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"Economic and Security Challenges Faced by Smart Grid"

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Firma dello studente

M.Dassoum _____

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ABSTRACT

This thesis aims to introduce the Smart Grid and to compare it to the traditional electrical grid. Next were described the various components of the smart grid, the aim of each and the flow of power and information throughout the process.
Moreover, the different types of technical problems, cyber attacks and threats that can affect the Smart Grid were explained with several proposed security solutions including cybersecurity.
Furthermore, the advantages of the smart grid and its economic disadvantages affecting the market were cited and defined.

Keywords: Smart Grid, Substation, Cybersecurity,Threats, Power, Information, Smart meter, Transmission, Distribution, Advantage, Disadvantage.

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LIST OF ABBREVIATIONS

SG: Smart Grid

ICT: Information and Communication Technology

AMI: Advanced Metering Infrastructure

MDMS: Meter Data Management System

ARERA: Italian Regulatory Authority for Energy, Networks and Environment

MC: Marginal Cost

AC: Average Cost

RPI: Retail price index

MEF: minimum efficient scale

HAN: Home Area Networks

SCADA: Supervisory Control and Data Acquisition

P: Price

EU: European Union

IoT: Internet of things

WAN: Wide area network

PMU: phasor measurement unit

DOG: disruption of grid

DOP: denial of power

TOP: theft of power

VPN: Virtual private network

AES: Advanced Encryption Standard

MFA: Multi-factor authentication

OTP: One time Password

PV: photovoltaic

CO2: Carbon dioxide

BESS: Battery energy storage system

DP: Dynamic programming

MG: Micro grid

Km: Kilometers

DER: Distributed energy resources

SS: Smart sensor

GW: Gateway

PDC: Phasor data concentrator

DAU: Data aggregator unit

WAMS: Wide area management system

EMS: Energy management system

IDS: Intrusion detection systemSmart Grids definition and typesChapter 1-

IPS: Intrusion Prevention system

PLC: Power line communication

Kwh: Kilowatt-hour

IOE: Internet of Energy

MPC: Model Predictive control

CBA:Cost-benefit analysis

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INTRODUCTION

The electric grid is an interconnected network of transmission lines, transformers and substations that deliver electricity from producer to consumer. A smart grid (SG) is an organized electrical grid that allows, through Information and communication technology (ICT), a double ways communication flow of data and electricity between the producer and the final consumer, it promotes and collects data through digital communication technology that enables it to proact, react and detect any issue that may occur to the web through self-healing capabilities. One of the best features of the smart grid is granting customers the capability of being active participants to manage and moderate the energy consumption in the peak demand times to save energy and mitigate bills efficiently. Although it consists of sensors along the transmission lines, in addition to computers and new technologies that work simultaneously, to enable transmission of power and information. The complexity of the network makes it a target to hackers therefore, securing the information is a vital asset when dealing with the smart grid, and it is one of the most important pillars to protect it against any hack or fault with the support of the advanced metering infrastructure (AMI) and a meter data management system (MDMS) that constitute the basic smart grid components [1] .The demand on renewable resources is vividly increasing globally such as photovoltaic, hydroelectric turbines and wind that are mainly used as power sources when installing smart grids. Indeed, most key industries across Europe come under the control of the state, since 1926 national electricity grid was established and later in 1947 over 500 independent electricity suppliers were nationalized.[2] Governments intervene by managing and setting regulations and policies locally, regeonaly, and nationally for controlling natural gas, water and electricity trading. The main aim of these regulations is protecting consumers rights and the interests of users and consumers. Limitate consumption costs in the market such as ARERA1 Italian Regulatory Authority for Energy, Networks and Environment

Established by Law No. 481 of 1995, ARERA is an independent administrative authority that operates to ensure the promotion of competition and efficiency in public utility services and protect the interests of users and consumers.

