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Smart Grid Technology: The Future of Intelligent Power Management

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Abstract

Abstract-The existing Power Grids are antiquated, congested and inefficient in many ways and it does not take full advantage of new automation technologies that for example can prevent an outage or restore power much faster after an outage. It does not take advantage of new materials which can make the equipment throughout the grid more efficient. This technology proposes a method for better implementation of smart grids that integrates technologies of advanced sensing, control methodologies and communication capabilities into the current power grids at both the transmission level and distribution levels.

In principle, the smart grid is an upgrade of the common electricity grids. This upgrade is expressed in the ability to operate in conditions of uncertainty in order to route the power supply in an optimal way that responds to a wide variety of situations, to encourage users in off-peak hours and charge premium rates from consumers who use energy during peak hours. The key to this capability is fast, accurate and two-way transmission of information between all parts of the grid. Situations that require fast response can occur at all parts of the grid – at the chain of production, transmission and consumption. The source of the event could be in the environment (sudden cloudiness that decreases solar power, or a very hot day that increases the demand for air conditioning), in parts of the grid itself (sudden failures, the need for proactive maintenance) or in the demand (work hours compared to hours of rest).

The smart grid is the integration of electrical and digital, information and communication which facilitates integration of business processes and systems to yield real measureable value across the power delivery chain .it is an intelligent future electricity system that connect all supply, grid and demand elements through a communication system .Smart grid delivers electricity to consumers using two way digital technology that enable the efficient management of consumers, efficient use of the grid to identify and correct supply –demand imbalances ,Smart grid solutions enables utilities to increase energy productivity and power reliability while allowing the consumers to manage the usage and cost through real time information exchange. It impacts all the components of the power system like generation, transmission and distribution.

Index Terms:*Automation, electricity grid, smart grid, solar power.*

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1. INTRODUCTION

In the present era, due to increased power demand to meet the industrial requirements, the shortfalls in power generation have been attempted to mitigate between supply and demand through developments of National Grid connected systems where all the national power generation sources are connected to National grid and on the basis of the zonal requirement, the energy management is implemented.

With this concept, the issue related to power outage has been reduced to some extent and is able to control the transmission losses and improve the transmission efficiency to some extent. This leads to 60% efficient for grids based on the latest technology which may be the solution for the above mentioned problem: SMART GRID TECHNOLOGIES.

To implement systematically the energy requirement for different zones, it necessarily requires a strategic program of distribution of energy. SCADA and other continuously monitoring systems though in trend but for quick effective and efficient distribution of energy needs, a smart system which can take into account the requirements of the zones and the availability of energy from the different sources in the zones is required without human interference. Smart grids increase the connectivity, automation and co-ordination between these suppliers, consumers and networks that perform either long distance transmission or local distribution tasks.

A smart grid is a term that covers modernization of both the transmission and distribution grids. The concept of a smart grid is that of a "digital upgrade" of distribution and long distance transmission grids both to optimize current operations by reducing the losses, as well as open up new markets for alternative energy production.

Some of the benefits of such a modernized electricity network include the ability to reduce power consumption at the consumer side during peak hours, called Demand side management; enabling grid connection of distributed generation power (with photovoltaic arrays, small wind turbines, micro hydro, or even combined heat power generators in buildings); incorporating grid energy storage for distributed generation load balancing; and eliminating failures such as widespread power grid cascading failures.

1.1.SMART GRID:-

The smart grid is an advancement of the present electrical grid system. Smart grids establish a two way communication between the utility and the consumer efficiently.

This system enables new technologies to be integrated such as wind, solar etc. energy production. This grid helps us to manage the ever changing electricity needs.

In the smart grid system, utility centers are interconnected.

1.2.DEFINITION:-

A smart grid or smart electric grid or smart power grid or intelligrid or future grid is defined as a modernized electrical grid which sets up an automated two way communication between end user and utility to deliver power efficiently using information and communication technology.

1.3. AIMS OF SMART GRID:-

- To meet the increasing global demand for electricity by providing sufficient capacity.
- It makes the grid reliable, flexible, efficiency and sustainability of power.
- Reducing Power Theft.
- Higher Quality.
- Fewer Blackouts.
- To manage, monitor and respond to the energy problems.

