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A REVIEW ON SMART GRID – A FUTURE ENERGY MANAGEMENT SYSTEM

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Abstract: The primary focus of this paper revolves around the examination of the smart grid, heralded as a pivotal future tool for managing all energy resources. These intelligent grids intertwine with cutting-edge technology to furnish sustainable electrical supply over the long haul while enhancing energy productivity. Notably, smart energy meters assume a crucial role within the smart grid framework, juxtaposed with their conventional counterparts. In addition to delving into energy management systems within the smart grid, this paper sheds light on both the constraints and advantages associated with this innovative infrastructure, ultimately proposing viable solutions.

I. INTRODUCTION

As per the Electric Power Research Institute (EPRI), a smart grid system integrates digital services across all stages of power generation, distribution, and consumption to reduce costs, enhance efficiency, and minimize environmental impact. This technology enhances the dependability, flexibility, security, and efficiency of the energy system, crucial for its ongoing evolution. Key features of grid modernization include customer engagement, essential for a Smart Grid, where Smart Metering, while feasible independently, becomes integral to the Smart Grid's functionality.

Core drivers of the Smart Grid encompass Combined Multiple-Energy, Revenue Protection, Operational Satisfaction, and Energy Efficiency. These include the development and integration of responsive demand, urgent resource requests, and energy-efficient supplies. Furthermore, advancements include the deployment of smart meters, grid services, status communication systems, and transmission automation through real-time, automated, collaborative technologies, optimizing the operation of appliances and consumer devices.

Moreover, the integration of intelligent devices and consumer electronics facilitates enhanced communication between customers and power generation entities in a bidirectional manner. This emphasizes the role of intelligent meters, such as smart meters, in enabling efficient communication and interaction within the smart grid ecosystem.

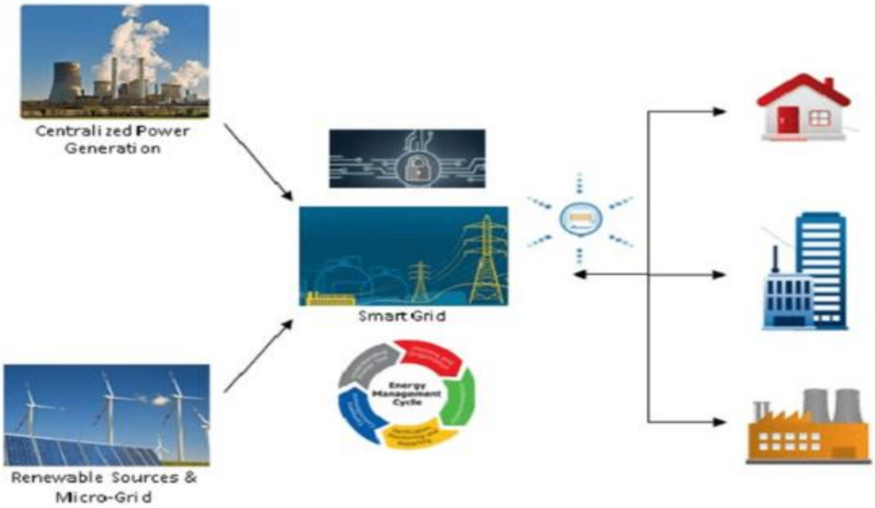

Fig1: Concept Of Smart Grid

A Smart Grid system represents an intelligent electrical network that orchestrates the actions of all its interconnected users, including generation units, consumers, and those who serve both roles. Its primary aim is to furnish a cost-effective, durable, and secure power supply. The term "smart grid" denotes a next-generation power transmission network leveraging information technology and advanced mechanisms for efficient operation.

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In terms of technological advancement, the electricity sector has historically trailed behind the telecommunications industry. However, a parallel can be drawn with the telecom sector's evolution over the past decade. Initially, mobile phones served limited functions, primarily facilitating voice calls. Yet, in recent years, this industry has undergone a remarkable transformation, offering a plethora of services through cutting-edge IT and innovative technologies. Similarly, the power industry is now undergoing a significant shift with the advent of the smart grid, which, akin to the Internet, is garnering considerable attention from various sectors (Lamba, 2011).

According to the International Energy Outlook 2017, global energy consumption is projected to surge by 28% from 575 quadrillion British Thermal Units (BTUs) in 2015 to 736 quadrillion BTUs by 2040. This rise in energy demand is expected to present new opportunities for the global solar panel recycling market in the coming years. Additionally, heightened concerns about climate change and the sustainability of fossil fuels have spurred a surge in demand for renewable energy sources in the global power generation mix. The contribution of renewable energy (including hydropower) to the global power generation mix witnessed a remarkable 26% increase in 2018 compared to 2000 (Surender Rangaraju, 2021).