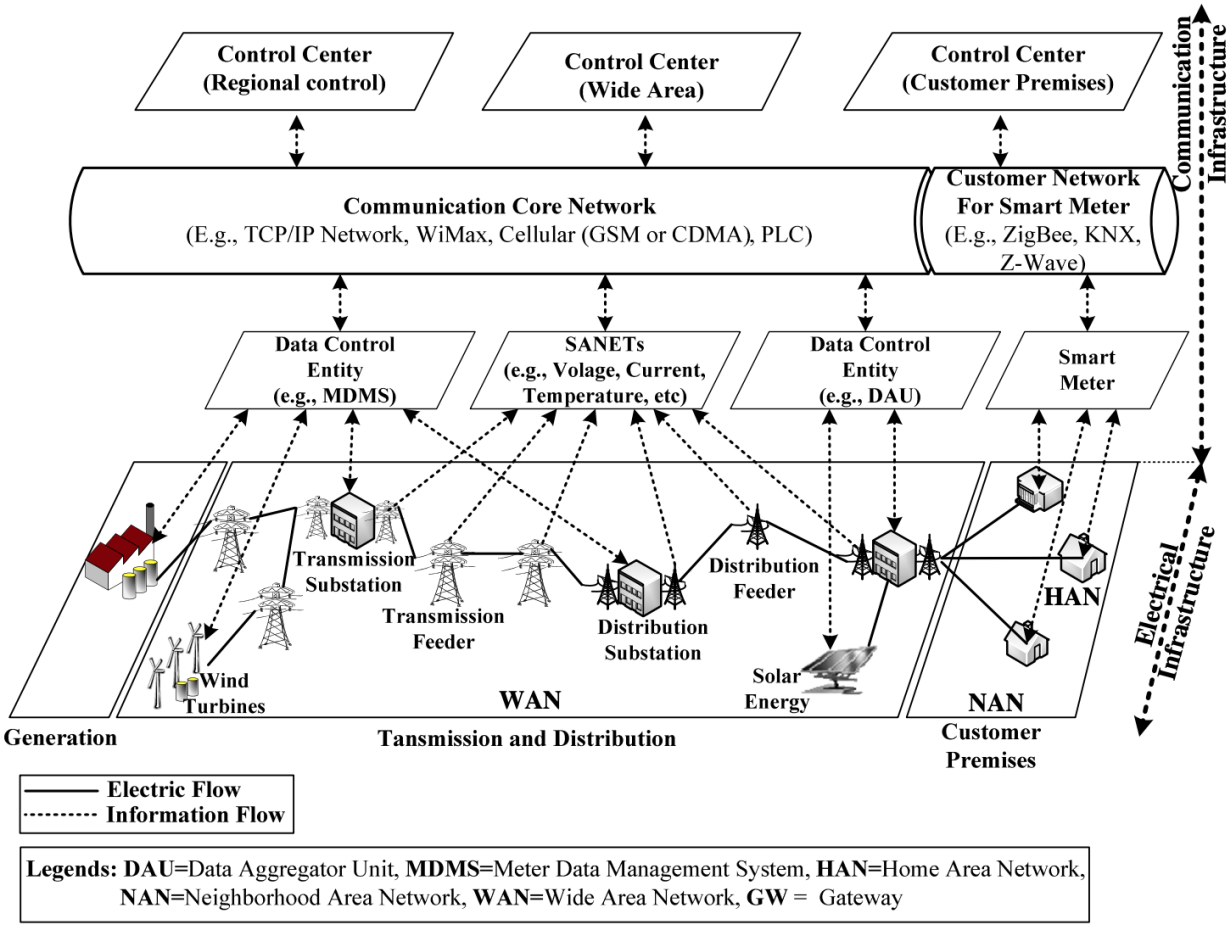

Figure 1: Example of SG electrical and communication infrastructure divided into four phases: Production, Transmission, Distribution and Utilities. [10]

Chapter 1- Smart Grids definition and types

A smart grid is an intelligent network that permits the delivery of data and electricity between producer and consumer. It is an evolution of the traditional electric grid. It is a sophisticated power and information delivery system integrated with information communication technology (ICT) to detect and react to variations in the system.

Below is a table that compares the traditional electric grid with the smart grid.

Traditional electric grid	Smart grid
Delivery of electricity	Delivery of data and electricity
One way communication from producer (Power generation plant) to consumer	Two ways communication between producer and consumer
Absence of self healing capacity, normal grid function is manually restored by a technician after detection of a problem and this takes a lot of time	The grid can detect problems in the network and heal itself (automatic recovery). power can be redirected to the convenient path and this will minimize the down time and the affected area.
Few sensors are available	Sensors are present throughout the pathway and are numerous
centralized power generation plants with traditional infrastructure, renewable power sources cannot be implemented through the pathway	Power generation is distributed such that renewable resources as solar panels or wind turbines can be implemented at some individuals who can produce energy and send it back to the grid
Absence of real-time monitoring and consumption management.	Provides real-time information about power consumption and distribution, so that consumers can plan their activities accordingly (minimize the usage of electricity in peak times)
Power distribution is monitored manually and limited to the level of power generation	Power distribution is automatically monitored all over the data and power pathway via sensors and can be routed remotely according to necessity.