1.4. OBJECTIVES:-

- To have enough computer intelligence to control the grid better and make it more autonomous and self-healing.
- To make the use of existing power infrastructure more efficiently.
- To include the capabilities of monitoring, analysis, control and communication in the national electrical delivery system to improve the output of the system while decreasing the consumption of energy.
- Better situational awareness and operator assistance.
- Autonomous control actions to enhance reliability.
- Efficiency enhancement by maximizing asset utilization.

1.5. NEEDS OF SMART GRID:-

- The electrical grid is becoming more fragile.
- Appliances are getting more sensitive to electrical variations.
- To increase reliability and efficiency.
- Conventional electrical grids are inefficient networks highly prone to power failures.
- It has become stressed grid structure.
- Energy demand is increasing at a faster rate than energy supply.
- Customer’s expectations are becoming more aware.
- Customers expect to receive information to help them manage their energy usages.
- Green house gas emission is increasing due to increase in energy consumption.
- Reduce carbon foot prints.
- Improve distribution management and decision support software self healing where automated control for distribution.

1.6. ROLE OF SMART GRID:-

Existing grids were designed to deliver electricity to the consumers and bill them once a month. The energy demands have been rising and it has become difficult for the existing grids to cope up with it. Smart Grids introduces a two-way communication where electricity and information can be exchanged between the customers and utilities. Smart Grids integrates advanced new technologies, Smart meters and there is a provision for data monitoring and control. It also integrates renewable energy such as the wind and solar energy to the grids. Besides that, the consumers can manage their electricity usage by measuring the electricity consumption through the Smart meters installed at their homes. Smart appliances can be designed which would adjust their run schedules to reduce electricity demand on the grid at critical times and lower the energy bills. Electricity is more costly during peak times because additional and often less efficient power plants must be run to meet the higher demand. Smart grids will enable utilities to manage and moderate electricity usage with the co-operation of their customers.

1.7. CHARACTERISTICS OF SMART GRID:-

The Electric Power Research Institute (EPRI), the U. S. National Technology Laboratory and the Smart Grids European Technology platform have defined seven principal characteristics of a smart grid. To full-fill the objective of electrical power sector, the Smart Grid has the great characteristics as follows.

- **Self-healing:-**A grid, which is able to rapidly detect, analyze, respond and restore from perturbations.
- **Empower and Incorporate the consumer:-**The ability to incorporate consumer equipment and behaviour in the design and operation of the grid.
- **Tolerant of Attack:-**A grid that mitigates and stands resilient to physical and cyber security attacks.
- **Provides power quality needed by 21st century users:-**A grid that provides a quality of power consistent with consumer and industry needs.

- **Fully enables maturing electricity markets:-** Provides competitive markets for those who want them.
- **Optimizes assets:-** A grid that uses IT and monitoring to continuously optimize its capital assets while minimizing operations and maintenance costs.
- **Clean and Green:-** With the large-scale of renewable energy sources, Smart Grid can reduce the potential impact on the environment e.g., carbon emission reduction, more green energy.

1.8. FEATURES OF SMART GRID:-

- Significantly reduces the environmental impact of the whole electricity supply system.
- Enhances the reliability and the security levels.
- Provides the end user for choice of supply.
- Bi-directional energy flow.
- The load supported by smart grids will vary periodically depending upon the necessity of the end user.
- Peak curtailment.

Way for the usage of renewable resources.

2. SMART GRID COMPONENTS

The Smart Grid consist the various component. All components are inter-related and inter-linked too. All components must be integrated to enhancement the reliability, more efficiency and security as shown in fig. They are-

- Smart meter
- Phasor measurement unit (PMU)
- Information transfer
- Distribution generation

They are explained below.

2.1. Smart Meter:-

Figure 1:-Smart Meter

Smart meters are advanced meters that identify energy consumption in more detail than a conventional meter which is shown in the fig.1. The technology used is far more advanced. They have the ability to communicate information via a second network back and forth between your homes. Smart meters are foundation for updating existing electrical systeminto smart grid because they have two way communications between utility and user that is it receives information from utility and also transmits energy usage information to utility.

2.1.1.Tasks carried out by smart meter-

- Data collection
- Communications
- Data analysis
- Decision support

2.1.2. Smart meters are safe and secure:-

Smart meters have been thoroughly tested for safety and reliability. They have undergone extensive tests by utilities in USA. Smart meters operate at a level that is much lower (1.4%) than the maximum permissible exposure limits for radio frequency.

