SMART GRID: THE FUTURE OF POWER SYSTEMS

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Abstract: The power systems has been the most indispensible part of the modern era as it governs the electric power which is a fundamental utility in society, therefore it is not a surprise that a nation's development is indicated by the amount of electric power it consumes. Power systems today face many challenges as the demand for electricity has sky rocketed in recent years. In this scenario making grids smarter becomes imperative and smart grids are employed to alleviate many of the challenges that the power systems are currently facing. In recent years the smart grid concept was used and misused in variety of reports, studies and news releases. This paper mainly addresses the fundamental concepts involved in smart grids in order to provide clarity this much researched technology and it briefly discusses some of its main applications.

1. INTRODUCTION

The term "Smart Grid" refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers including their thermostats, electric vehicles, appliances and other household devices. The Smart Grid will be characterized by a two-way flow of electricity and information to create an automated, widely distributed energy delivery network. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and to enable the near instantaneous balance of supply and demand at the device level.

The Smart Grid is not a new grid infrastructure. It is an integration of four essential building blocks in the existing power system. The building blocks consist of sensor systems, communication infrastructure, control units, and centralized management systems, where the centralized management systems represent the brains of the Smart Grid. These components are discussed in detail in following sections of this paper.

The Smart Grid refers to both the transmission grid and the distribution grid. The Smart Grid will require a combination of interoperable hardware and software components. Some of these components already exist, but there are enormous challenges to developing hardware, not to mention software, to incorporate the new Smart Grid elements with the existing grid infrastructure and control.

The Smart Grid term is widely used and misused. Because the term encompasses a wide range of issues, providing a concise, precise definition is not simple. Indeed, the utilities themselves find it challenging to understand what the smart grid is all about.

There have been a number of studies which have estimated some of the benefits of a Smart Grid. Each varies somewhat in their approach and the attributes of the Smart Grid they include. None provides a comprehensive and rigorous analysis of the possible benefits of a fully functional Smart Grid. The culmination of attention by utilities, regulators, and society for smart grid systems to address operational and electrical efficiencies, improving system reliability, and reducing ecological impacts, has resulted in a significant number of discussions around the applications of a Smart Grid. The later sections of the paper also provides a comprehensive review of the main application of the smart grids.

2. DEFINITION

As stated earlier the concept of smart grid is a recently emerged topic and therefore there is no precise definition for the term SMART GRID. But according to International Electro-technical Commission (IEC) and the European Technology Platform on smart grid, smart grid can be defined as

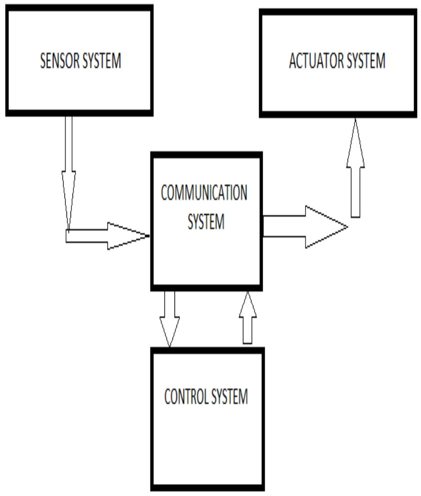
"A Smart Grid is an electric power network that utilizes two-way communication and control-technologies to cost efficiently integrate the behaviour and actions of all users connected to it – in order to ensure an economically efficient and sustainable power system with low losses and high levels of quality, security of supply and safety"

3. BUILDING BLOCKS OF SMART GRIDS

As stated earlier the smart grid includes the present infrastructures with some additional blocks namely, (a).sensor, (b).communication unit (c). control algorithm and (d) .control actuators to inculcate the following functions

1. A sensor system to measure the system state.
2. Communication infrastructure to transmit data/information back and forth.
3. Control algorithms that analyze information and generate control signals to alter the system state.
4. Actuators that effect the desired changes.