The deployment of smart meters is commonly associated with the implementation of smart grids. Initially introduced in the 1970s and 1980s, these meters were utilized to transmit customer data back to the grid. Despite subsequent technological advancements, the paramount focus remains on ensuring the reliability and efficiency of energy transmission and delivery through the electric power grid.

However, recent studies emphasize that grids and network systems should serve not only for transmission and distribution but also for generating clean and sustainable energy. This shift aims to mitigate greenhouse gas emissions, underscoring the evolving role of energy infrastructure in fostering environmental sustainability (Osama Majeed Butt, 2021).

II. THE SMART ELECTRIC ENERGY SYSTEM

The vision of a future Modernized Grid system necessitates careful financial justification and rigorous testing before widespread adoption. However, achieving the status of a Smart Grid does not require implementing all features simultaneously; instead, each new feature can be developed independently, with its own cost justification and return on investment assessment. Once advancements have been thoroughly tested, a fully implemented Smart Grid is expected to possess the following characteristics:

- Facilitate the utilization of renewable energy resources to combat global climate change.
- Encourage greater user engagement to enhance energy conservation efforts.
- Ensure system security by employing cyber-secure communication systems.
- Optimize the utilization of existing assets to ensure long-term viability.
- Improve energy flow efficiency to reduce energy losses and expenses (Gharavi & Ghafurian, 2011).

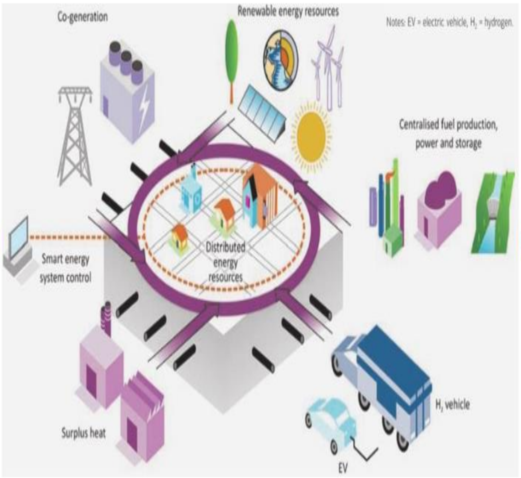

Fig 2. Integrated And Intelligent Energy Network Of The Future (IEA, 2013)

It's crucial to understand that the Smart Grid, as described earlier, doesn't merely enhance the traditional electric system; rather, it lays the groundwork for optimizing the utilization of current resources while facilitating the integration of novel functionalities. While centralized power will maintain its significance within the Smart Grid, the inclusion of large-scale wind and solar energy will emerge as pivotal elements in the generation mix, particularly where cost-effectiveness is feasible.

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III. COMPARSION WITH CONVENTIONAL ELECTRICAL SYSTEM

In an electrical system, a network interconnects energy producers and consumers through transmission and distribution networks. A traditional power system model is often contrasted with the smart grid, encompassing generating stations, transmission lines, and distribution lines catering to diverse loads. Additionally, control centers play a pivotal role in facilitating power system operations and control. Amid various system issues, the power system protection unit serves to safeguard the electric power (Pankaj Gupta, 2021).

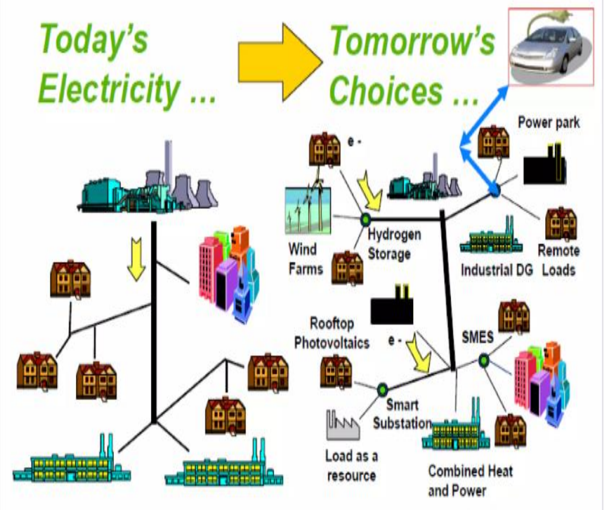

Fig. 3. Smart Grid - A Tomorrow's choice

The traditional power system is juxtaposed with the smart grid as a prospective energy management solution aimed at meeting power demands. Below are the characteristics of each system, highlighted alongside a comparison in Figure 4. The transmission system experiences significant utilization to accommodate the escalating demand, as demand distribution varies across the country (Surender Rangaraju, 2021).

