SMART GRID: POWER GRID OF FUTURE

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ABSTRACT

The power sector across the world is facing numerous challenges including generation diversification, demand for reliable and sustainable power supply, energy conservation and reduction in carbon emission. It is evident that such critical issues cannot be addressed within the confines of the existing electricity grid. Smart Grid is next generation digitally enhanced power system assimilating concepts of modern communications and control technologies which allows much greater robustness, efficiency and flexibility than today's power systems. As smart grid is identified as solution to various challenging problems of power system, so aspects regarding its implementation are important. A smart grid impacts all the components of a power system especially the distribution level.

Keywords: *Conventional Grid, Information and Communication Technology (ICT), Smart Grid.*

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I. INTRODUCTION

Currently, energy demands is increasing exponentially and energy saving has become need of the hour. Many countries witnessed the energy deficiency which directly impacted development of the state and environment through greenhouse gas (GHG) emissions. The reason for such an inefficient and unstable electric system is lack of advancement in electrical transmission and distribution system [1].Thus a technological revamp is required in the practices involving production, management and consumption of electricity along with new grid infrastructure.

The smart grid is a modern electric power grid infrastructure for improved efficiency, reliability and safety, with smooth integration of renewable and alternative energy sources, through automated control and modern communications technologies [2]-[3]. In other words, a Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies [4]. For instance, according to [5]−[8], the smart grid refers to a way of operating the power system using communications, power electronics, and storage technologies to balance production and consumption at all levels as shown in Fig 1. Also the comparison in Table I asserts that conventional grid needs to be replaced by Smart Grid for pervasive control and monitoring.

Smart grid has the potential to reduce the cost of electric power and supply cleaner power to the consumers. Smart grid is a more efficient resilient system with improved reliability and increased conservation and energy efficiency. Researches around

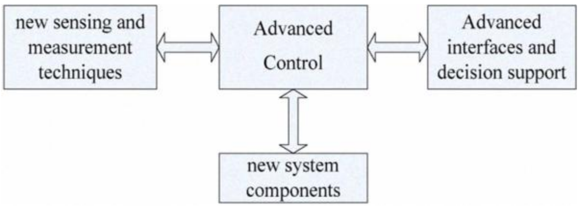

Fig 1.Key technical fields in Smart Grid [4].

Table I: Comparison Between Existing Grid And SMART Grid

CONVENTIONAL GRID	**SMART GRID**
Electromechanical	Digital
One way communication	Two way generation
Centralized Generation	Distributed generation
Hierarchical	Network
Failures &Blackouts	Adaptive &Islanding
Limited Control	Pervasive control

the world are working on Plug-in Hybrid Electric Vehicles (PHEV) which can store energy and acts as backup generators for homes and can assist the grid during peak hours. Smart grid can communicate with appliances, which contain onboard intelligence. Customers with smart thermostat can communicate with the grid to adjust device setting to help optimize load management of electric devices such as air conditioner or pool pump.

The paper is divided in to five parts. Starting with introduction, next section covers the objectives of Smart grid. Similarly, next section constitutes the key technologies involved in Smart grid followed by progressive methodologies. Last section consists of concluding remarks.

II. OBJECTIVE OF SMART GRID

Key objective of Smart Grid can be summarized as:

- Self-healing: The grid rapidly detects, analyzes, responds and restores
- Empowers and incorporates the consumer: Ability to incorporate consumer equipment and behavior in grid design and operation
- Tolerant of attack: The grid mitigates and is resilient to physical/cyber-attacks
- Provides power quality needed by 21st-century users: The grid provides quality power consistent with consumer and industry needs
- Accommodates a wide variety of supply and demand: The grid accommodates a variety of resources , including demand response, combined heat and power, wind, photovoltaics, and end-use efficiency
- Fully enables and is supported by competitive electricity markets.

III KEY TECHNOLOGIES OF SMART GRID

The literature review suggests that a smart grid is not a single concept but rather a combination of technologies and methods. Smart Grid involves the convergence of information technology and communication technology with power system. The key technologies can be summarized as distributed energy access, advanced metering infrastructure, integrated communication system and control & automation.

a) Distributed Energy

It comprises of distributed generation, distributed energy storage and demand response as shown in Fig2.