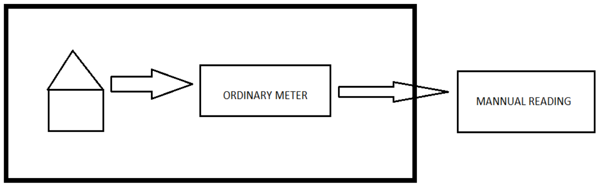
THE BELOW DIAGRAM DECPICTS THE FOUR ESSENTIAL BLOCKS OF ANY SMART TECHNOLOGY

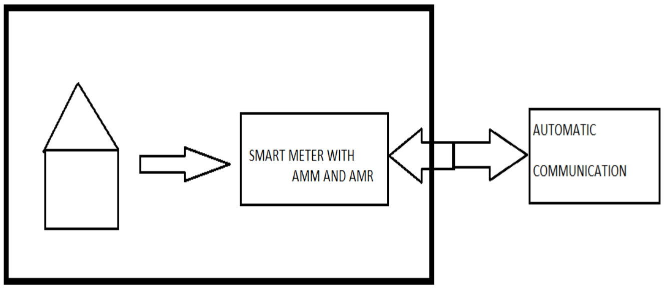


A).SENSOR :-

The smart meter is a combination of a sensor (that can measure and communicate electricity consumption in real-time), logic (that enables communication with the operator), and an actuator (that enables active control of consumer appliances). Real-time pricing of electricity consumption will provide customers with the incentive to load shift from peak to off-peak periods (demand response) and to promote energy efficiency measures. **Advanced Meter Reading (AMR)** identifies in detail, and often in real-time, the electricity consumption of a house, building, or entire company.

Advanced Meter Management (AMM) is the ability to receive control signals from the operator and to switch off local electric appliances. Smart meter will automatically will detect and report faults which will enable distribution grid operators to perform necessary remedial actions more quickly.





Smart Electric Vehicle Chargers will become a necessity when the quantity of electric vehicles (EVs) reaches a critical mass, due to the significant stress that charging can place on the power systems. Fast charging, in which high power is drawn in a relatively short time period, will be essential for mass commercialization of EVs. Managing this additional load on the system will necessitate smart devices that can determine which cars should be charged, by how much, and at what time, as based on the charging state of the car battery, user inputs, and the current system load state. The storage capacities of car batteries make them an attractive backup for the power system. Vehicle-to-grid (V2G) describes a system in which EVs communicate with the grid, either by delivering electricity back to the grid or by throttling their charging rate. Most EVs are parked for 95 % of the time and their batteries could let electricity flow from the car to the grid and back, which could be of significant value to the utility companies. However, increased charging and recharging can reduce the battery lifetime.

Phasor Measurement Units (PMU) or synchro-phasors1 measure the voltage amplitude and phase angle at network buses and current phasors in transmission lines and transformers. The state of the power system is defined as a collection of positive sequence voltage phasors at all network buses. The measurements are taken many times per second and have a precise time "stamp" to within a microsecond. Measurements from multiple geographical locations are synchronized to a common time reference using a Global Positioning Satellite (GPS) receiving clock. Many PMU's also provide other measurements, such as individual phase voltages and currents, harmonics, local frequency, and rate of change of frequency.

B). COMMUNICATION INFRASTRUCTURE:-

Communication technology will link together all the units and control logics of the Smart Grid. One aspect is two-way connection of consumers and distribution operators, while the supply of rapid, secure, wide-area communication for transmission operators is another.

Fiber optic communication transmits information by light passage through an optical fiber. Fiber optics ensures reliable, high speed communication and is important for dedicated high-speed broadband in the power industry. Wide Area Measurement Protection and Control Systems (WAMPACS) rely on fast communication, and is probably best achieved using fiber optics. Fiber optics is also increasingly installed in households and, in the future, will be used for communication between smart meters and the utilities.

