Smart Grid: Advanced Electricity Distribution Network

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ABSTRACT *: The Smart Grid concept is conceived as a means to optimize the operation and to improve the reliability of the electric delivery system. As environmental concerns and energy consumption continue to increase, utilities are looking at cost effective strategies for improved network operation and consumer consumption. Smart Grid is a collection of next generation power delivery concepts that includes new power delivery components, control and monitoring throughout the power grid and more informed customer options. A "smart grid" leverages digital technology to improve reliability, security, transparency, connectivity, interoperability, and efficiency. It enables information collection and communication throughout the system, from generation to transmission and distribution to end users. The Smart Grid can't be reduced to a simple formula. The broadest interpretation sees the electric industry transformed by the introduction of two-way communications and ubiquitous metering and measurement. It will enable creation of more reliable, more efficient and more secure electrical infrastructure.*

Keywords**:** *Smart Grid, Self-healing, Power system, Commercial agreements, Electricity markets, Interconnectivity*

1. INTRODUCTION.

"Smart grids," as the name implies, are sophisticated, digitally enhanced power systems where the use of modern communications and control technologies (the former also known as ICT, or Information and Communications Technologies) allows much greater robustness, efficiency, and flexibility than today's power systems. Designers also aim for smart grids to save money. Additional terms used include a "Self-healing grid," which can repair itself in the event of any failure or attack. There is no single definition of a smart grid, nor is there any standard architecture or design for a Smart Grid. This makes things difficult for utilities, planners, and the government, but it also highlights the enormous potential and opportunities in this space. Smart Grids are best defined by functionality, especially since the underlying technologies for achieving these goals are still under evolution. We can list following objectives of a Smart Grid:

1. Enabling informed participation by customers
2. Accommodating all generation and storage options
3. Enabling new products, services, and markets
4. Providing the power quality for the range of needs in the 21st century economy
5. Optimizing asset utilization and operating efficiently
6. Addressing disturbances through automated prevention, containment, and restoration
7. Operating resilience against all hazards

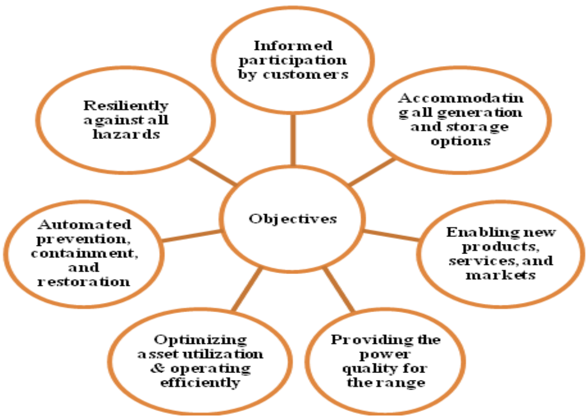

Fig . 1 Objectives of a Smart Grid

2. WHAT IS SMART GRID?

2.1 Definition of Smart Grid

Based on physical power grid, smart grid is a new type power grid which highly integrates modern advanced information techniques, communication techniques, computer science and techniques with physical grids.[1] It has many advantages, such as improving energy efficiency, reducing the impact to environment, enhancing the security and reliability of power supply and reducing the power loss of the electricity transmission network and so on.

The objectives of smart grid are: fully satisfy customer requirements for electrical power, optimize resources allocation and ensure the security, reliability and economic of power supply, satisfy environment protection constraints, guarantee power quality and adapt to power market development. Smart grid can provide customer with reliable, economical, clean and interactive power supply and value added services.

2.2 The Characteristics of Smart Grid

Smart grid holds the promise that the power sector can go "green" by not simply reducing the use of dirty power generation methods but instead become a system that can take more aggressive measures to lower greenhouse gas emissions through efficient integration of renewable energy sources.[1] Smart grid that focuses on improving demand-side management for energy and promoting renewable energy could be a transformational force that redefines the way people view energy generation, transmission and consumption, in that such grids would encourage active engagement by the broader society, not just power sector specialists. Smart grid mainly has features as secure and reliable, efficient and economical, clean and green, flexible and compatible, open and interactive, integrated and so on.

2.2.1 *Secure and Reliable:*

The power grid is still to maintain the power supply capacity to the users, rather than a large area power outage when big disturbances on the power grid, faults, natural disasters and extreme weather conditions, or man-made damage happen.

2.2.2 *Efficient and Economical:*

The power grid can improve the economic benefits through technological innovation, energy efficient management, orderly market competition and related policies. The power grid is in support of the electricity market and power transactions effectively to achieve the rational allocation of resources and reduce power losses and finally to improve the efficiency of energy.

