Cutting Edge Research And Development In Smart Energy Grids: A General Survey

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***Abstract*— The global shift towards a cleaner world has resulted in a need for the modernization of traditional power grids. Traditional power grids are limited in the capabilities they can perform, such as lack of communication. Moreover, their heavy reliance on fossil fuels has a detrimental impact on our environment. Smart power grids provide solutions for the above-mentioned issues using technologies such as sensors, communication networks, and artificial intelligence resulting in an improvement of performance. Integration of the above-mentioned technologies into the current electrical infrastructure enables data collection and two-way communication between consumers and energy producers. This paper provides an insight into the cutting-edge research and development associated with the applications, challenges, and prospects in smart energy grids.**

***Keywords*— Renewable energy, Energy Efficiency, Smart Grids, Emission Reduction**

I. INTRODUCTION

As the worldwide demand for cleaner energy has increased, there is a great need for the improvement of our current energy infrastructure. Traditional power grids deliver energy from power plants directly to the consumer in a one-way system. Smart energy grids are meant to acquire real-time information from the systems where the energy consumption is taking place and relay the energy consumption data information back to information control. Smart energy grids not only deliver energy from power generation plants but also make energy distribution more manageable and can integrate various technologies, such as artificial intelligence, to further enhance efficiency [1]. Smart Grid technology is designed to revolutionize the distribution and consumption of electrical energy.

Implementing smart grids does not only enhance reliability and efficiency but can also better support other energy sources such as solar, wind, and hydroelectric power [2]. As urban areas continue to grow in population and size, the demand for energy increases. Having smart grids will help reduce the consumption of fossil fuels and promote the usage of alternative energy sources that are sustainable in the long term, and lower carbon emissions. The implementation of smart grids is already in progress in numerous countries across the world, including regions in Europe, India, and China, to better support the transition towards renewable energy [2].

To better understand why smart energy grids are essential for our modern-day energy systems, we need to understand the evolution of power grids. Electronification history began in the 19th century with the invention of Direct Current (DC). This invention later inspired others such as Nikola Tesla to create the first Alternating Current (AC) electric system used in 1893 during Chicago's World Columbian Exposition Fair. As the power grid evolved, so did the need for a reliable and more efficient way to distribute energy. Traditional power grids allow only one-way communication from power plants to consumers. In doing so, the power that is generated mostly uses fossil fuels which release harmful emissions into the environment. Smart grids use supervisory control and data acquisition (SCADA), energy management systems (EMS), and energy sensors [6] to help collect and analyze data. Using these resources, smart grids can identify and balance energy supply and demand effectively, making energy distribution and utilization more adaptable and sustainable. The interest and development of smart grids began in the 21st century, driven by technological advancements as well as the push for renewable energy [13]. Additionally, many countries have realized the impact of climate change has on our planet. Today, smart grid technology continues to grow in interest for a variety of reasons and has been implemented in different parts of the globe.

II. SMART GRIDS

A smart energy grid is characterized by an interconnection of modern technologies that allows for easier monitoring, ease of electrical control, and optimizing efficiency [1,3]. The idea of smart grids is based on a system of multiple devices and sensors working together, gathering information and data, and utilizing the gathered information to efficiently control the supply and demand of energy in different areas. The technology used in smart grids includes sensors and monitoring devices, advanced metering infrastructure (AMI) and smart meters, communication networks, grid automation, etc.

Smart Systems & Grid

Smart systems are used to give already existing energy infrastructure a boost in performance by embedding different systems that can sense, trigger, and active control. They can be integrated with electrical grids, transforming them into a smarter grid. Smart systems can perform and improve functionality with active learning in different environments and adapt in any environment with any given task in real time [5]. Combining smart systems with current electrical grids gives us a smart grid. A smart grid uses two-way flows of both energy and data. Unlike traditional power grids that have a one-way flow of electrical energy, smart grids incorporate different components that allow for data collection and decision making, which enable more efficient and reliable grid operation and energy distribution.