2.2. Phasor Measurement Units:-

A phasor measurement unit (PMU) or synchrophasor is a device which measures the electrical waves on an electricity grid, using a common time source for synchronization. Time synchronization allows synchronized real-time measurements of multiple remote measurement points on the grid. High speed sensors called PMUs distributed throughout a transmission network can be used to monitor the state of the electric system. Phasor are representations of the magnitude and phase of alternating voltage at a point in the network. Using a PMU, it is simple to detect abnormal waveform shapes.

2.2.1. Benefits of PMU:-

- Using a PMU, it is simple to detect abnormal waveform shapes.
- Time synchronized sub-second data.
- Dynamic behavior observing.
- High data rates and low latency due to computation.

2.3. Information Transfer:-

Information transfer technology is needed to extend the two way communication feature into home application. It is just the process of moving messages containing information from a source to a sink. Protocols such as WI-FI, Zig-Bee, Bluetooth and infrared are most popular. In smart grid system it is encouraged for all these technologies to be compatible with one another.

Zig-Bee uses very low energy and goes to sleep mode when not in use. Zig-Bee devices are often used in a mesh topology to be able to transmit data for over long distance. Information is passed through the other Zig-Bee devices in order to reach more distant ones. It is targeted at applications that require low data rate, long battery life and secure networking. This technology is intended to be simpler and less expensive than WI-FI or Bluetooth.

2.4. DISTRIBUTION GENERATION:-

Distribution Automation (DA) system is defined as “a system that enables an electric utility to remotely monitor, coordinate and operate distribution components, in a real time mode from remote locations”

Distributed generation refers to the use of small scale power generation technologies located closer to the consumer, capable of reducing cost, increasing reliability, diminishing emissions and expanding energy options. Generation will be closer to the load, which reduces transmission line construction cost and transmission power losses thus improving efficiency.

Supply and demand is one of the basic concepts of all industries. It is the one with which the current grid struggles a lot, as the moment electricity is being generated, it has to be consumed. It is imperative to have the "right" supply available to deal with every contingency at any time problem may arises when amount of electricity generated does not meet the required demand during peak demand period.

Therefore, in order to meet the required demand, without knowing when will the peak demand be, grid operators brings in generation assets called peaker plants to ensure that the required demand is met. Peaker plants are very costly and need more fuels to operate. Distributed generation will help utilities to decrease the amount of electricity produced. This renewable electric generation can provide the same surplus of electricity that peaker plants do. It therefore, will reduce the cost for utilities to meet peak demand.

3. WORKING OF A SMART GRID

In the conventional grid system grid system, conservation of energy is possible only to a certain extent. The difficulty in communication and the energy losses, we can adopt to an improvised electrical grid system known as smart grid. This type of grid system supports a two way communication between the utility and the end user. As shown in the fig.2

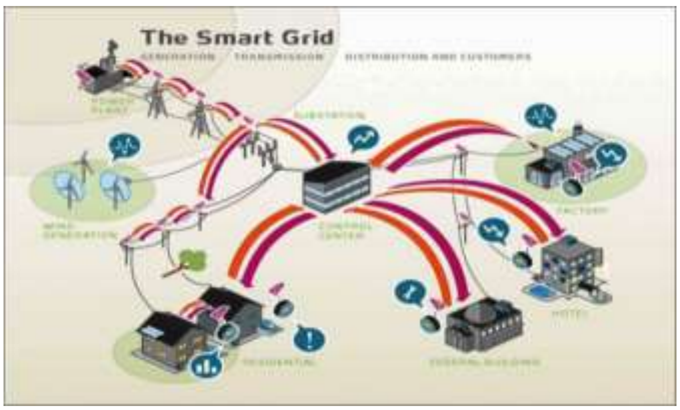

Figure 2:-Working of smart grid

The working of a smart grid can be divided into four steps:

- Generation
- Transmission
- Distribution
- End user

3.1. Generation:-

Presently, thermal, hydro and nuclear power provides maximum contribution to the energy being produced in India. Smart grid technology gives an opportunity to use both renewable and non renewable resources as well as usage of stored energy.