2.2.3 *Clean and Green:*

A large-scale of renewable energy sources can be fed into the grid which will reduce the potential impact on the environment.

2.2.4 *Optimization:*

The power grid can improve power supply reliability and security to meet electricity demand in digital age. The optimal cost to provide qualified electricity to the community. Smart grid can optimize utilization of assets, reduce investment costs and operation and maintenance costs. Quality of power meets industry standards and consumer needs. Provide various level of power quality for the range of needs.

2.2.5 *Interactive:*

Interaction and real-time response to the power market and consumers, which improves service. Mature wholesale market operations in place, well integrated nationwide and integrated with reliability coordinators. Retail markets flourishing where appropriate. Minimize transmission congestion and constraints.

2.2.6 *Self-healing:*

The power grid has capabilities such as real-time & on-line security assessment and analysis, powerful control system for early warning and prevention control automatic fault diagnosis, automatic fault isolation and system self-recovery capability. Self-Healing and adaptive to correct problems before they become emergencies. Predictive rather than reactive, to prevent emergencies ahead rather than solve after. Resilient to attack and natural disasters with rapid restoration capabilities.

2.2.7 *Flexible and Compatible:*

The power grid can support correct, reasonable integration of renewable energy sources and it is suitable for integration of distributed generation and micro power grid. Besides, it can improve and enhance the function of demand side management to achieve the efficient interaction capability with users. Accommodate all generation and storage options. Very large numbers of diverse distributed generation and storage devices deployed to complement the large generating plants.

2.2.8 *Integrated:*

Unified platform and models are used on the power grid. It can achieve a high degree of integration and information sharing of power grid, and to achieve standard, normative and refined management, which integrates the infrastructure, processes, devices, information and market structure so that energy can be generated, distributed, and consumed more efficiently and cost effectively. Thereby achieving a more resilient, secure and reliable energy system. Integrated to merge all critical information.

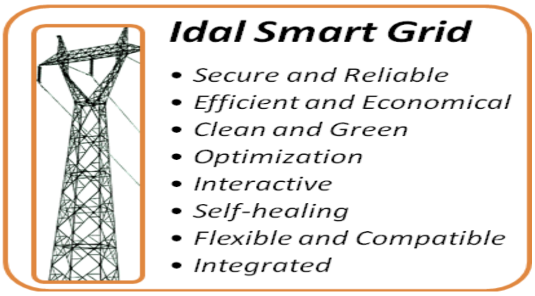

Fig. 2 Characteristics of Smart Grid.

3. COMPONENTS OF POWER SYSTEMS AND CHANGES IN A SMART GRID

Generation in most modern power systems is a mostly centralized affair, with a wide portfolio of generation technologies based on availability of primary fuels as well as costs. In the US and India, coal dominates generation. Larger and larger generating stations have been built over time, typically with economies of scale in mind.[3]

Transmission lies in the "middle" of the power system interconnecting generation with distribution systems. Transmission lines are typically long distance and high voltage. Since waste heat losses are proportional to the square of the current, which is inversely linked to the voltage, transmission is high voltage or extra high voltage – hundreds of kilovolts are common. Voltages are stepped up (or down) using power transformers, which are present at a number of stages of a power system.

Distribution is the last physical component of a power system, and is usually the retail end of the system (though retail can be separated from the physical distribution system). Distribution is also like transmission in the sense that this carries power towards consumption points, but there are two main differences. First, the voltages are lower (perhaps tens of kilovolts at most, before being converted to 120V or 220V for end-users), and second, the branching of lines is usually in the form of a tree structure. In transmission, different circuits interconnect, even forming loops for managing bulk power transfer. Distribution is mostly unidirectional power flow, going from the sub-station (where the power transformer separates it from transmission) to the consumer.[4]

