that nearly 90% of all power outages and disturbances have their roots in the distribution network, the move towards the smart grid has to start at the bottom of the chain, in the distribution system. Moreover, the rapid increase in the cost of fossil fuels, coupled with the inability of utility companies to expand their generation capacity in line with the rising demand for electricity, has accelerated the need to modernize the distribution network by introducing technologies that can help with demand-side management and revenue protection.

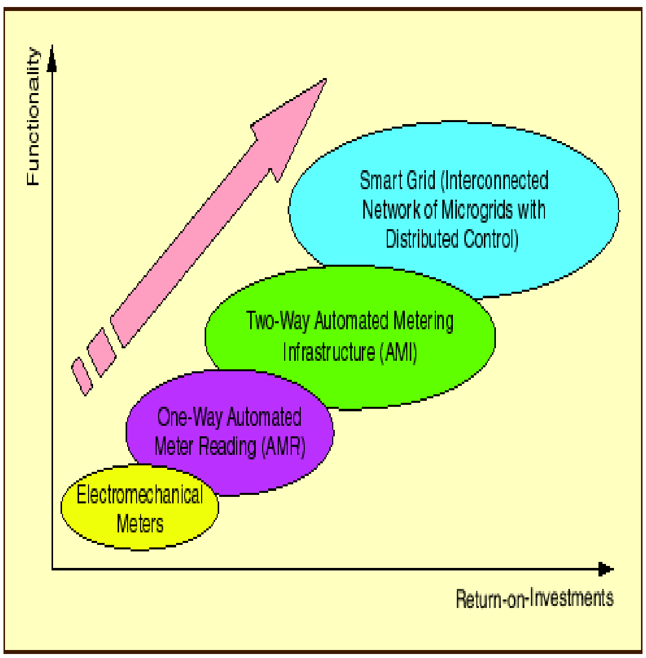


Figure 2: The Evolution of the Smart Grid [2]

As Figure 2 shows, the metering side of the distribution system has been the focus of most recent infrastructure investments. The earlier projects in this sector saw the introduction of automated meter reading (AMR) systems in the distribution network. AMR lets utilities read the consumption records, alarms, and status from customers' premises remotely.

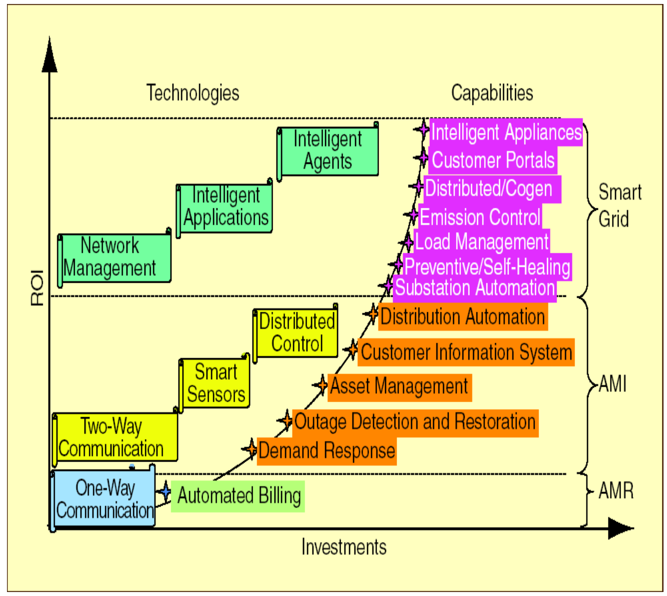


Figure 3: Smart grid Return on Investments [2]

As Figure 3 suggests, although AMR technology proved to be initially attractive, utility companies have realized that AMR does not address the major issue they need to solve: demand-side management. Due to its one-way communication system, AMR's capability is restricted to reading meter data. It does not let utilities take corrective action based on the information received from the meters. In other words, AMR systems do not allow the transition to the smart grid, where pervasive control at all levels is a basic premise.