3.2. Transmission:-

Electric transmission systems carries large amount of power at high voltages from generators to substations. Transmission systems must be kept highly reliable to prevent blackouts and ensure robust energy markets. Synchrophasor technology has emerged as key enabler for improving transmission reliability and operations. Phasor measurement units (PMUs), Phasor data concentrators (PDCs), wide area communication networks, and advanced transmission applications are building blocks of a smarter and more reliable transmission system.

The transmission of electrical energy from utility to the transformers uses optical fiber technology and high voltage direct current (HVDC) which thus lowers electrical losses and is less expensive.

3.3. Distribution:-

The distribution system routes power from the utility to residence through power lines, switches and transformers. Utilities typically depends on complex power distribution schemes and manual switching to keep power flowing to the consumer.

A key component of distribution intelligence is outage detection and response. Along with smart meters, distribution intelligence will help to quickly identify the source of a power outage so that technicians can be immediately dispatched to the problem area. The smart grid distribution intelligence counters these energy fluctuations by automatically identifying problems, then rerouting and restoring power delivery.

Outage response is one aspect of distribution intelligence that is commonly referred to as distribution automation (DA).

3.4. End User:-

End-users can be homes, commercial centers, buildings etc. These are connected to the smart grid via the smart meter. The smart meters control and manage the flow of electricity to and from the customer and also provide information regarding the usage of power. Each customer has a separate domain comprised of electricity premise and bidirectional communication networks. Customer may as well generate, store and feed electricity back into the smart grid.

4. COMPARISION BETWEEN CONVENTIONAL GRID AND SMART GRID

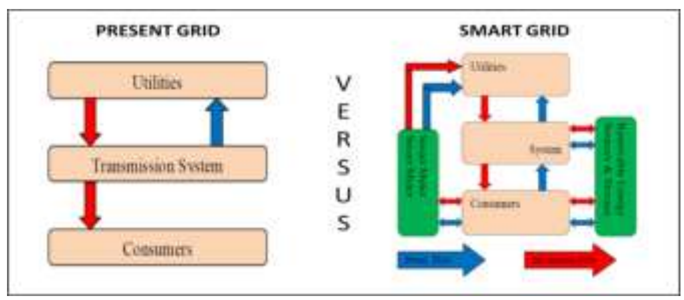

Figure 3:-Present Grid Vs Smart Grid

	CONVENTIONAL GRID	SMART GRID
1	Electromechanical	Digital
2	One way communication	Two way communication
3	Centralized generation	Distributed generation
4	Few sensors	Sensors throughout
5	Manual monitoring	Self monitoring
6	Manual restoration	Self healing
7	Limited control	Pervasive control
8	Monopoly	Oligopoly

Table-1:Comparison between conventional grid and smart grid

5. TECHNOLOGIES IMPLEMENTED IN SMART GRID

The present electric grid does not take the fully benefit of advance censors, communication systems and computational abilities to enhance the service and reduce cost. For such reason various new technologies implemented in the smart grid to overcome the disabilities of current grid which are as follows-

5.1. Advanced Distribution Automation:-

ADA provides continuous monitoring and automatic control of key distribution system assets, along with the integration of distribution supervisory control and data acquisition (SCADA) systems. Advanced distribution automation (ADA) includes intelligent sensors that gather and process information from various strategically important feeder locations, advanced electronic controls, and two-way communication systems to optimize system performance. The ADA system collects and reports data on voltage levels, current demand, MVA levels, VAR flow, equipment state, operational state, event logs, and other important information about the state of the electric distribution system, allowing operators to remotely control capacitor banks, breakers, and voltage regulators in an optimal manner. Substation automation, when combined with automated switches, reclosers, capacitors, and advanced metering, will enable full smart grid functionality.

5.2. Intelligent Feeder Head-End Reclosers and Relays:-

Replacing electromechanical protection and control systems with microprocessor-based, intelligent relays and reclosers is an integral part of the electric utility's smart grid strategy. Approximately 70% of all feeders will include intelligent reclosers and relays. The advantages of using intelligent electronic devices (IEDs) at the head end of the feeder instead of conventional electromechanical relays and controls include the following:

- It enables continuous monitoring and analysis of measurements (current, voltage, etc.) for the associated power apparatus and the ability to process these measurements locally to compute other useful parameters such as distance to fault.
- It provides the ability to transmit any parameter that is measured or computed by the IED to external systems and users via industry standards–based communication facilities.
- It offers self-diagnostic capabilities that enable IEDs to detect many types of internal failures and automatically inform the distribution system operator or other person in charge so that corrective action can be taken before a device is called on to operate for a power system fault (and fails to operate correctly).