Table 1: comparison between the traditional electric grid and smart grid (7).

The figure below represents a simple representation of the traditional electrical grid, showing its main components and the unidirectional electric flow pathway.

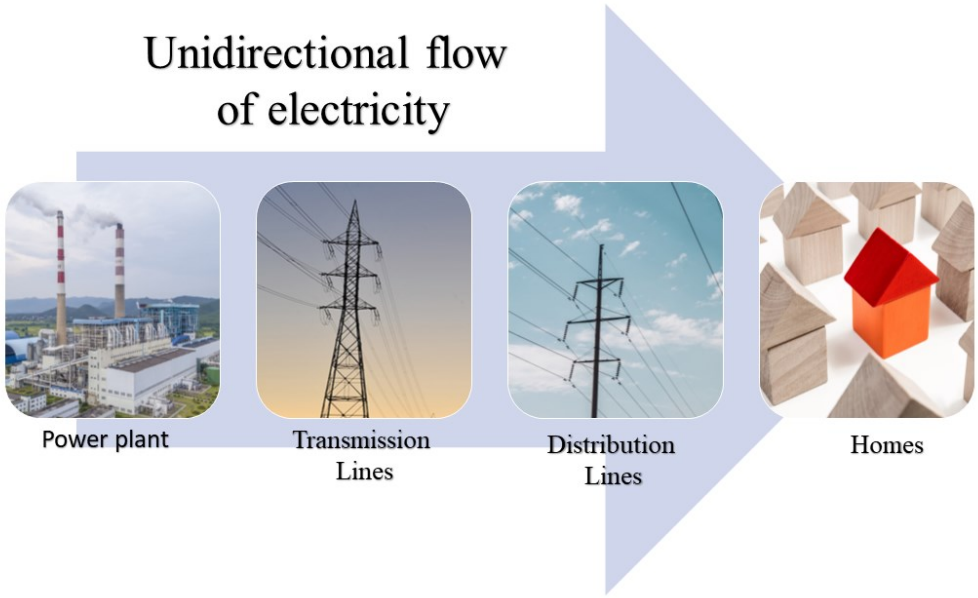

Figure 2: a simple representation of the traditional grid

A smart grid is an evolutionary element that cannot act solely. The pathway of power and data delivery is constituted of many necessary elements with different functions to maintain an efficient and stable power distribution.

Smart grid consists of varieties of parts and equipment, controllers, complex interconnected elements, power lines, nonlinear operation, and a large number of technological parts. These systems must be highly organized and installed precisely, and all the components should be tested and to guarantee the continuous operation of the system properly.

Energy production and transmission should always remain credible and securely protected according to the ministry of economic development and by the Italian regulatory authority.[3]

regulatory authorities play an essential role in this regard to protect producer, transmitter, and consumer's rights and assure a fair supply of energy with the fair competition.. furthermore, The

European Commission will highly ensure respect to environmental regulations by assessing all the impacts that may affect the environment and its biodiversity.[6]

The goal of the European Union (EU) for the year 2020 was to increase renewable energy supply up to 20% of total demand and reduce energy consumption by 20%.

Diversity in Europe presents states that can pay for a service and others that can provide it. There is where an idea of projects of common interest was born to encourage all states to participate in the development of infrastructure needed for the implementation of smart grids and the use of renewable energy. The EU commission insisted on the importance of building connections between European states so that any company has the right to sell their energy services over all the states, and this will enforce competitive prices. Participating states will benefit from an accelerated permit granting procedure as well as funding, grants, and guarantees. These projects involve at least two states showing economic development, flexibility, and having energy storage sites. Once selected, states participating in the projects can apply for funding that may reach 80% according to innovation and synergy between states.

corresponding regulations are mainly related to infrastructure and the energy market. To achieve goals set by the EU commission, it is necessary to integrate solar and wind energy. Moreover, to introduce smart meters that permit consumers to use energy transmitted by smart grids efficiently.

