

Smart Grid System & its Salient Features

By

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ABSTRACT

The nature of contemporary buildings is rapidly evolving. In the past, buildings primarily served as places for people to live, work, and learn. They must now be intelligent. Dynamic assets, smart buildings reduce energy costs, increase occupant comfort, and communicate issues. Along with interacting with external components, smart buildings are also expected to work with electrical grids, environmental conditions, and their organizations' missions. The current wave of innovation in technology has quickened the evolution of building operations, making smart buildings even smarter.

1. Introduction

1.1. What is the smart grid?

A smart grid is a modern electricity infrastructure that incorporates digital technologies, communication systems, and automation to efficiently manage the flow of electricity. By integrating advanced metering infrastructure, distribution automation, demand response, energy storage, and renewable energy sources, smart grids can optimize energy consumption, reduce waste, and lower overall costs for both utilities and customers. Smart grids can also improve the reliability of the energy system, reduce greenhouse gas emissions, and give customers more control over their energy consumption (Ibrahim Alotaibi, 2020). The complexity of the smart grid involves multiple technologies, including sensors, meters, communication networks, and advanced control systems, allowing for real-time monitoring and control of the grid. This enables reduced energy waste, improved reliability, and enhanced security.

Moreover, the smart grid enables utilities to optimize resource use and reduce reliance on traditional power plants by integrating and coordinating a wide range of energy resources, such as distributed energy resources like rooftop solar panels and electric vehicles. The smart grid also brings significant economic advantages, including reduced energy costs and increased energy efficiency. By providing accurate and timely information about energy usage, the smart grid allows utilities to better manage their resources and reduce waste. Consumers can also track their energy usage in real-time and make adjustments to lower their energy bills. Overall, the smart grid represents a critical infrastructure upgrade that promotes a more sustainable and resilient energy system.

One of the key features of smart grids is their ability to enable two-way communication between utilities and customers, making the grid "smart" by sensing energy usage along transmission lines and from the customer's side. This feature, combined with the integration of IT technology, creates an exceptional opportunity for supporting the development of smart zero energy buildings and communities and offers a step towards the Internet of Things for the Energy and Building Industry (Jian Wang, 2020). The role of buildings in this framework is crucial, as the hierarchical, centrally controlled grid of the 20th Century is not well-suited to the needs of the 21st Century. The smart grid, on the other hand, can be considered a modern electric power grid infrastructure for enhanced efficiency and

reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy, and network availability. This paper addresses critical issues on smart grid technologies and the integration of buildings in this new power grid framework.

1.2. Smart grid systems

Smart grids are a critical component of the modern electricity system, utilizing advanced data and communication technologies to improve the efficiency, reliability, and sustainability of power generation, distribution, and consumption. One of the key features of smart grids is the use of keen lattices, which facilitate the balanced and intelligent exchange of energy between providers and consumers. By integrating technologies such as distributed microprocessor systems, renewable energy sources, and power storage units, smart grids can improve the flexibility and reliability of energy systems, while also minimizing the negative impacts of power outages. Additionally, the use of real-time data analysis and two-way communication enables faster recovery of power services in the event of an outage, preventing potential cascading failures that could impact critical infrastructure and public safety. Ultimately, smart grids represent a significant step forward in the evolution of the energy system, offering a more intelligent, efficient, and sustainable approach to power generation and distribution.