A smart grid impacts all the components of a power system. Generation is likely to change with a drive towards more renewable and distributed generation. Of course, some renewable like wind farms are large scale and interface with transmission networks, but many renewable are small-scale, and hence appropriate for interconnecting at the distribution level. This fundamentally changes the design of the grid, beyond any policy or regulatory changes distributed end-user generation entails. Other changes in a distribution system include greater automation and switching, allowing for more physical control over which lines are opened or closed. Smart systems also allow better use of variable capacitor banks or static VAR compensators (which improve power quality from inductive loads like motors), automatic reclosers (which overcome temporary outages), etc. While these power engineering technologies are also used without a smart grid in place, a smart grid allows far greater control and measurement than available today, allowing greater optimization. Transmission will change in a smart grid with several upcoming technologies. First is the use of phasor measurement units (PMUs), which can precisely measure the state of a power grid. Given electricity operates at 50 or 60 Hertz (cycles per second), minor changes are hard to measure today, especially across a large transmission system covering tens of thousands of route kilometers. Given the improvement in measurement, communications, and analysis techniques (i.e., computing power), we can now accurately measure the state of the system. This is important because now small deviations or jumps in operating parameters (such as the phase of the power) can let operators know when something is amiss. This is useful for preventing sudden blackouts or widespread ("Cascading") failures. It turns out that there is often a fair amount of time to fix problems before problems spread causing a system-wide failure; the August 2003 blackout in Northeastern US actually had somewhere close to an hour where something drastic such as cutting off an entire city could have been tried to isolate the problem.

The alternating current (AC) power grid operates in a synchronous manner (in phase), and power flows are limited over transmission lines not because the wires cannot take the load (thermal limits are usually higher) but because different segments can slip out of synchronization if there are sudden stresses (e.g., the loss of a major interconnection tie line). With PMUs in place, we can more safely increase the power transfer capacity while simultaneously knowing more about the risks of wide area grid level failures. [4]

The other major change in transmission systems may come from the use of Flexible AC Transmission Systems (FACTS). These are power electronics that physically control the flow of power, instead of relying on uncontrolled physics driven by differences in potential (voltage). With FACTS, one could divert power based on both technical needs as well as commercial agreements.

However, much of the smart grid focus in a power system is at the distribution level. For starters, this is where consumption occurs (not to mention payments are made).[5] Demand is also what drives supply, so managing consumption helps the overall system. It is also the space requiring most effort given the vast distribution of customers and the highly heterogeneous systems typically in place.

One subset of smart grids is smart metering. Here, again, there is no one definition of a smart meter. The earlier incarnations of smart meters were ones that allowed automated meter reading (AMR). This has since grown into advanced metering infrastructure (AMI) where the meter not only measures, stores, and communicates loads and other power statistics in (near) real time, but it can also be a point for control (through connect/disconnect capabilities) and signaling to consumers and their devices for load control.

4. DESIGNING A SMART GRID: STAGES OF CAPABILITIES

Not only are the technologies within a smart grid evolving, even using today's technologies there can be a number of designs for a smart grid based on business case, legacy needs, regulatory guidance, etc. Across this continuum, we can identify a number of capabilities, with some that are linear (like below) and some capabilities than can be deployed independent of others. Some of these functionalities are typically not even considered part of a smart grid, rather, are part of modern grid operations and management

Fig. 3. Stages of capabilities.

4.1 Accounting

Accounting involves measurements to know what is flowing where and when – in a smart grid one can measure in small time increments, taking measurements beyond just energy consumption (kWh) such as peak load, power factor, etc. In India, a strong driver is to cut down theft and other losses, which can be tens of percent.

4.2 Auditing

Auditing goes beyond accounting by reconciling power flows across different locations. This requires integration of what could be disparate measurement systems. However, auditing is historical in nature, and the analysis and reconciliation might be done, say, once per month. This is only partially useful for theft control.

4.3 Monitoring

With monitoring, measurements are undertaken in real-time or close to real-time. Such a system allows signaling in case of a problem, e.g., the loss of a line due to bad weather. Power systems often have Supervisory Control and Data Acquisition (SCADA) systems for monitoring, but these have typically only been deployed at higher voltages.

4.4 Control

Control is a general term for making operational changes in a power system, e.g., opening or closing a circuit, capacitor bank switching, feeder switching etc. Control combines ICT with physical power system equipment. One change in a smart grid beyond traditional power engineering technology is the integration of data across various points to allow system level analysis and decision-making. Decisions could even be automated, or at least semi-automated. Such distributed intelligence is one feature of a smart grid that is not present today.

5. INTERCONNECTIVITY – A KEY REQUIREMENT

In a smart grid, all the various nodes need to interconnect to share data as and where needed. This leads to a number of issues, beyond the costs of building out such a large communications network. First and foremost is the issue of defining boundaries, ownership, and responsibilities. Is the power utility to build out its own network, or rely on the third party telecommunications providers? Will a third party be reliable enough for emergency and control needs? Is wide enough coverage available for universal deployment?[10]

Most designs typically end at the consumer premise, given utilities typically do not want to become involved with activities inside the consumer home or office. Here, the meter or alternative gateway becomes the interface and boundary. However, it's unclear as to the best design for signaling appliances or devices directly. Some signals might need to be broadcast, while others customized. The good news is that the connectivity bandwidth is modest. One doesn't need broadband for such applications.