Supply and demand of the electricity system should always remain stabilized through managing the energy flows in the entire country, for achieving this target, energy management and control plays the main role in producing and transmitting energy required on the national grid in real-time. We refer to this action by the term called dispatching therefore, management in real time and coordination of production is essential starting from the power stations to the transmission, and full integration and exploitation of renewable quantities. This national strategy is activated in the Italian market and managed by the Terna control center of high voltage grids across 26 borders, over 74000km power lines, and 3 submarine cables.

The figure below is a simplified representation about the SG architecture, showing some essential components of the SG system that will be defined and detailed in this dissertation.

Figure 3: Example of Smart grid architecture [17]

1.1 Electric power generators

instead of the traditional power generation plant alone, the smart grid includes the usage of distributed multi-sources electricity. This feature increases power distribution efficiency and reliability. Small scale power generators (DER) can be located near the consumer such as photovoltaic panels, hydropower, and wind turbines,.... which consist of renewable resources that are a good green alternative for the traditional power generating plant. As per the International Energy Agency: *"Renewables, including solar, wind, hydro, biofuels, and others, are at the center of the transition to a less carbon-intensive and more sustainable energy system."* [11]

According to their capacity and consumer needs, these resources can be used alone or in combination with the traditional plants to produce energy. These resources are necessary to keep a stable energy pathway, since it is possible, in the case of the smart grid, to send electricity to the main grid, and thus compensate for any production or delivery failure from the main plant. [8]

1.2 Transmission and distribution lines

It is the backbone of the smart grid that interconnects substations via network lines. It is used to deliver electricity and data from the substation to NAN (for example, to deliver electricity from the power station to the consumer and facilitate power transmission from one domestic country to another. Transmission lines characteristics are very important to ensure endurance against electricity load and any emergency to prevent any flow interruption or power outage. [33]

1.3 Data Collector and sensing nodes

This is used to collect data from different sources that are generated at different times, collected data will be processed.[27]

1.4 Control center

the control center is operated by technicians that are responsible for the continuous control of smart grid functionality, especially distribution and transmission cycles. They monitor the substations, transformers, and feeders. In addition, they manage the dynamic load of energy, faults, and outages. The main purpose of their mission is to ensure the uninterrupted and safe delivery of power and data throughout the network. [10]

1.5 Smart meters

is an electrical advanced device that registers the energy consumption of the consumer and monitors voltage levels and current flow. Information is communicated to consumers and energy suppliers. The smart meters send data collected to the supplier via a smart wireless communication network. Therefore, suppliers can monitor the system and send accurate bills to consumers that can reliably pay them. Furthermore, consumers can know the energy consumption and the charges in real-time and especially at peak times so they can schedule their appliances usage accordingly, although they can freely check their energy consumption and have a record about their energy usage. Also, smart meters can measure the amount of energy that solar systems or wind turbines are sending to the main grid so the load can be managed accordingly. Smart meters are also capable of informing the supplier about theft and fraud attacks to ensure system security. A smart meter

communication infrastructure is needed to link energy suppliers to the meter in a wireless way. [14]

Below you can find an image showing a real smart meter showing the real-time unit cost of electricity per hour and the monthly consumption. It also shows a menu so the consumer can navigate to different modules to check the status of his consumption and bills.

Figure 4: Smart meter example [18]

1.6 Smart sensors (SSs)

Provides the status of the smart grid such as real-time data usage, monitoring, control, and all data related to the grid's operation and protection in real-time.

1.7 Electric power substations

Electrical substations constitute the link between the distribution and transmission systems. The essential element is the transformer whose role is to lower the high voltages coming from the transmission system so they will be suitable for distribution. Substations are responsible for isolating some components of the system besides the main role of controlling the distribution and transmission power to another unit in the system through circuit breakers. [28]

Mainly there are three essential types of substations with different roles, they function in different locations in the smart grid.

- **Step-up substation**: The role of this substation is to increase the voltage arising from the power plant so electricity can be transmitted efficiently.
- **Step-down substation**: The role of this substation is to decrease the voltage coming from transmission lines (sub-transmission voltage)/ this type of substation is used to supply industries.
- **Distribution substation**: the role of this substation is to decrease the sub-transmission voltage so it can be sent to industries, commerce, and residences.