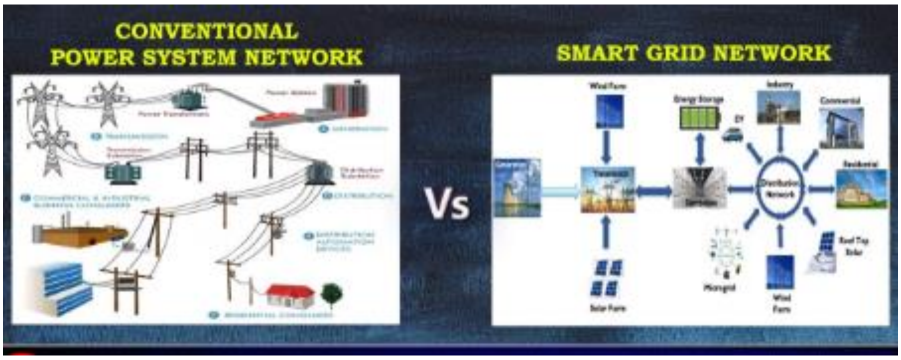

Fig. 4. Smart grid and conventional power system

The conventional power infrastructure is inflexible, posing challenges in integrating electricity from alternative sources or efficiently managing additional services requested by consumers. Consumers typically have limited insight into their electrical energy consumption, relying on monthly bills received retrospectively. Real-time monitoring and control are primarily confined to generation and transmission, with only a handful of utilities extending these capabilities to the distribution system, resulting in passive consumer participation. Energy flows uni-directionally from the source to the customers in this setup. These are key characteristics of the traditional power system in real-time scenarios.

IV. IMPLEMENTATION OF ENERGY MANAGEMENT IN SMART GRID

The Energy Management System (EMS) originated as a control center in the 1960s, evolving into the Energy Control Centre (ECC) by the 1970s. With the introduction of advanced computerized SCADA (Supervisory Control and Data Acquisition) systems in the 1990s, it transitioned into SCADA-EMS, culminating in a real-time EMS incorporating various control techniques such as Demand Side Management (DSM), Load Control (LC), and Distribution Management System (DMS).

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Electricity suppliers, including electric utilities, power plant operators, and manufacturing units, leverage energy management to efficiently regulate their generation units. For instance, electric utilities can employ energy management to activate generators with the lowest operating costs to meet specified power demands from customers, while generators with higher costs cater to additional load demands during peak hours, thus optimizing operational costs.

System operators, such as those managing transmission and distribution systems, utilize energy management to modulate power flow, reducing energy losses on the network and facilitating the cost-effective integration of renewable energy sources like PV and wind farms. End-users encompass households, residential and commercial buildings, and industries (Alzaareer, 2019).

EMS encompasses various goals, including technical, economic, techno-economic, environmental, and socio-economic objectives. While much EMS research focuses on achieving economic goals such as minimizing operational energy costs and maximizing distributor profits, it's crucial to consider technical constraints. Ignoring these constraints could lead to optimal economic performance at the expense of power outages, failures, or damage to distribution network equipment.

Technical aspects addressed by EMS include energy quality, transformer degradation, and equipment performance. Tackling these issues enhances system performance, prolongs equipment lifespan, improves power quality, and reduces maintenance and downtime (Meryem Meliani, 2021).

Energy management remains a viable strategy for optimizing the transmission system. The centralized structure of an Energy Management System (EMS) typically comprises a central controller equipped with a high-performance processing system and a secure, dedicated network for energy management purposes. This controller, operated by an aggregator or utility, aggregates data from various nodes, including consumption patterns of loads/energy consumers and energy production from Distributed Energy Resources (DERs). Optimization algorithms are then employed to achieve specific objectives (Yan, 2015).

Research contributions in this domain emphasize the potential of solar and wind energy for large-scale deployment, along with the feasibility of Demand-Responsive flexible loads (DR). For instance, innovative planning techniques considering DR have been proposed for energy systems integrating extensive wind generation (Verma, 2018).

V. CONTROL STRATEGIES ON SMART GRID

When integrating renewable energy sources and Energy Storage Systems (ESS) into the grid, control mechanisms play a pivotal role. Consequently, various control strategies are explored, focusing on intelligent control and optimization approaches within renewable energy systems incorporating Hybrid Energy Storage Systems (HESS).