It is worth clarifying any potential use of the Internet. The Internet is the public, global, interconnected network comprising of multiple smaller networks owned and operated by a number of entities. It has no owner or controller. Most ICT designs for a smart grid do not advocate directly using the public internet given security, control, and predictability concerns (the Internet as of today is designed for "best effort" data communications). "Broadband" is merely end-user high-speed connectivity to the public Internet. It can be used for many functionalities, but there are challenges when it comes to predictability, control, etc. given it ties back to the Internet.

A "smart home" also requires interconnectivity such that the meter (or gateway) can signal appliances, devices, etc. Here, management and security are the key concerns, combined with ease of deployment. Each home might have dozens of nodes to be controlled, from appliances, heating/ventilation/air conditioning (HVAC), solar panels, electric vehicles, etc. Plug-in electric or hybrid vehicles require a smart grid because one needs to ensure they use off-peak power for charging, and one would like flexibility of location for charging a vehicle.

6. SOME RESEARCH ACTIVITIES ON SMART GRIDS

In the following some of the most important international researches on SMART GRID are described. The tasks of the IntelliGrid program, initiated by Electric Power Research Institution (EPRI), are the creation of the technical foundation for a SMART GRID that links electricity with communications and computer control to improve reliability and customer services. This program can provide methodologies for open standards and requirement-based technologies with the exploitation of advanced metering, distributed automation, demand response, and wide area measurement. Grid Wise is a vision, developed by the Department of Energy and industry contributors, based on the opinion that a basic conversion of a power system to an intelligent, adaptive and self-healing network with market-based structures for creating profits at all levels of the system requires information, communication and control technologies in the whole system. The National Energy Technology Laboratory set up the Modern Grid Initiative (MGI) [that pointed out that policy and technology actions are required to allow the modernization of the electric system in the US.[12] The SMART GRID strategies are based on the integration of existing technologies that can enable the fundamental characteristics of a modern grid. The Distribution Vision 2010 consortium is matching the advancement of new technologies to provide the achievement of automated distribution systems. Automation and advanced distribution systems give an option for higher reliability and operation of a Smart Grid. The SMART GRID program, established by the European Technology Platform (ETP) in 2005, built a joint vision for the European networks of 2020 and beyond. According to this program the European electricity networks should be flexible to requests of customers, available to network users and renewable power sources, secure and endowed with high quality of power supply.[9]

7. DESIGN CHALLENGES

There are a number of technical design issues for which there are no easy answers – each utility will be slightly different based on existing architecture, legacy equipment, topology, demographics, etc. Utilities often span different geographies, consumer mixes, etc., not to mention often incorporate assets decades apart in technology (sometimes made more complex through acquisitions or restructuring). What would work well in one case may not be optimal in another.

As an example, the US power grid typically has relatively s mall distribution transformers serving 4-7 homes. In Asia or Europe, the consumer voltage is 220 or 240 volts instead of 110 volts, and a distribution transformer typically serves 100-200 homes. This could dramatically impact the choice of wide area communications technologies, e.g., enhancing the value of and increasing the bandwidth requirements of an aggregation point or concentrator for data flows.

Beyond issues of complexity and scale, there are several broad technology issues all utilities will have to face. ICT evolves very rapidly, while power systems have much longer lives. It is tough to design for something that should last 20 years. This requires modularity and upgradeability, which raises costs. ICT can be made cheaper by integration on-chip, but this reduces the flexibility. A balance must be struck.

Security of the system is paramount given the vast financial and safety implications of a smart grid. This is one reason that most people do not advocate using the Internet per se, though they may use Internet Protocols on a private network. Security cannot be added on but must be designed in from the start. A worst case scenario would be for a hacker to turn on our stove!

A subset of security is privacy. At the very least, the power company will know when you are or aren’t home. More sophisticated analysis could lead to much more information, including consumption patterns (a proxy for wealth), how many people are home, etc. There have already been cases of law enforcement using power data for investigatory needs. This space needs integrated legal, regulatory, and technical planning, keeping in mind the needs of the citizens.[8]

8. STATUS OF SMART GRIDS

Various utilities around the world have taken steps towards deploying a smart grid. A number of nations also have regulations and legislation towards smart metering if not smart grids. Perhaps the largest deployment to date has been Enel, in Italy, where all 27+ million consumers have smart, bi-directionally communication, and controllable meters. However, with continuous improvements in technology, new deployments (e.g., Boulder, Colorado, or Southern California) are “smarter” in their capabilities. Smart grids remain a work in progress, and there are other projects ongoing around the world. [7]

In developing countries, smart grids have not been the focus of the utilities given the other challenges they face, including supply shortfall, theft, financial losses, etc. However, given their small base of present deployment, it is possible that they could leapfrog to smart grids, while at the same time using them as a means to improve their operating and financial sustainability.