Consequently, AMR technology was short-lived. Rather than investing in AMR, utilities across the world moved towards advanced metering infrastructure (AMI). AMI provides utilities with a two way communication system to the meter, as well as the ability to modify customers' service-level parameters. Through AMI, utilities can meet their basic targets for load management and revenue protection. They not only can get instantaneous information about individual and aggregated demand, but they can also impose certain caps on consumption, as well as enact various revenue models to control their costs. The emergence of AMI heralded a concerted move by stakeholders to further refine the ever-changing concepts around the smart grid. In fact, one of the major measurements that the utility companies apply in choosing among AMI technologies is whether or not they will be forward compatible with their yet-to-be-realized smart grid's topologies and technologies.

3.3 SMART GRID AND INFORMATION TECHNOLOGY

Diversifying the energy sources for generation of electricity and adaptation of a distributed generation with enhanced communication features is a central part of transformation into an intelligent grid. One may consider this as a true emergence of information technology (IT) into energy technology (ET) Electric energy systems have been undergoing profound changes throughout the world. Technically, the increasing presence of alternative energy resources, usually intermittent and geographically dispersed, pose challenges to conventionally centralized power system operation. The conventional centralized, top-down electric power industry is being transformed towards a distributed, bottom-up electric energy system, characterized by active participation of new energy resources [9].

The decentralization of the electric energy systems operation is facilitated by the development in information technology (IT) devices. The cost and performance of state-of-the-art sensing, communication, actuation, and computing devices (e.g. phasor measurement units, fast switching power electronics devices) provide opportunities for a more proactive decision making framework for the changing electric energy industry, commonly referred to as "smart grids" [10] [11]. While efforts have been made to provide device level with advanced sensing and actuation hardware and/or software, much remains to be done to understand the role of information necessary to achieve better performance of the system as a whole.

4 WHAT'S NEW ABOUT SMART GRID?

- Technology advances to enable profitable building energy management using intelligent control strategies combined with storage and local generation.
- Micro grids are small-scale grids (e.g. campus, neighbourhood) with local renewable generation capacity that interconnects with more conventional distribution systems.
- Demand-side elasticity reduces transmission, energy storage and central generation infrastructure costs [3].
- Markets that allow the customer to buy and sell electricity based on dynamic rates.
- Two-way communications that allow market signals to propagate to the consumers with load forecast and generation bids going back to the grid controllers and market operators [3].
- Electricity product differentiation is buying electricity based on quality, carbon-content and other characteristics [3].
- Opportunities to participate in slow and fast demand response.

5 THE ENVIRONMENTAL IMPACTS OF SMART GRID

The resulting forecasts of global power sector CO_2 emissions are illustrated in Figure 4. The Conservative Scenario leads to 5 percent reduction in annual power sector CO_2 emissions by 2030, with the average annual growth rate in CO_2 emissions dropping from 0.7 percent to 0.5 percent. The Expanded Scenario produces even further reductions. Power sector CO_2 emissions in 2030 drop by 16 percent relative to the Business as Usual (BAU) case. CO_2 emissions are essentially flattened under this scenario, with the annual change in CO_2 emissions becoming an average decrease of 0.1 percent per year.