At the primary level, classical control strategies rely on local measurements and provide quick responses without requiring external connections. These strategies encompass functions such as islanding detection, output control, and power sharing control. Secondary control levels typically involve Energy Management Systems (EMS), while tertiary control levels operate at the grid's macro level, facilitating communication and coordination among multiple microgrids to align with the main grid's requirements.

Advanced control techniques, such as cache control for ESS and adaptive droop control for long-term battery operations, offer improved effectiveness and reliability compared to traditional droop controllers. Vector control of power is utilized for delivering active and reactive power to the grid, necessitating decoupling control of reactive and active current components. Intelligent control methods, including fuzzy logic, artificial neural networks, and genetic algorithms, are employed to enhance control efficiency (Rabbani, 2020).

VI. CHALLENGES IN SMART GRID

Future intelligent grid technologies rely on two-way communication systems, advanced control systems, and robust computational capabilities. These technologies encompass Phasor Measurement Units (PMUs) for system reliability assessment, digital meters for enhanced consumer information and outage reporting, relays for efficient substation fault recovery, automated feeder switches for power rerouting, and batteries for energy storage and grid support (Office of Electricity, n.d.).

However, smart grid field projects encounter several challenges in measurements, cost-benefit analysis, and data interpretation. Drawbacks include issues related to data collection, assessing societal benefits, generalizing findings, interpreting grid responses, and addressing regional variations in electric service provision (Bossart & Bean, 2011).

The smart grid's metering and control system consists of heterogeneous wired and wireless networks and devices, each with its own regulations and security requirements. Addressing these challenges involves dealing with stringent security needs, limited computational resources, time-sensitive message delivery, and managing diverse authentication and protection systems. While efforts have been made to address security vulnerabilities, significant hurdles remain before widespread smart grid implementation (Xinxin Fan, 2013).

Moreover, smart grid communications raise privacy concerns due to the potential inference of consumer behavior from energy usage data. To mitigate privacy risks, advanced privacy-preserving security techniques need development and integration into smart grid networks. These techniques should enable utility firms to conduct routine activities based on aggregated power usage data while ensuring individual consumers have access to real-time usage statistics (Xinxin Fan, 2013).

VII. MERITS OF SMART GRID

Intelligent grids offer the potential to satisfy growing consumer demand without necessitating extensive infrastructure upgrades. They mitigate the occurrence and duration of long-term outages, reducing subsequent restoration costs while significantly lowering emissions, thus promoting environmental sustainability. Moreover, intelligent grids contribute to energy conservation by minimizing oil usage and associated shortages, enhancing overall energy security. By automatically adapting to fluctuating load conditions, they eliminate technical glitches and enhance operational efficiency.

The implementation of Demand-Response mechanisms further alleviates strain on smart grid assets during peak periods, reducing the likelihood of failures. Additionally, intelligent grids minimize power loss during transmission and distribution processes, resulting in cost savings across various operational aspects such as power generation, meter reading, testing, and maintenance (RF Wireless World, 2012).

VIII. DEMERITS OF SMART GRID

The initial investment required for implementing a smart grid is substantial and time-intensive, leading to increased personnel costs. However, this burgeoning market for smart grids holds the potential to catalyze a new era in power distribution, thereby generating numerous job opportunities.

In a smart grid system, network congestion and performance issues pose significant challenges during emergencies. Traditional communication networks may prove unreliable during adverse weather conditions such as windstorms, heavy rain, or lightning strikes, necessitating the establishment of a robust and continuous communication network. Additionally, the replacement of analog meters with advanced electronic meters incurs significant costs. Furthermore, the absence of regulatory standards and norms for smart grid technologies, coupled with a lack of official technological documentation, presents additional hurdles (ForumAutomation, 2018).

IX. CONCLUSION

The smart grid system presents both advantages and challenges, but let's focus on the positive aspects. It addresses the growing demand for future power needs by seamlessly combining electricity and information transmission. By integrating various power sources and collecting comprehensive consumption data, the smart grid facilitates efficient energy management. It identifies regions with unused electrical power, which can then be harnessed through microgrids and Energy Storage Systems (ESS) and utilized, for instance, to power electric vehicles.

Moreover, the smart grid benefits numerous industrial sectors, particularly those with critical power requirements. Even in challenging circumstances, smart grids are designed to ensure optimized stability and efficiency, providing reliable power supply when needed most.

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