9. MOVING AHEAD WITH SMART GRIDS

While there are uncertainties if not fears about costs of a smart grid, amplified because the benefits will accrue over a long time, the benefits likely will improve as deployments increase and costs fall. Most regulators agree that with or without a smart grid, consumer costs are likely to rise, sometimes drastically, given the constraints of fuel supply, environment, sustainability, etc.

Today, we have the chicken-and-egg issue of low-volumes/high-costs, which need to be converted into low-costs/high-volumes (almost like commodities). How can we achieve this? One solution involves the use of government funds or other external support. This is to help early adopters who face higher costs than others, who then help the industry move along a positive learning curve.[10]

Another solution involves more experimentation and innovation. This is in not only underlying technologies (where many ingredients exist but there may be space for breakthrough technologies) but also in operating and business models. The latter is especially the case given consumer behavior and response is a key component of realizing benefits. Beyond pilot deployments, which are in the field, some researchers advocate for more controlled testbeds where more radical and unknown innovations can be researched, developed and deployed, in addition to simply testing the existing state-of-the-art.

Possibly the most important step for smart grids is the creation of standards, so that not only will production costs fall through competition but also utilities will not face a lock-in into proprietary solutions. Ideally, such standards should be open standards not controlled by any one entity. Rather, a collaborative or open process should lead to the respective stakeholders coming up with the right standards, combining industry, government, regulators, etc. There are already a number of industry bodies and consortia creating standards for aspects of smart grids. This work will continue, including efforts by IEEE, EPRI, and the US National Inst. of Standards and Technology (NIST).

The case of WiFi (“wireless Ethernet”) is a good example of ICT innovation, commoditization, and standards. WiFi is the standard by the WiFi Alliance, an industry-driven consortium, which adds standards for inter-operability and security. This sits on top of technical standards by IEEE (IEEE802.11). WiFi began as IEEE 802.11, and in just a decade the speed has increased from 2 Mbps to hundreds of Mbps (802.11n standard). At the same time, the costs have fallen from over $1,000 per node to a few dollars per node (with WiFi now embedded in personal computer chips by manufacturers). While we cannot claim similar advances are likely in smart grids, there is still room for substantial improvements in price points with increase in volumes and standardization. [11]

The Indian Government program on Revised Accelerated Power Development and Reform Program (R-APDRP, $10 billion, of which some 20% is for ICT) are just small steps towards the total effort required in this space. Utilities or planners should not rush into Smart Grids without due analysis and discussion, but, at the same time, should not wait indefinitely for the solutions to "mature." Varying levels of smart grids are already under way – the challenge is to try and reach the virtuous circle of technology improvements, standardization, and scale deployments as rapidly and as cost-effectively as possible.

10. DISCUSSION

We are proposing a new addition that is putting two way connections between electricity supplier and customer for the sake of transmission of electricity from supplier to customer and customer to supplier ie. Customer is selling its stored electricity to supplier when having is extra electricity than its own use. From above concept the customer can drop down its own electricity bill. In this we can put a concept of peak hour ie. During peak hour eg. 7 AM to 10 AM and 6 PM to 10 PM the rates of electricity are increased as compared to normal rates.

11. CONCLUSION

In conclusion, the smart grid brings both benefits and design challenges to the utility, its customers, and the associated technologists. The electric power system is arguably the world's largest machine, if one defines a machine as a series of interconnected parts that form a common system. Transient stability, I2R losses, communications, security, system architecture and modeling are all parts of the complex picture.

There are several points to progress toward the smart grid. Operational Technology and Information Technology departments should become closer. Security has to be considered from the beginning of the project. Data communications is often the largest missing piece. The project needs to be done in well defined phases. Phase 0 is learning of all existing and in-flight projects within the utility. Systems integration is essential to realizing benefits. The primary mission is still to keep the lights on. The data deluge must be managed. Knowledge capture is part of smart grid planning and results. The work is not all technical; there are strategy and change components for the employees.

To accommodate a more flexible, dynamic, secure, and diverse system, the smart grid is an essential component on the path to the energy future of 2030.

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