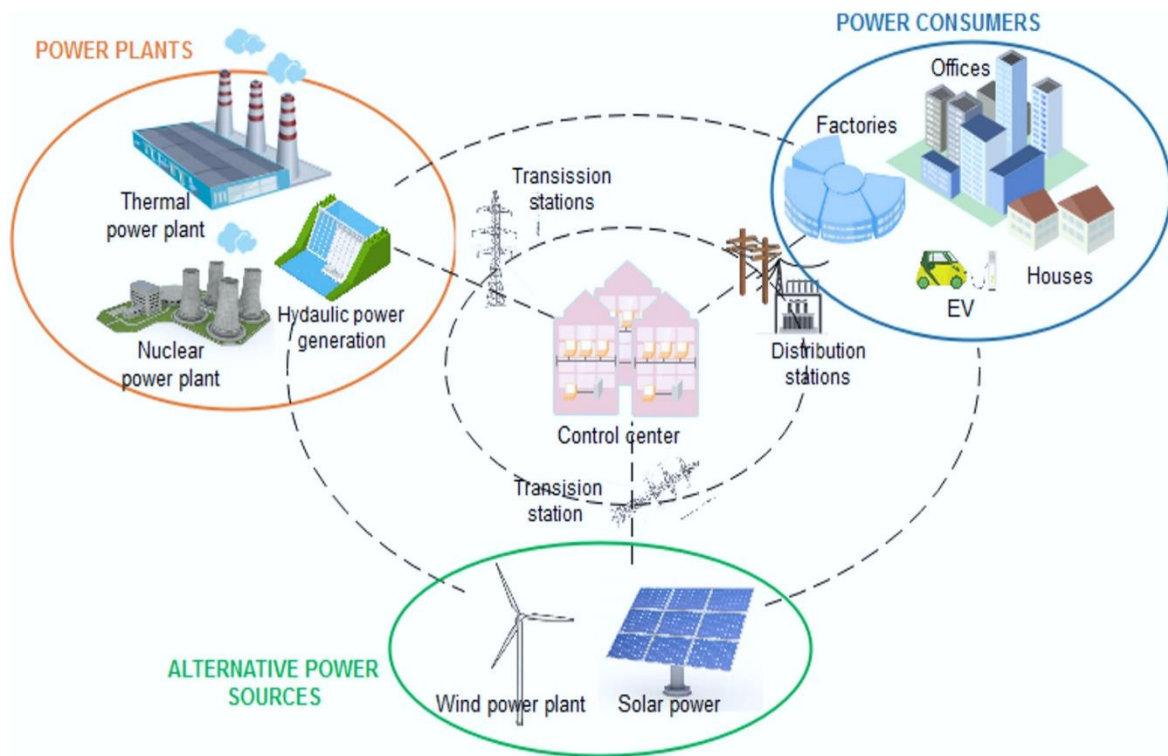


Figure 1concept of the smart grid

Smart grids are revolutionizing the way we generate, distribute, and consume energy. One of the key advantages of smart grid technology is the real-time, two-way communication that enables faster recovery of power services after a power outage. This is critical in preventing cascading failures that can negatively impact banking, communication, manufacturing, transportation, and security. To achieve this, smart grids use digital sensors, intelligent metering methods, and sophisticated control systems equipped with analytical tools to automate, control, and monitor the bi-directional flow of power. However, this advanced technology also presents new security challenges, as smart meters become attractive targets for cyber-attacks. Information intelligence attacks can compromise the accuracy of the system and inject incorrect data into calculations. This presents a significant challenge for load forecasting models and the broader energy community. To address this, the smart grid employs numerous distributed plants instead of relying on one large plant, limiting the risk of a catastrophic failure. Additionally, the use of smart switches and a self-regenerating system ensures that power is quickly restored in the event of an outage. Overall, the smart grid represents a significant step forward in the evolution of the energy system, offering a more efficient, sustainable, and secure approach to power generation and distribution.

2.Literature review

2.1. how smart grid systems work in buildings

Smart grid systems use a combination of hardware and software technologies to monitor and control energy usage in buildings. These systems typically include sensors and meters that collect real-time data on energy consumption, as well as control systems that can automatically adjust energy usage based on this data.

In a building with a smart grid system, energy consumption data is collected by sensors and meters installed throughout the building. This data is then sent to a central control system, which uses software algorithms to analyze the data and make decisions about how to adjust energy usage.

For example, if a building is experiencing high demand for energy, the smart grid system can automatically adjust the heating and cooling systems to reduce energy usage. Or, if renewable energy sources such as solar panels or wind turbines are available, the system can automatically switch to these sources to reduce reliance on fossil fuels.

Smart grid systems can also enable demand response programs, which encourage building occupants to reduce energy usage during times of peak demand. In a demand response program, building occupants are notified of a peak demand event and encouraged to reduce energy usage by turning off non-essential appliances or adjusting their thermostat settings. This helps to reduce strain on the energy grid and avoid the need for power outages.

2.2 Features of the Smart Grid

The smart grid speaks to the complete suite of current and proposed reactions to the challenges of power supply. Since of the differing run of variables there are various competing scientific classifications and no understanding on a widespread definition. In any case, one conceivable categorization is given here.

2.2.1. Reliability: One of the primary characteristics of a smart grid is reliability. A smart grid is designed to be more reliable than traditional power grids by utilizing advanced technologies, such as sensors, automation, and real-time monitoring. These technologies allow for quicker detection and isolation of issues, such as power outages or equipment failures, minimizing the impact on the overall system (Eenergy, 2008).

In traditional power grids, utilities may not be aware of an outage until a customer reports it. In contrast, a smart grid can detect issues as they occur, enabling utilities to quickly respond and restore power. Furthermore, the smart grid can identify issues in the grid that may lead to future outages, allowing utilities to proactively address these issues before they

cause further problems. Overall, the reliability of a smart grid helps to improve the overall quality of service and reduce the duration of power outages (] Xia S, 2014).