Goals & Benefits

With the global increase in energy demand and consumption continuing to rise annually, we are faced with numerous problems related to climate change. The primary goal of integrating smart grids with our current energy infrastructure is to lower greenhouse gas emissions, improve the current infrastructure, and make the system more reliable for all who use it.

One of the key goals for incorporating newer and more updated grids is to allow the grid to be more accommodating for variable power sources such as solar and wind. Additionally, reliability and performance will increase with real-time communication, active learning, and monitoring problems in the system that may contribute to power outages. Another objective associated with future grid systems is job growth. According to sources, the growing market in renewable energy and the discovery of new ways to harvest and transport energy are expected to create around 19 million additional jobs by 2050 [4].

Smart grids provide a wide range of benefits and advantages compared to traditional grids in the context of system improvement and consumer satisfaction.

- **Enhanced Efficiency:** Smart Grid Technology provides an improvement in energy pressmen, distribution, and consumption with smart meters and improved system monitoring.
- **Reliability:** With real-time monitoring that oversees the grid, reliability improves, along with the minimization of power outages.
- **Environmental Impact**: By reducing the usage of fossil fuels and other sources of nonrenewable energy, the use of smart grids will help lower greenhouse gas emissions
- **Renewable Energy Adoption: Smart Grid** has easier integration with other sources of renewable energy such as solar and wind, ensuring that newer methods of energy can be introduced more easily.

Challenges & Limitations

With the integration of different technologies into a smart grid, a range of challenges can arise. When working with IoT devices, the smart grid system becomes vulnerable to data leaks, overloads, and cybersecurity threats. The electrical components that are used to construct the grid all operate in different environments, making it difficult to maintain high performance in different regions.

Security is another concern when it comes to smart grids. With numerous devices working together, they become more vulnerable to different data breaches or cyberattacks. To ensure confidentiality within the grid system, stronger encryption and authentication are used. Additionally, with having to manage many devices, energy distribution problems may arise in large scale distribution as well as when the networks complexity increases [6].

Beyond the security issues, smart grids also face different obstacles. Significant investment is needed to upgrade many of the grid lines and outdated infrastructure with newer devices. These upgrades are necessary for the grid to last long term, but financially, this may be difficult for many regions to acquire. Along with financial challenges, another issue is data management. Massive amounts of complex data are processed and acted upon in real-time. Without sophisticated software as well as reliable processing power and interpretation of data, delays are possible which could impact the stability of energy grid.

III. AI INTEGRATION IN SMART GRIDS

As artificial Intelligence (AI) continues to push boundaries in the context of what it can do and as the energy sector continues to be increasingly digitized, AI based systems can handle and process large sets of data, learning patterns, and decision making. These capabilities enable easier and smarter management across both conventional and renewable energy sources. AI gives advanced solutions to challenges that regular methods struggle to handle. This section will provide a brief explanation of artificial intelligence and explore the applications of integrating artificial intelligence into smart grids.

Artificial Intelligence

At the heart of AI integration in smart grid is how adaptable and capable it is. Artificial Intelligence systems are computer systems that can perform and complete tasks which typically require human intelligence to do. Some examples of such tasks are reasoning, learning, or decision-making. Machine learning (ML) is a subset in AI; it enables systems to analyze and recognize patterns in data sets that, over time, will improve its performance [7].

AI Applications in Smart Grids

As power systems become more digitalized, AI can be used to help assist human operators in decision making. Some key applications include:

- **Demand Response:** AI predicts and manages energy consumption patterns for peak load reduction and cost efficiency
- **Fault Detection and Predictive Maintenance: Artificial** Neural Networks (ANN) and Deep Learning (DL) are models that can identify system issues before it occurs and try to replicate how humans think and learn.
- **Energy Distribution Optimization:** A vital task AI can accomplish is balance supply and demand trends in real time, as well as making it easier to integrate renewable energy sources.

IV. INTERNATIONAL SMART GRID ADOPTION

Numerous institutions and countries have already started to research and implement smart grids into their system. Some academic institutions, such as the University of Waterloo [10] and York University [11] have laboratories dedicated to research and publishing papers and journals on their discoveries related to smart grid technology. Indeed, research is important to find newer ways to deliver sustainable energy.