Broadband over power lines (BPL) uses the existing power lines to transmit communication signals, such as broadband internet. It can also be used to network appliances within a building using in-house electricity wires. BPL is only suited to medium and low voltage power lines, and communication using BPL requires combination with another communication technology at higher voltage levels. BPL signals cannot pass transformers without a bridge, due to the electric design of the transformers. BPL is a good option in rural areas. However with the rate of fiber optic roll-out increasing, BPL will probably be most suitable for in-house use, networking appliances within a building and enabling measurement and switching commands from smart meters
.

GSM (Global System for Mobile Communications) is a well known and widespread technology that can also be used as a communication channel for the power grid. GSM is used to secure communications between operation centers and substations, enabling communication with the vast number of smart meters installed. However, since
GSM is a public network, security issues could be more critical. The advantages are low price and its widespread use globally.

C). CONTROL SYSTEMS:-

ENERGY MANAGEMENT SYSTEM (EMS) are systems of computer-aided tools used by power system operators to monitor, control, and optimize the performance of the power system, including generation, transmission & distribution (T&D), and consumption. Thus, the EMS represents the "brains" of the power grid.

Transmission Systems today employ SCADA systems as integral parts of EMS. SCADA performs the monitoring and control functions in EMS. SCADA systems are highly distributed. A SCADA control centre performs centralized monitoring and control, based on information received from remote stations. Automated or operator-driven supervisory control commands can then be sent to remote station control devices that can control local operations. Problems with SCADA include slow refresh rate, latency, and skew (see Table 1), resulting in lower accuracy and "visibility" of the power system state.

Traditional EMS applications are model-based, and thus the results are only as good as the accuracy of the model. Measurement-based applications do not suffer from this. The introduction of synchronized WAMPACS has already begun in several countries, including U.S., central-western Europe and the Nordic countries, China, and Russia . WAMPACS analyze the data transmitted from PMU's deployed over a large portion of the power system substations and transmission lines. Data from multiple locations are synchronized to a common time reference using GPS.

Important uses of WAMPACS include state estimation and advanced real-time visualization of power systems, real time congestion management, stability enhancement, improved damping of inter-area oscillations, the design of advanced warning systems and adaptive protection systems, validation of system models, and analyses of the causes of blackouts.

D). ACTUATORS:-

A number of actuators in the existing grid will also be part of the Smart Grid concept, including, among others, switches and circuit breakers. Here, focus will be on the new elements, including smart meters, new Flexible AC Transmission System (FACTS) devices, and energy storage units. Smart meters and Smart EV chargers act as both sensor and control equipment, and have been described earlier in this paper.

The power flow in power systems follows the laws of physics. Previously, power flow control was mainly based on mechanical devices, such as transformer tap changers and turbine governors, which have limited flexibility and speed of control. FACTS devices are high power electronic devices that can perform control at a very high speed. Some are connected in shunt to the grid to provide reactive power and voltage control, while others are connected in series to provide control of power flow.

FACTS devices provide the system operator with a measure of freedom in operating the system. FACTS devices have already been installed in many parts of the world. A Smart Grid will improve control and increase the benefits from using existing and new FACTS devices. There are many different FACTS devices, of which the five most common are listed below. All these are based on controllable semiconductors

- STATIC VAR COMPENSATOR
- STATIC SYNCHRONOUS COMPENSATOR
- THYRISTOR CONTROLLED SERIES CAPACITOR
- STATIC SYNCHRONOUS SERIES COMPENSATOR
- UNIFIED POWER FLOW CONTROLLER

Distributed Energy Storage will play a vital role in future power systems. Strategically located energy storage plants could serve various purposes, including:

- Defer upgrades of line and substation / distribution transformer using peak load shaving
- Balance consumption and protection of electricity
- Provide islanding capabilities during grid faults by supplying power to important loads

Batteries have been installed at many distribution substations, particularly in Japan, but also in U.S. Most of these installations are sodium-sulphur (NaS) and lead-acid batteries. Typical power capacity is in the range of a few MW, with several hours of discharge capacity. Very recently, lithium-ion technology has also been considered and is currently being installed at several locations, including a distribution substation in Norfolk, UK and a power plant in Southern California, U.S. Several of the battery facilities interface with the power system through voltage source converters (VSCs). This enables simultaneous voltage control and control of active power balance in the grid, which is an additional advantage to current FACTS technology that primarily focuses on stabilizing grid voltage. Smaller battery facilities can be installed at low voltage level closer to the customers. An important driver is the expected drop in costs of small battery systems due to development progress and mass-production of electric car batteries.