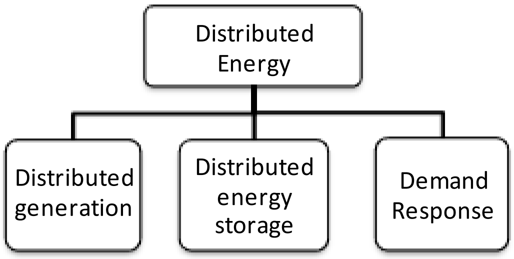

Fig.2 Components of Distributed Energy

1) Distributed Generation:

It is defined as the small scale power generation which is well connected to distribution system. The generation takes place near the sites of consumption and is normally not included in central dispatch of the distribution system. With the help of distributed generation, the distribution portion of the grid becomes active. Due to active characteristic, operation of the grid becomes more flexible [9].Further, addition of distributed generation to the grid provides improved local power supply availability, especially during disaster as shown in Fig 3 [10-11].

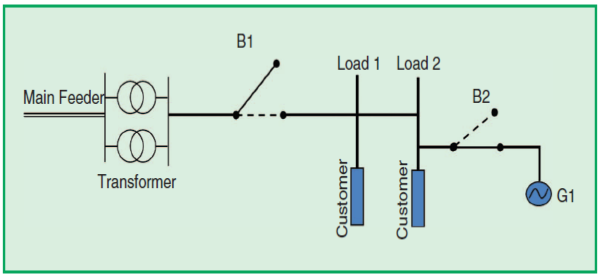

Fig.3 Power resupply with distributed generation [10]

The use of distribution generation should be encouraged as it improves the voltage profile and reduces the losses. It also enhances the use of clean sources of electricity production

[12].Nowadays, distributed generation is applied at data centre and various campuses with an ICT facility and even in air conditioning systems [13].

2) Distributed Energy Storage:

Renewable energy (RE) proves to be a driving force in reducing carbon dioxide emissions. The renewable energy, namely, wind and solar, can't be dispatched to meet the demand in a power system. Thus concept of energy storage comes in picture. The level of stored energy varies from KW to MW with a large discharge time. The energy storage involves various technologies such as pumped energy storage, sodium sulphur batteries and flywheel energy storage [14] as shown in Fig 4.

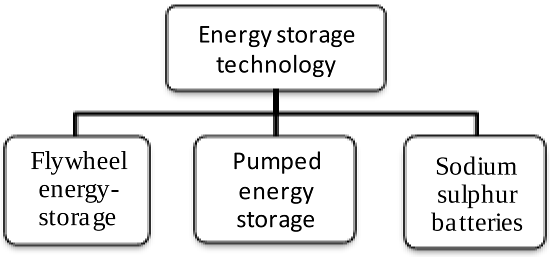

Fig.4 Different technologies of Energy storage.

Pumped energy storage utilizes the stored water of the hydro plant as a source of energy during night. This method of energy storage is fit for hydro plant ranging in between few hundreds of MW. Compressed Air Energy Storage (CAES) utilizes compressed air foe storage of energy. CAES is suitable technique for places such as mines, caverns or depleted gas wells. The capacity of this method is 15MW to 800 MW.

Moving further, sodium sulphur batteries came in to existence in 1960. Primarily, it was designed for electric car but further advancement made it suitable for wind energy storage system.

Flywheel energy storage can be defined as electromechanical storage system in which energy is stored as kinetic energy of rotating mass[15].The rotor which operates in a vacuum and spins on bearing, stores the energy .The range of power storage varies from 40KW to 1.6 MW. It works as the substitution for UPS. Storage devices enable fast controls in a smart grid and improve reliability.

3) Demand Response:

The action of consumer load reduction in an emergency or high price condition is granted through demand response. During peak load or congested operation, consumer load is normally reduced [16].Researchers suggest that non emergency demand response in the range of 5 to 15% of system peak load reduces real time electricity prices [17]. Nowadays, due to transition in demand side management, consumers can participate in the market competition [18].Demand response is advantageous as it is capable to flatten the load profile and improve reliability.

b) Advanced Metering Infrastructure (AMI):

The evolutionary process of Smart Grid requires the deployment of a metering solution with two way communications to the electric meter which is coined as AMI. It provides new information to optimize the operation of system. This information helps in providing load profile, demand, time of use, voltage profile and power quality.

Moreover, two way communications enable time stamping of meter data, outage reporting and conservation during peak periods. The exchange of information and control operations require a communication networks. Neighborhood area network (NAN) is created for smart meters equipped with communication interfaces. Through backhaul, an AMI wide area network, consolidation of meter data is done is shown in Fig 5.