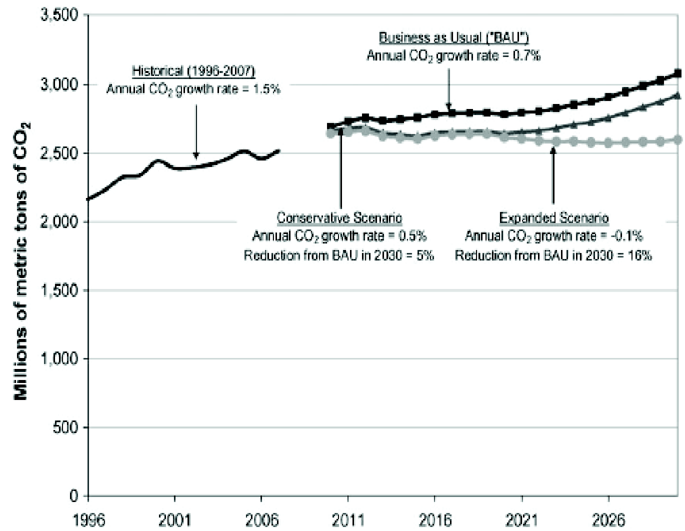
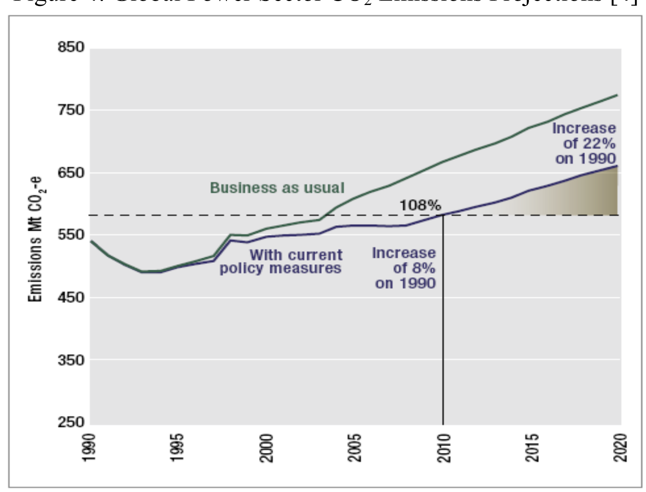


Figure 4: Global Power Sector CO_2 Emissions Projections [4]



Australia's 2020 greenhouse gas emissions forecast shows significant growth from 1990; 90% of which comes from the stationary energy sector. Indicatively, if the 108% target was extended to 2020, an additional 77Mt of abatement per year is required by 2020 beyond current measures.

Source: Australian Greenhouse Office, Tracking to the Kyoto Target, 2005

Figure 5: Australian GHG Emissions Projected to 2020 [12]

Figure 5 highlights the challenge to deliver future deep cuts in greenhouse gas emissions. Australia's GHG emissions are rising and this trend is projected to increase until atleast 2020. By 2020, national emissions are projected to reach 22% above 1990 levels, even with current measures delivering significant abatement. Most of this increase will come from the stationary energy sector which is projected to rise to 170% of 1990 levels by 2020.

These reductions are the product of several changes to the power system. Fewer coal and natural gas plants are built, because there is generally a lower need for new capacity due to the decreased demand for electricity. In the Expanded Scenario much of this capacity is displaced with cleaner renewable resources. The reduction in line losses also reduces the amount of electricity that must be produced by power plants in order to meet demand.

5.1 REDUCE GREENHOUSE GAS EMISSIONS

Worldwide demand for electric energy is expected to rise 82 percent by 2030 [7]. Unless revolutionary new fuels are developed, this demand will be met primarily by building new coal, nuclear, and natural gas electricity-generation plants. Not surprisingly, world CO_2 emissions are estimated to rise by 59 percent by 2030 as a result.

The Smart Grid can help offset the increase in CO_2 emissions by slowing the growth in demand for electricity. A Smart Grid will:

- Enable consumers to manage their own energy consumption through dashboards and electronic energy advisories. More accurate and timely information on electricity pricing will encourage consumers to adopt load-shedding and load-shifting solutions that actively monitor and control energy consumed by appliances.
- In deregulated markets, allow consumers to use information to shift dynamically between competing energy providers based on desired variables including energy cost, greenhouse gas emissions, and social goals. One possibility is an "eBay for electricity" where continual electronic auctions match energy consumers with producers. Users could include utility companies, homeowners with rooftop solar panels, and governments with landfills that reclaim methane gas. This open market approach could accelerate profitability and speed further investments in renewable energy generation [5].
- Broadcast demand-response alerts to lower peak energy demand and reduce the need for utility companies to start reserve generators. Remote energy-management services and energy-control operations will also advise consumers, giving them the choice to control their homes remotely to reduce energy use.
- Allow utility companies to increase their focus on "Save-a-Watt" or "Mega-Watt" programs instead of producing only power. These programs are effective because offsetting a watt of demand through energy efficiency can be more cost-effective and CO_2-efficient than generating an extra watt of electricity [8].