2.2.2.Security: The integration of digital technologies in a smart grid can create potential security vulnerabilities. Therefore, smart grids must have advanced security measures, including encryption and authentication, to prevent cyber-attacks and ensure the safety of the system (Husam Suleiman).

Smart grids can be vulnerable to various types of cyber-attacks, including hacking and malware (Y Yan, 2012). A successful cyber-attack can cause significant damage to the grid, leading to power outages and other issues. Therefore, it is essential that smart grids have robust security measures to prevent and mitigate these attacks.

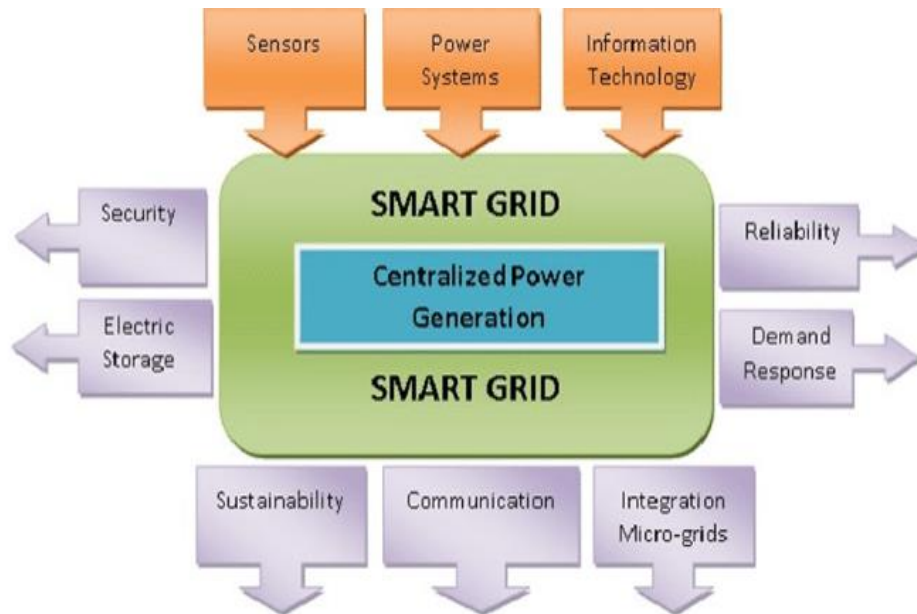
2.2.3.Demand Side Management System: Smart grids utilize a demand side management system, which allows utilities and consumers to manage energy consumption in response to changing demand and pricing. This system can include features such as time-of-use pricing, which incentivizes consumers to use energy during off-peak hours, and demand response programs, which incentivize consumers to reduce energy use during times of high demand (Antonio Colmenar-Santos, 2015).

The demand side management system allows utilities to optimize the use of energy resources and reduce the need for expensive and polluting peaker plants. At the same time, consumers can benefit from lower energy bills by adjusting their energy usage patterns according to pricing incentives.

2.2.4. Self-Healing: Smart grids can also be designed with a self-healing capability, allowing the system to automatically detect and respond to issues without requiring manual intervention (Vikram K, 2018). This can include features such as automatic rerouting of power or isolation of faulty equipment to maintain the overall integrity of the system.

The self-healing capability of a smart grid helps to reduce the impact of power outages and other issues by enabling the system to respond quickly and efficiently to any problems that arise (M., 2015). This can also help to reduce the duration of outages and minimize the number of customers affected.

2.2.5. Metering: Smart grids utilize advanced metering infrastructure, which allows for two-way communication between utilities and consumers, providing real-time information on



energy

Figure 2 Overview of Smart Grid architecture

consumption and allowing for more accurate billing. This can also allow for the optimization of energy use and the integration of renewable energy sources (Osama Majeed Butt a).

Smart meters provide customers with real-time information on their energy consumption, allowing them to make informed decisions about their energy usage and identify areas where they can reduce energy waste. Utilities can also use this information to better manage their resources and reduce waste.

2.2.7. Micro-grids and Integration of Renewable Resources: Smart grids can integrate micro-grids, which are small-scale power grids that can operate independently or in conjunction with the main grid. Micro-grids can incorporate renewable energy sources such as solar or wind power, providing more sustainable and efficient energy solutions. The integration of these renewable resources into the smart grid can also help to reduce greenhouse gas emissions and promote sustainability (M, 2015).

Micro-grids can operate independently from the main grid, providing power during outages or other issues. This can help to reduce the impact of outages on customers and improve

the overall reliability of the system. Furthermore, the integration of renewable energy sources into the smart grid can help to reduce reliance.