4. APPLICATIONS

The main applications or objectives of a smart grid can be categorized into following three categories

- Delivery optimization
- Demand optimization
- Asset optimization

Delivery Optimization consists of the efforts by the electric utility to improve the efficiency and reliability of the delivery systems.

Demand Optimization focuses on solutions to empower the end consumer and to better manage the evolving demand and supply equation along the distribution feeder.

Asset Optimization is the application of monitoring and diagnostic technologies to help manage the health, extend the useful life and to reduce the risk of catastrophic failure of electrical infrastructure.

A). DELIVERY OPTIMIZTION:-

Delivery Optimization includes two major areas which will be reviewed separately, Efficiency and Reliability. Utilities have deployed methods to improve the efficiency of their electrical systems. There are certain benefits in delivery optimization

The benefits typically include:

- Improved distribution system efficiency
- Reduced distribution line losses
- Improved voltage profile along feeder
- Improved system stability and capacity
- Defered capital upgrades
- Reduced energy demand
- Reduction of environmentally harmful emissions

B). DEMAND OPTIMIZATION

In recent years, Demand Optimization has generated a significant amount of interest. Often the benefits from Demand Optimization is what is in mind when regulators installation of smart metering. These are the benefits most directly experienced by the end consumer.

Empowering Customer Choice & Control:

• Critical Peak Pricing
• Time of Use Rate
• Green Power Choices
• CO2 Management Choices
• Prepaid Metering
• Voluntary or Automatic Control of Energy Demand
• Usage Management – by Appliance
• Home Energy Management
• Net Metering, collecting KWH, KVARH, Voltage,
• Power Quality

Providing Security & Safety Management:

• Energy Theft
• Tamper Detection
• Visual inspection during installation
• Monitoring and base lining usage patterns
• Interruptions and usage pattern changes
• Detect load-side voltage with disconnect

Enabling Distributed Generation:

• Photo Voltaic (Solar)
• Wind
• Biomass
• Geothermal

Incorporating Distributed Storage:

• Li-Ion Battery
• Fuel Cells
• Plug in Hybrid Electric Vehicle (PHEV as a storage device)

C). ASSET OPTIMIZATION:-

Much of the modern electrical system was installed over 40 years ago. Unfortunately, many devices in the system are frequently being pushed to operate at overload conditions. One of the single most expensive pieces of the distribution system is the station power transformer. Given that the general life expectancy of power transformers is around 40 years; this can result in a risky and expensive challenge. Asset optimization is incorporated in smart grid by monitoring and diagnostics on the primary station transformer, station breaker, and distribution.

The monitoring and diagnostics of the station transformer can include simply monitoring temperatures or continuous monitoring of the oil for combustible gasses and moisture. Advanced monitoring today can calculate internal hot spot temperature, the transformer dynamic load ability and future capacity over time, the insulation aging factors and data from many other models. Monitoring of the station or line protection relays provides valuable information regarding the health of the breaker including operatingtimes, total interrupted fault current, and operation counts. Data collected from the meters can help determine near realtime loading on the distribution cables, especially the underground cables, and loading on the local distribution transformers. This can help distribution engineers improve the distribution planning and design and help rebalance the load along the phases.

5. CONCLUSION

In this paper the fundamental building blocks of the smart grid technology is analyzed and explained comprehensively. As the magnitude of research regarding this recent trend in power system it is imperative to understand these basic concepts and application in a clear cut manner. Basically the concepts are explained by employing the fundamental block involved in smart grids and its applications were explained with the major principle objectives expected from a smart grid.

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