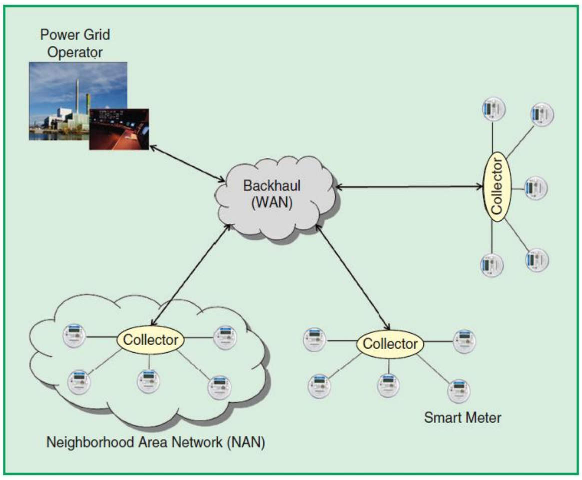

Fig.5 AMI communication network [19].

The exhaustive study of A. Mahmood *et al.* suggested advanced features for AMI [19].Finally, leveraging AMI systems in a logical and cost effective strategy to allow realization of the Smart Grid [20].

C) Communication System:

Experiences have shown that the hierarchical, centrally controlled grid of the 20th century is ill-suited to the needs of the 21st century. To address these challenges, smart grid came into existence. A communication system is the key component of the smart grid infrastructure [21]-[23]. This encompasses the communication systems to enable real-time, two-way data throughout the network [24]. The existing grid lacks communication capabilities, while a smart power grid infrastructure is full of enhanced sensing and communication and computing abilities.

Mainly, two mode of communication exist, namely, wired and wireless. These two different communication media is used for data transmission between smart meters and electric grid. Wireless communications has ease of connection to difficult or unreachable areas whereas, wired communication do not have interference problems and its operation is independent of batteries. Wireless communication technology such as Zigbee, 6LoePAN, Z-ware is utilized for data flow from sensors and electrical appliances to smart meters. Cellular technologies or the internet can be used for data flow between smart meters and grid data centre's. Table II describes the smart grid communication technologies.

TABLE II : Smart Grid Communication Technologies [6]

Technology	**Spectrum**	**Data-rate**	**Coverage Range**	**Applications**	**Limitations**
GSM	900-1800 MHz	Up to 14.4 Kbps	1-10 Km	AMI,HAN,Demand response	Low data rates
GPRS	900-1800 MHz	Up to 75 Kbps	1-10 Km	AMI,HAN,Demand response	Low data rates
3G	2.11-2.17 GHz	384 Kbps-2Mbps	1-10 Km	AMI,HAN,Demand response	Costly spectrum fees
WIMAX	2.5 GHz, 3.5 GHz	Up to 75Mbps	10-50 Km, 1-5 Km	AMI, Demand response	Not widespread
PLC	1.30 GHz	2-3Mbps	1-3 Km	AMI, Fraud Detection	Harsh
ZigBee	2.14 GHz-915 MHz	250 Kbps	30-50 Km	AMI,HAN	Low data rates

There are various requirement of communication system for smart grid. Primarily, the system security should be robust enough to prevent cyber attacks. A smart grid should be scalable enough to facilitate the operation of the power grid [25].A hybrid communication technology can be used to provide system reliability, robustness and availability. For feeding the communication equipment, a telecom hybrid power system is depicted in Fig 6.

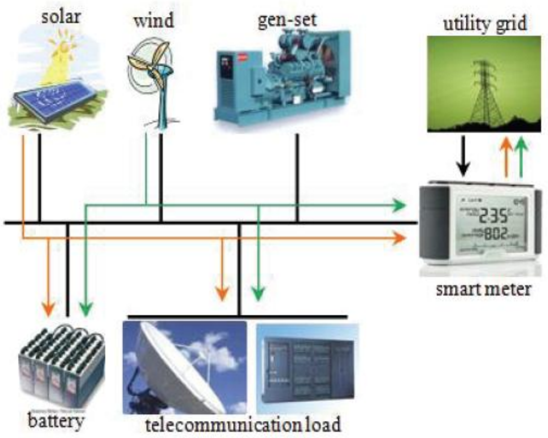

Fig.6 Telecom hybrid power system as element of smart grid [25].

It includes renewable energy sources, energy sources and storage system and smart meter. Energy from hybrid power system can be delivered to the grid, which means that quality of voltage must be grid quality [26].

d) Control and Automation:

Smart grid requires fault tolerant technologies to detect fault either caused by bad or broken connections, bad connection or sensor failure. To maintain security and reliability of the system, real-time data is required which is fed to the wide area monitoring and control systems smart sensors. One of the effective control systems, namely WAC, is implemented whose design is based on dual heuristic program (DHP) method [27]-[29].