3.2. Smart Grid vs. Traditional Electricity Grid

To adapt to a dynamic energy market and improve the user experience with energy, centralized electricity generation from power plants has steadily shifted toward a distributed energy resource over time (Escobar, 2021). There are many reasons why the existing electricity infrastructure needs to be upgraded to a smart grid, including:

- The availability of more renewable energy and linked technologies
- market deregulation for energy
- Changes in electricity production
- Increase in electric vehicle use
- The need for remote grid control, the advancement of meters, and the policies governing
- renewable energy
- Increase in isolated microgrids and microgeneration Prosumers are people who create, use, share, and sell energy.

2.3.1. Traditional Grid versus Smart Grid

The traditional grid cannot effectively meet the demand for reliable power supply due to a number of problems. Table 2.1 contrasts the features of the preferred smart grid with those of the conventional grid (Rahat Hossain, 2013).

Table 1 Comparison between the traditional and smart grid

Traditional Grid	Smart Grid
electromechanically, Solid State	Digital/Microprocessor
One-way and local two-way communication	Global/integrated two-way communication
centralized generation	Accommodates distributed generation
Limited protection, monitoring and control systems	WAMPAC, Adaptive protection
Manual restoration "	Automated, "self-healing"
Monitor equipment remotely	Monitor equipment remotely
Limited control system contingencies	Pervasive control system
Estimated reliability	Predictive reliability

2.4.How to design smart grids and predict process costs

Designing a smart grid requires careful planning and consideration of various factors, including the specific needs and requirements of the grid's stakeholders, the availability of technology and infrastructure, and the complete goals and objectives of the grid. The cost of designing and implementing a smart grid can vary widely depending on a range of factors, including the size and complexity of the grid, the level of technology and infrastructure required, and the regulatory and policy environment. In general, the cost of implementing a smart grid can be significant, and may require significant investment from utilities, governments, and other stakeholders.

2.4.1. The following are some key steps in designing a smart grid:

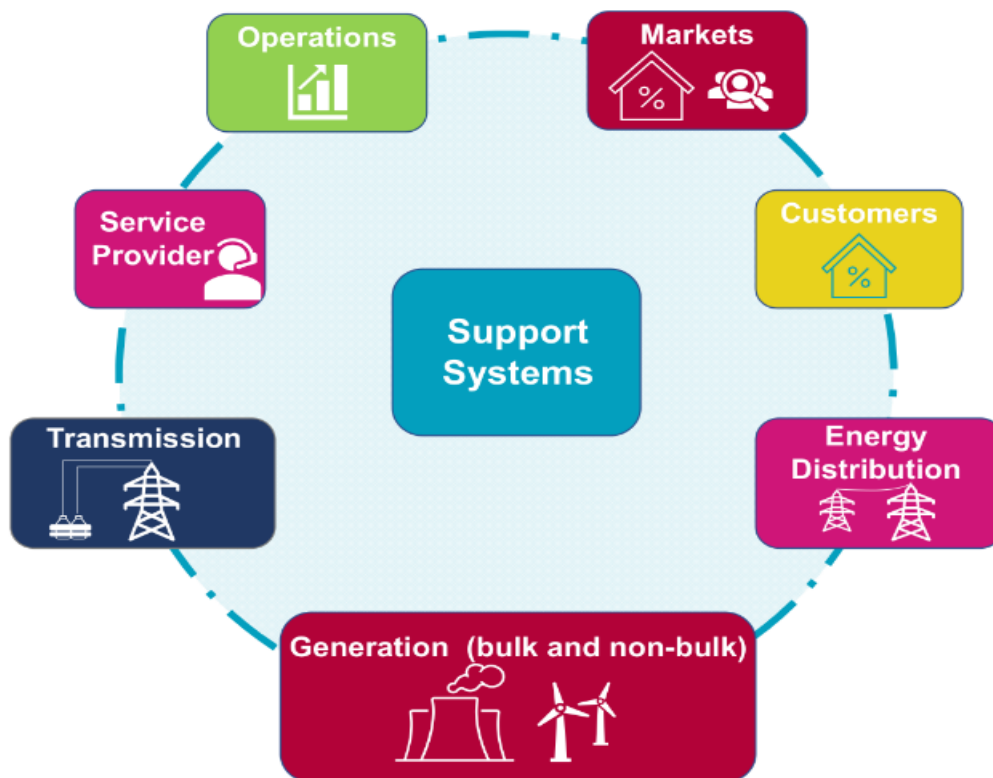
- Conduct a comprehensive needs assessment: This involves analyzing the existing power grid infrastructure, identifying areas of inefficiency, and determining the requirements for the smart grid, such as advanced metering, demand response, and energy storage.
- Develop a detailed implementation plan: This involves creating a roadmap for the deployment of smart grid technologies and infrastructure, including timelines, budget estimates, and milestones.
- Consider the role of stakeholders: This involves identifying the various stakeholders in the smart grid, such as utilities, regulators, consumers, and technology providers, and determining their specific needs and requirements.
- Determine the necessary technology and infrastructure: This involves selecting the appropriate technology and infrastructure to support the smart grid, such as advanced sensors, communication networks, and control systems.
- Ensure interoperability and standards compliance: This involves ensuring that the various technologies and systems used in the smart grid can communicate and interoperate effectively, and comply with relevant industry standards.