5.3. Distribution Fault Anticipators:-

Distribution fault anticipation (DFA) technology is demonstrating ground-breaking advances in the use of sensitive monitoring to detect minute electrical precursors that signal an impending failure of line apparatus. Many failures and incipient failures have been documented using advanced instrumentation on numerous feeders across North America. Current efforts are taking advantage of the installed equipment to expand the library of signatures while concurrently studying requirements and constraints for integrating the technology into systems for practical use.DFA technology can benefit a wide spectrum of utility engineering and operating personnel. By detecting precursors to failures, it gives utilities tools to achieve greater awareness about the health of their systems and to take primitive action to avoid outages. New signatures continue to be added to the library of documented failures, with three previously undocumented failure signatures added as a direct result of the most recent efforts. Early results demonstrated the proof of this concept and collected data from operating feeders by capturing, documenting, and characterizing signatures indicative of failures and incipient failures. This entailed the instrumentation of 60 feeders at 14 substations of 11 utility companies across North America and resulted in the collection of a massive amount of operational feeder data and numerous signatures associated with various stages of apparatus failure. Researchers then developed algorithms to characterize the collected data and demonstrated the ability to use the data to diagnose many faults and fault precursors.

5.4. Advanced Metering Infrastructure:-

An advanced metering infrastructure (AMI) involves two way communications with smart meters, customer and operational databases, and various EMSs. AMI, along with new rate designs, promises to provide consumers with the ability to use electricity more efficiently and to individualize service. AMI will also enable utilities to operate the electricity system more robustly.

5.5. Distribution Voltage and VAR Control:-

Voltage and var control is not a new concept. In fact, all electric distribution systems require some form of voltage and var control, the objectives being to maintain acceptable voltage at all points along the feeder and to maintain a high power factor. Recent efforts by distribution utilities to improve efficiency, reduce demand, and achieve better asset utilization have underlined the importance of voltage/var control and optimization in the overall smart grid strategy. From a technology standpoint, voltage/var control and optimization have a significant advantage over other smart grid initiatives because in many cases it is possible to leverage existing facilities, such as voltage regulators and switched capacitors that already exist on many distribution feeders. Smart grid software will be able to combine information flowing from the automated substations with SCADA data points throughout the distribution system to analyze and recommend reconfiguration of the distribution system for optimum performance.

5.6.Fault location, isolation, and service restoration system(FLISRS):-

Fault location, isolation, and service restoration (FLISR) includes automatic sectionalizing and restoration, and automatic circuit reconfiguration. These applications

accomplish DA operations by coordinating operation of field devices, software, and dedicated communication networks to automatically determine the location of a fault, and rapidly reconfigure the flow of electricity so that some or all of the customers can avoid experiencing outages. Because FLISR operations rely on rerouting power, they typically require feeder configurations that contain multiple paths to single or multiple other substations. This creates redundancies in power supply for customers located downstream or upstream of a downed power line, fault, or other grid disturbance.
For Example:-

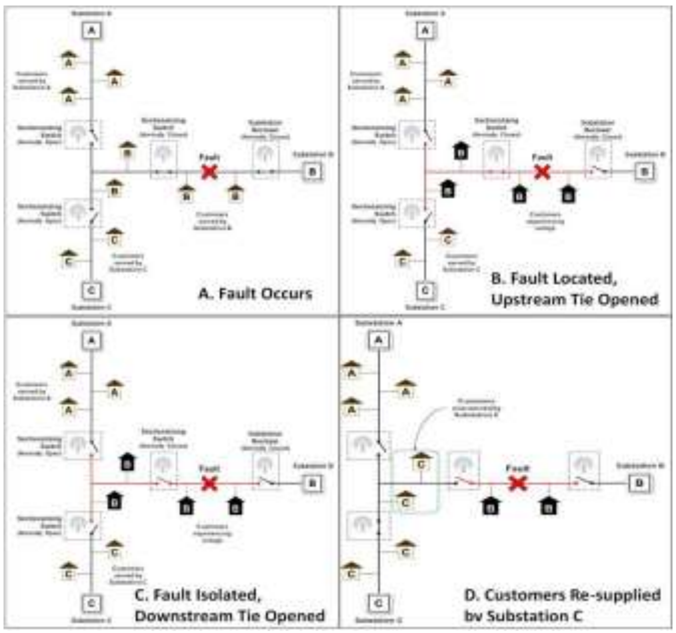

Figure 4:- Schematics illustrating FLISR Operations.