6 SMART GRID BENEFITS

A Smart Grid that incorporates demand management, distributed electricity generation, and grid management allows for a wide array of more efficient, "greener" systems to generate and consume electricity [5].

In fact, the potential environmental and economic benefits of a Smart Grid are significant. A recent study, providing homeowners with advanced technologies for accessing the power grid to monitor and adjust energy consumption in their homes. The average household reduced its annual electric bill by 10 percent [6].

If widely deployed, this approach could reduce peak loads on utility grids up to 15 percent annually, which equals more than 100 GW, or the need to build 100 standard sized coal-fired power plants over the next 20 years. This could save up to $200 billion in capital expenditures on new plant and grid investments, and take the equivalent of 30 million autos off the road.

7 PLATFORM FOR SMART GRID R&D

- The electric power industry provides the platform and the context
- Telecommunication, IT and computer industries provide the technology and software to interface with the electric power network
- The electric power industry will require new generation of engineers who are versatile in several disciplines

8 THE FUTURE : THE KEY CHALLENGES

- Strengthening the grid – ensuring that there is sufficient transmission capacity to interconnect energy resources, specially renewable resources, across Europe [1]
- Moving offshore – developing the most efficient connections for offshore wind farms and for other marine technologies
- Developing decentralised architectures – enabling smaller scale electricity supply systems to operate harmoniously with the total system
- Communications – delivering the communications infrastructure to allow potentially millions of parties to operate and trade in the single market [1]
- Active demand side – enabling all consumers, with or without their own generation, to play an active role in the operation of the system

- Integrating intermittent generation – finding the best ways of integrating intermittent generation including residential microgeneration
- Enhanced intelligence of generation, demand and most notably in the grid
- Capturing the benefits of distributed generation and storage [1]
- Preparing for electric vehicles – whereas smart grids must accommodate the needs of all consumers, electric vehicles are particularly emphasised due to their mobile and highly dispersed character and possible massive deployment in the next years, which would yield a major challenge.

9 REFERENCES

[1] Engineering & Technology, "Smart Grid Thinking", 23 may - 5 June 2009, p 46-49.

[2] IEEE Power & Energy Magazine, "The Path of the Smart Grid".

[3] BACnet Today, A Supplement to ASHRAE Journal.

[4] The Electricity Journal, Elsevier Inc., April 2009, Vol. 22, Issue 3.

[5] Wes Frye, "Transforming the Electricity System to Meet Future Demand and Reduce Greenhouse Gas Emissions", Cisco Internet Business Solutions Group, November 2008.

[6] Pacific Northwest National Laboratory, "Department of Energy Putting Power in the Hands of Consumers through Advanced Technology", January 2008, http://www.pnl.gov/topstory.asp?id=285

[7] Energy Information Administration, "Administration of International Energy Outlook Information 2008" http://www.eia.doe.gov/oiaf/ieo/highlights.html

[8] Jim Rogers, Duke Energy CEO, December 2007.

[9] M. Ilic, "From hierarchical to open access electric power systems," Proceedings of the IEEE, Vol. 95, Issue 5, pp.1060-1084, May 2007.

[10] S. M. Amin and B. F. Wollenberg, "Toward a smart grid," IEEE Power & Energy Magazine, Vol. 3, Issue 5, pp.34-41, Sep/Oct 2005.

[11] F. F. Wu, K. Moslehi, and A. Bose, "Power system control centers: past, present, and future," Proceedings of the IEEE, Vol. 93, Issue 11, pp.1890- 1908, Nov 2005.

[12] Darren Bilsborough, "Smart Grids: A Powerful Enabling Technology", Smart Grid Forum, 2009, http://ece.curtin.edu.au/local/information/Darren Bill-Smart-Grids-Forum-Perth-301109.pdf