2.5.STEPS TO REALIZATION

A smart grid that are dependable, secure, economical, effective, efficient, safe, and environmentally responsible, a smart grid is necessary (JAVADI, 2020). A vast array of technologies must be developed and put into use in order to realize the Smart Grid vision. To be realized, the following steps must be taken:

1. Integrated Communication
2. Modern Hardware
3. Modern Control & Instrumentation (I&C)
4. Smart Software

2.5.1. Integrated Communication system: The ability of every new significant system and device to communicate with every other system on the grid is a requirement for the development of a true smart grid (NETL, 2007). This crucial "interoperability" relies on a coordinated framework of protocols and standards, which is still in the very early stages of



development. A smart grid's unusual platform is displayed in figures 3:

Figure 3A smart grid communication platform

The most sophisticated IP-based communications systems, for example, will be required by the grid of the future. The smart grid is dynamic and interactive for real-time information and power exchange due to high-speed, fully integrated, two-way communication technologies. There are several types of communication media, including:

- ❖ Copper wiring

- ❖ Optical fiber
- ❖ Power Line Carrier (PLC)
- ❖ Wireless technologies
- ❖ Broadband over Power Line technologies (BPL)

For the next generation and the available integrated communication system, it can be divided into three main categories, as shown in the table2:

Table 2 Integrated Communicated Systems for Smart Grids

Group No.	Group Name	Technology
1	Broadband over power Line	❖ BPL
2	Wireless Technologies	❖ Multiple address system radio ❖ Paging networks ❖ Spread spectrum radio ❖ WiFi ❖ WiMax
3	Other Technologies	❖ Internet2 ❖ PLC ❖ Fiber to the home (FTTH) ❖ Hybrid fiber coax (HFC) ❖ Radio frequency identification (RFID)

2.5.2. Advanced Hardware: play an active role in determining the electrical behavior of the grid. These power system devices apply the latest research in:

- Materials
- Superconductivity
- Distributed Generation
- Energy storage
- power electronics
- Microelectronics (Grid Friendly Appliance)

to produce higher power densities, greater reliability and power quality, enhanced electrical efficiency that produces major environmental gains and improved real-time diagnostics.

Table 3 summarized such devices in 5 groups:

2.5.3 Modern Control Methods and Instrumentation (IC): New techniques and algorithms keep track of the parts of the power system, allowing for quick analysis and prompt, appropriate action in the event of any event. It consists of tools and algorithms that analyze, diagnose, forecast, and take the necessary corrective actions to prevent faults. Figure 4 demonstrates the presence of these control components throughout the grid.

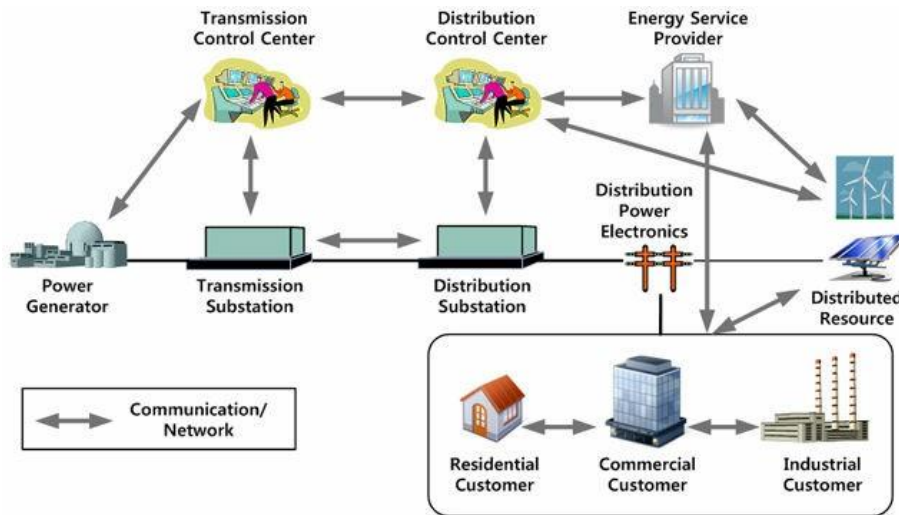


Figure 4 Control Center in all parts of grid

Table lists some of the technologies used in these fields.