Fig.4 presents simplified examples (A-D) to show how FLISR operations typically work. In (Fig. A), the FLISR system locates the fault, typically using line sensors that monitor the flow of electricity and measures the magnitudes of fault currents, and communicates conditions to other devices and grid operators.

Once located, FLISR opens switches on both sides of the fault: one immediately upstream and closer to the source of power supply (Fig. B), and one downstream and further away (Fig. C). The fault is now successfully isolated from the rest of the feeder.

With the faulted portion of the feeder isolated, FLISR next closes the normally-open tie switches to neighboring feeder(s). This re-energizes un-faulted portion(s) of the feeder and restores services to all customers served by these un-faulted feeder sections from another substation/feeder (Fig. D). The fault isolation feature of the technology can help crews locate the trouble spots more quickly, resulting in shorter outage durations for the customers impacted by the faulted section.

6. ADVANTAGES

According to the report from NIST (National Institute of Standards and Technology), the anticipated benefits of Smart Grid are as follows:

- Improving power reliability and quality.
- Optimizing facility utilization and avoiding construction of back-up (peak load) power plants.
- Enhancing capacity and efficiency of existing electric power networks.
- Improving resilience to disruption.
- Enabling predictive maintenance and self-healing responses to system disturbances.
- Facilitating expanded deployment and integration of renewable energy Sources.
- Accommodating distributed power sources.
- Automating maintenance and operation.
- Reducing greenhouse carbon emissions by enabling electric vehicles and new power sources.
- Reducing oil consumption by reducing the need for inefficient generation during peak usage periods.
- Increased opportunities to improve grid security.
- Enabling transition to plug-in electric vehicles and new energy storage options.
- Increasing consumer choice.
- Enabling new products, services, and markets.

7. DISADVANTAGES

- Biggest concern: it has security and privacy.
- Two-way communication between power consumer and provider and sensors so it is costly.
- Some type of meter can hacked.
- Hacker gain control of thousand even millions, of meters.
- Not simply a single component, various technology components are used are software, system integrators, the power generators.

8. APPLICATIONS

Smart grid has wide range of applications which are as follows:

- **Plug-in electric vehicles:-**
  Plug-in electric vehicles (PEVs) are now being rolled out to consumers throughout the United States. The Smart Grid will have the infrastructure needed to enable the efficient use of this new generation of PEVs. PEVs can drastically reduce our dependence on oil, and they emit no air pollutants when running in all-electric modes.
- **The Smart Home:-**
  It is the computerized control in your home and the appliances can be set up to respond to signals from your energy provider to minimize their energy use at times when the power grid is under stress from high demand, or even to shift some of their power use to times when power is available at a lower cost.
- **Smart Appliances:-**
  Smart appliances will be able to respond to signals from your energy provider to avoid using energy during times of peak demand. This is more complicated than a

simple on and off switch. For instance, a smart air conditioner might extend its cycle time slightly to reduce its load on the grid; while not noticeable to you, millions of air conditioners acting the same way could significantly reduce the load on the power grid during off-peak hours.

- **Home Power Generation:-**
  As consumers move toward home energy generation systems, the interactive capacity of the Smart Grid will become more and more important. Rooftop solar electric systems and small wind turbines are now widely available, and people in rural areas may even consider installing a smart hydropower system on a nearby stream. Companies are also starting to roll out home fuel cell systems, which produce heat and power from natural gas.

9. CONCLUSION

- Smart Grid is a concept designed to provide electricity in more efficient way by better allocating electricity according to consumer's need.
- It integrates multiple energy sources and avoid over-generation as well.
- In foreign countries, namely the UK and USA, started to implement as they see it as a solution of energy and environment pressure in their own country.

Also implementation of smart grid will basically change the way of power utilization.

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