IV. PROGRESSIVE METHODOLOGIES

In present scenario, a lot of effort is put in by researchers and scholars in the field of Smart grid. Smart grid is attracting enormous attention as various benefits are associated with it. The concept of smart grid is nascent so various new improvements and advancement are poured in from all around the world. In the same perspective, CARLOS *et al.* suggested a new modeling methodology that integrates the cyber and physical components for future energy system. In cyber and physical energy system (CPES), each subsystem interacts with each other to achieve a particular application objective within a specific time frame. The control strategies associated with CPES are network based control [30], multi-agent modeling and control [31] and online prediction [32].

Subsequently, E. Ortjohann introduces a multi-level hierarchical control strategy involving clustering concept [33].It forms new distribution generation units into a mini-grid or micro grid. It can further add into main system or can operate as an islanded mode as shown in Fig. 6

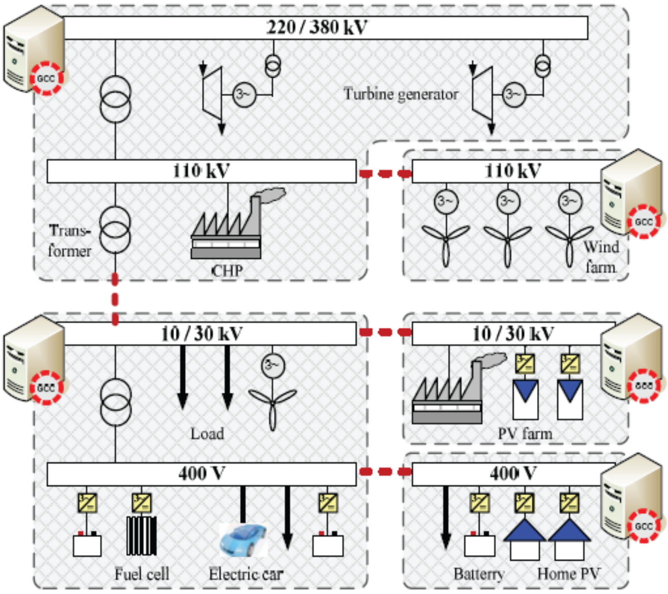

Fig.6 A Sample cluster concept of power system [33].

Grid cluster control (GCC) is established for power flow management in each area. To fulfill the requirements of tomorrow's energy system, new concepts in power electronics are needed. The intensive study of D. Divan *et al.* suggested thin AC convertors for smart and controllable grid [34]. The concept constitutes direct AC conversion using semiconductor switches small LC filters, switchgear as depicted in Fig 7.

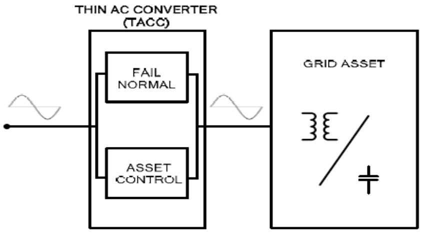

Fig.7 Concept of thin AC convertor [34].

In 'Fail Normal' mode of operation, the failure of thin convertor regains the normal function of the assets of the grid. Further, E. Ortjohann *et al* proposed an innovative concept of modular inverter design for three-phase inverter. The introduced concept offers the required flexibility and adaptability for modern power supply system's [35]. A new range of power semiconductor devices was suggested in the work of Leo Lorenz *et al.* [36]. On the other hand, the study performed by J.W Palmour *et al.* proves to be a milestone for IC based high voltage power devices for building a smart grid with distributed and fluctuating sources of power generation [37].

Fault location is a critical part of Smart distribution grid. The focus of the study performed by Q. Pang *et al.* is an algorithm concept of Multi-agent for fault location in smart grid [38]. Multi-agent system is combination of several agents with a proactive approach .It is applied for power disturbance diagnosis and its restoration along with secondary voltage control [39-42].

The concept of protection relay system for operation within a smart grid is introduced by the research work of F. Kawano *et al* as shown in [43].On the other hand, the concept of unmanned aerial vehicles for transmission lines for routine and emergency line inspection was devised through the effort of J. Toth [44].

Smart grid applications rely on highly robust and secure communications. In this respect, C. Wietfield *et al.* proposed wireless M2M communication network for smart grid application. However, J.J. Jamian suggested an approach for balancing the frequency of the system by adjusting its power consumption through a good data communication management [45].

V. CONCLUSIONS

This paper has reviewed the state of art in Smart grid to provide a clear perspective on various aspects to the researches and engineers working in this area. Smart grid is primarily assimilating communication and information technologies to enhance grid reliability and to enable integration of various smart grid resources such as renewable resources, demand response, electric storage. Smart grid will lead to a more integrated system in which loads become active participants and where opportunities for new business models will arise. Fortunately, the advent of new and advanced design methodology in Smart grid will open new frontiers in power system.

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