Table 3 Modern Control Methods for Smart Grids

Group No.	Group Name	Technology
1	Distributed Intelligent Agents	<ul style="list-style-type: none"> • Digital Relays • Intelligent tap changer • Energy management system • Grid friendly appliance controller • Dynamic distributed power control
2	Analytic Tools	<ul style="list-style-type: none"> • System performance monitoring and control • Phasor measurement analysis • Weather prediction • Fast load flow analysis

		<ul style="list-style-type: none"> • Market system simulation • Distribution fault location • High speed commutating
3	Operational Application	<ul style="list-style-type: none"> • SCADA • Substation Automation • Transmission Automation • Distribution Automation • Demand Response • Outage management • Asset optimization

Sensing and measurement - These technological advancements will help with routine meter reading, do away with billing estimation, and stop unauthorized energy use. Allowing consumer choice and demand response also contributes to a reduction in emissions. Figure depicts an example of a smart metering.

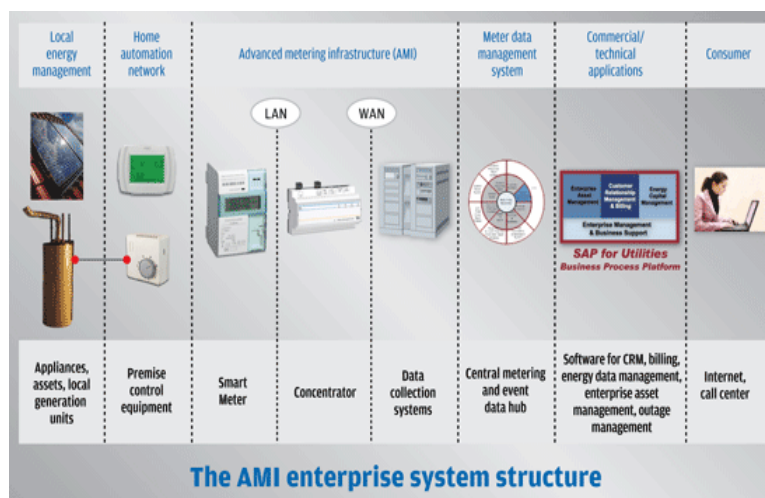


Figure 5 Smart Metering

2.5.4. Smart Software: Modern grids will need to make extensive, seamless, and frequently real-time use of software and tools that help grid managers and operators take decisions quickly. As well as enabling more advanced operator training, such a decision support requires improved interfaces that will enable more accurate and timely human decision making at all levels of the grid, including the consumer level. It also requires advanced,

intelligent software to make all events and situations as user-friendly as possible and that is following those point:

1. Improvement in the overall quality.
2. Detailed overview of the streetlighting infrastructure.
3. Little expense for installation.
4. Installation is quick and easy.
5. Rapid return on investment.
6. Low running costs.
7. The requirement for expensive visual inspections is reduced.
8. Maintenance costs are reduced by using a single photo cell in the center.
9. Proactive bulb replacement based on burn hour information.
10. The environment benefits from lower CO2 emissions 11. Lessens light pollution.
12. Eliminates dark areas, increasing street safety.
13. Expansion is simple to new regions or cities.
14. The operator can easily change the settings, i. E. During a special event.
15. Swift response to bad weather or traffic incidents.
16. 24-hour reports, including burn hours and faults, are quickly and easily accessible.
17. Operator can select Excel or HTML as the report format.

2.6.What are the advantages of the smart grid

2.6.1. Increased Energy Efficiency

- Smart grid technology enables more efficient and effective management of electricity generation, transmission, and distribution.
- It allows for real-time monitoring of energy consumption, which can help identify areas of energy waste and optimize energy usage (Yousuke Nozaki, 2011).

- Smart grid systems also allow for the integration of renewable energy sources, such as solar and wind power, which can help reduce reliance on fossil fuels and lower greenhouse gas emissions.

2.6.2. Improved Reliability and Resiliency

- Smart grid systems are designed to detect and respond to power outages more quickly and effectively than traditional grids.
- The technology allows for the isolation of affected areas and rerouting of power to minimize the impact of outages on customers.
- Smart grids also have built-in redundancies and backup systems, which can help prevent widespread outages and improve grid resiliency during emergencies.

2.6.3. Enhanced Customer Engagement and Control

- Smart grid technology enables customers to monitor their energy usage in real-time and make more informed decisions about their consumption patterns.
- Customers can also take advantage of dynamic pricing schemes, which offer lower rates during off-peak hours and incentivize energy conservation.
- Smart grid systems also allow for the integration of smart home technologies, such as smart thermostats and appliances, which can be controlled remotely and help reduce energy waste.