Country

Many countries have already decided to implement their own pilot projects and research regarding smart grids. The United States, Australia, Britain, Japan, and South Korea are countries that have acknowledged smart grid technology and their advantages in being able to reduce carbon emissions [12]. Some countries that have already developed or plan to investigate further into smart grid technology are Mexico, Brazil, Japan, Australia, and India [13]. The following figure 1 depicts different regions across the world that have been mentioned to expand or plan to expand their electrical infrastructure to incorporate Smart Grids.

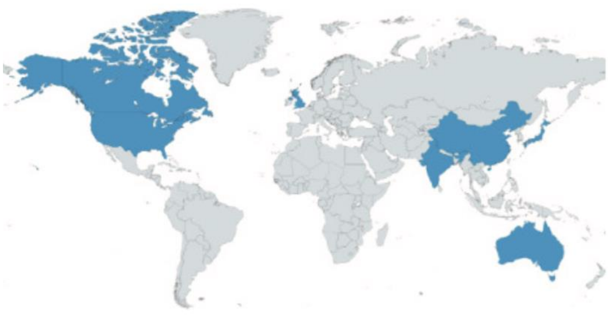

Figure. 1 The countries and continents examined in the following section can be seen highlighted in blue [5]

United States

The American Recovery and Reinvestment Act of 2009 provided the Department of Energy $4.5 Billion. This funding to the DOE was to modernize the electric power grid with their latest program, the Smart Grid Investment Grant [14].

The United States has already taken initiative with large projects such as the Smart grid Demonstration Projects (SGDP), a nationwide set of pilot projects that are tasked to test and research cutting-edge technology in various states such as New York, Ohio, Michigan and Pennsylvania [15].

Japan

The Japanese government has made early large-scale efforts to push towards smart grid development. In 2010 they launched four large-scale pilot projects in different cities as a national effort to push lower carbon energy systems. The smart grid pilot projects were supported by the Japan’s ministry of Economy and Trade and Industry (METI) and coordinated with other ministries that focused on communication, agriculture, and environment. Japan’s goal involving these projects was to create a community energy-management systems (EMS) that could also be integrated with other EMS’s.

India

India and its government have initiated a nationwide project to implement their own smart grid system. Their project was implemented by the Ministry of Power and spanned across

numerous cities in India. These cities include Ajmer, Assam, Tripura, Haryana, Kanpur, and Manesar. The above-mentioned projects covered 34,000 consumers, all with different incomes and power usage. A total of 12 projects is listed that have adopted different functionalities such as SCADA, distribution transformer monitoring, power quality measuring, load management, and cyber security [16]. These functionalities that are adopted are important to the study of how smart grids perform in different environments and with different consumer demands.

Australia

In 2009, the Australian government was interested in investing $100 million towards developing smart grid systems when a proposal was introduced. Five different sites in New South Wales were chosen to have the first smart grids established. The government worked alongside IBM, GE Energy, and Grid Net [12]. The project was planned to support 50,000 smart meter connections. The project was centered around building a WIMAX-based smart grid; WIMAX is a wireless communication that transmits real-time data between grids over large distances which allows the grid to be more controlled and monitored [17].

Australia has seen success in smart grid initiatives with the King Island Renewable Energy Integration Project (KIREIP). This project combined solar, wind, and battery storage with an advanced control system that drastically reduced their usage of diesel and at times achieved 100% renewable energy penetration. Experts predict that by 2030, 50% of Australia’s renewable energy sources will be managed through smart grids.

V. CONCLUSION

Smart grids solve many problems that currently occur with our current infrastructure of power grids. With the push for a greener and more sustainable world, smart grids help advance the transition towards a cleaner and more efficient energy system.

With the use of different advanced technologies, smart energy grids are more capable of handling greater demand as well as managing energy distribution. With AI becoming more popular and being integrated into our daily lives, new opportunities arise for optimization and decision-making within the grid

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