2.6.4. Better Asset Management

- Smart grids allow for more effective management of grid assets, such as transformers, substations, and power lines (Golam Rahman, 2013).
- Real-time monitoring and analytics can help identify potential equipment failures before they occur, allowing for proactive maintenance and reducing the likelihood of downtime.
- Smart grid technology can also improve asset utilization and extend the lifespan of equipment, reducing the need for costly replacements.

2.6.5. Increased Grid Security

- Smart grid systems incorporate advanced cyber security measures to protect against cyber-attacks and data breaches.

- The technology enables better detection and response to security threats, reducing the risk of power grid disruptions or compromise of sensitive information (BP Statistical Review of World Energy, 2011).
- Smart grids also enable more secure communication between grid operators and customers, reducing the risk of fraudulent activity or unauthorized access to the grid.

2.6.6. Economic Benefits

- Smart grid technology can help reduce energy costs for customers by improving efficiency and enabling dynamic pricing schemes (Admin, 2017).
- The technology can also help reduce overall energy consumption, which can lower the demand for expensive peak-load power and reduce the need for new power plants.
- Smart grid systems can also create new job opportunities in fields such as engineering, software development, and data analytics

2.7. What are disadvantages of the smart grid?

Smart grid technology has the potential to provide numerous benefits to both utilities and consumers, such as improved energy efficiency, increased reliability, and cost savings. However, there is a risk that these benefits may not be distributed equitably, and certain groups may be left behind. For example, low-income households may not have access to the latest smart appliances or technologies, and may not be able to afford the higher costs associated with a smart grid. Additionally, rural areas may face challenges in accessing the benefits of a smart grid due to a lack of infrastructure or limited resources. This could result in a widening of the digital divide and exacerbate existing inequalities. And there are more advantages of the smart grid that are following those points:

1. **Cost of Implementation:** One of the main disadvantages of implementing a smart grid is the cost involved. Upgrading the existing grid infrastructure to include smart technologies can be expensive, and this cost may be passed on to consumers through higher electricity bills.
2. **Cybersecurity Risks:** Smart grids are vulnerable to cyber-attacks, which could potentially disrupt electricity supply, cause physical damage, or compromise the privacy of consumer data. Ensuring the security of smart grid systems requires significant investments in cybersecurity measures and ongoing monitoring.

3. **Lack of Standardization:** The lack of standardization in smart grid technology can make it difficult for different components to work together effectively. This can lead to interoperability issues and hinder the ability to realize the full potential of a smart grid.
4. **Interoperability Issues:** Interoperability issues arise when different devices and systems within the smart grid are unable to communicate and exchange information with each other. This can result in inefficiencies, increased costs, and a lack of coordination between different components of the grid.
5. **Privacy Concerns:** The smart grid collects a large amount of data about electricity usage patterns and consumer behavior, which raises concerns about privacy and data security. Without adequate safeguards, this data could be used for malicious purposes or fall into the wrong hands.
6. **Technological Complexity:** Smart grid technology is complex and requires a high level of technical expertise to design, implement, and maintain. This complexity can make it difficult for utilities to train their staff or for consumers to understand how the system works.
7. **Resistance to Change:** Implementing a smart grid requires significant changes to the existing infrastructure, and this can be met with resistance from stakeholders who may be reluctant to invest in new technologies or change their behavior.
8. **Potential Job Losses:** The introduction of smart grid technology could lead to job losses in certain areas, such as meter reading or maintenance. However, it could also create new job opportunities in areas such as data analytics or cybersecurity.
9. **Reliance on Electricity:** The smart grid relies on electricity to operate, which means that any power outages or disruptions to the electricity supply could impact the system's ability to function effectively.
10. **Potential for Power Outages:** The complexity of smart grid technology means that there is a greater risk of power outages caused by software glitches or technical failures. This risk can be mitigated through effective system design, testing, and maintenance.

2.8. Application of the smart grid

1. Advanced Metering Infrastructure (AMI): AMI systems are a key component of smart grids and enable two-way communication between utilities and customers.

2. Distribution Automation: Smart grid technologies can be used to automate distribution systems, including switches, transformers, and other equipment. This enables utilities to monitor and control the distribution system in real-time, reducing outage times and improving overall reliability.

3. Demand Response: Smart grids can enable demand response programs that incentivize customers to reduce energy usage during times of peak demand. This can help reduce the need for expensive Peaker plants and reduce overall energy costs.

4. Electric Vehicle (EV) Integration: Smart grids can support the integration of EVs into the grid by enabling vehicle-to-grid (V2G) technology. V2G allows EVs to act as mobile batteries, storing excess energy from the grid and returning it to the grid when needed.

5. Microgrids: Micro grids are small-scale, localized power systems that can operate independently of the larger grid during times of disruption or outages.

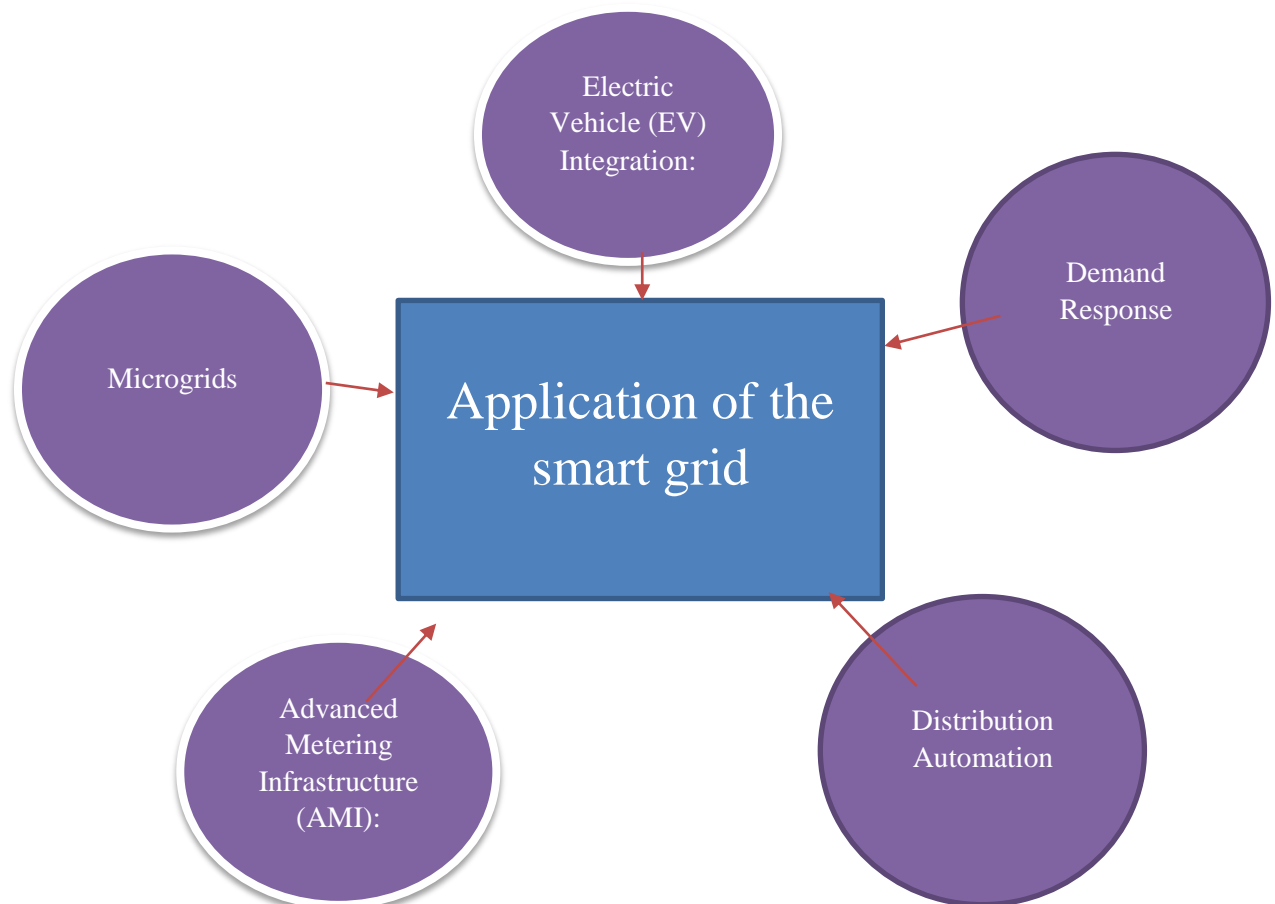


Figure 6 Application of the smart gri

Conclusion

In conclusion, Implementing smart grid technologies at such disparate speeds. With its effects in increased efficiency, consumer involvement, and reliability provided such powerful incentives for adoption and deployment. recently created smart technologies and information-gathering control systems that improve utility operations and business progress. There are clear disruptive challenges ahead, as renewable and disruptive energy sources grow in quantity and demand for an advanced, intelligent grid. The utilities will still face difficulties with system integration and interoperability when they implement new information management and control systems.

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