1.8 Phasor measurement unit

The sensor that measures the voltage of electrical waves on the smart grid to ensure the quality of power delivery. It generates a huge amount of phasor measurements in a small amount of time. Since the sensing nodes are deployed in several locations of the power grid demonstrates scalability challenges. Measuring the delivering power quality with the support of PMU by sending up to 30 reports per second. Distributed computation and sensor measurement techniques must be highly decentralized aggregation for actuator parameters.

The Control center is responsible for collecting and aggregating phasor data among PMUs and Phasor data concentrator (PDC) such as synchronous optical networks, WAMS are connected to PMUs for wide dynamic area coverage. Classical SCADA and Energy management system (EMS) provides limited local monitoring and control is the large coverage and that is one of the major advantages of WAMS. The main technical issues that may apply in the WAMS are delays and congestion. Because PMU leads continuous information sampling in real-time.

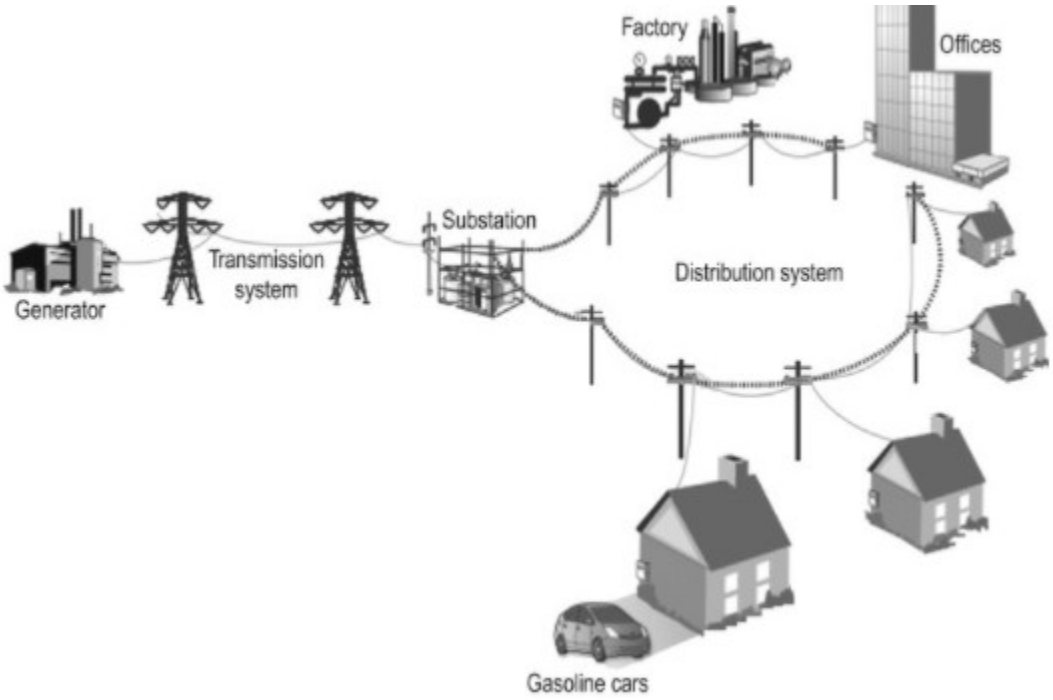

Figure 5: Substation placement in an electrical grid system[12]

We can assume that the Smart Grid constitutes a real big evolution to the electricity system. Several components were added to the traditional grid to get a smart one. Unfortunately, adding new items ends up by entering new vulnerabilities and gaps to the system that will be further discussed in the upcoming chapters.

Chapter 2- Cybersecurity and technical vulnerability

Cybersecurity is the activity of protecting the network, servers, and devices from intruders, hacks, and threats. It helps ensure data integrity during storage and transition. The complexity of interconnections of the SG and the network communication system make it an attractive area for weak spots that are a good target for cyber attacks [19]. Actually, Some components of the SG system are digitized and deal with IoT based infrastructure, therefore they may face several security issues and be attractive to risk cyber-attacks and threats. For example, the risk of smart meter cyber attacks increases if the meter wasn't resilient and hackproof.

In this section will be discussed the major components of the system that are exposed a higher risk of cyber attacks and threats, as well as the common security risks that they may face and their corresponding solutions.

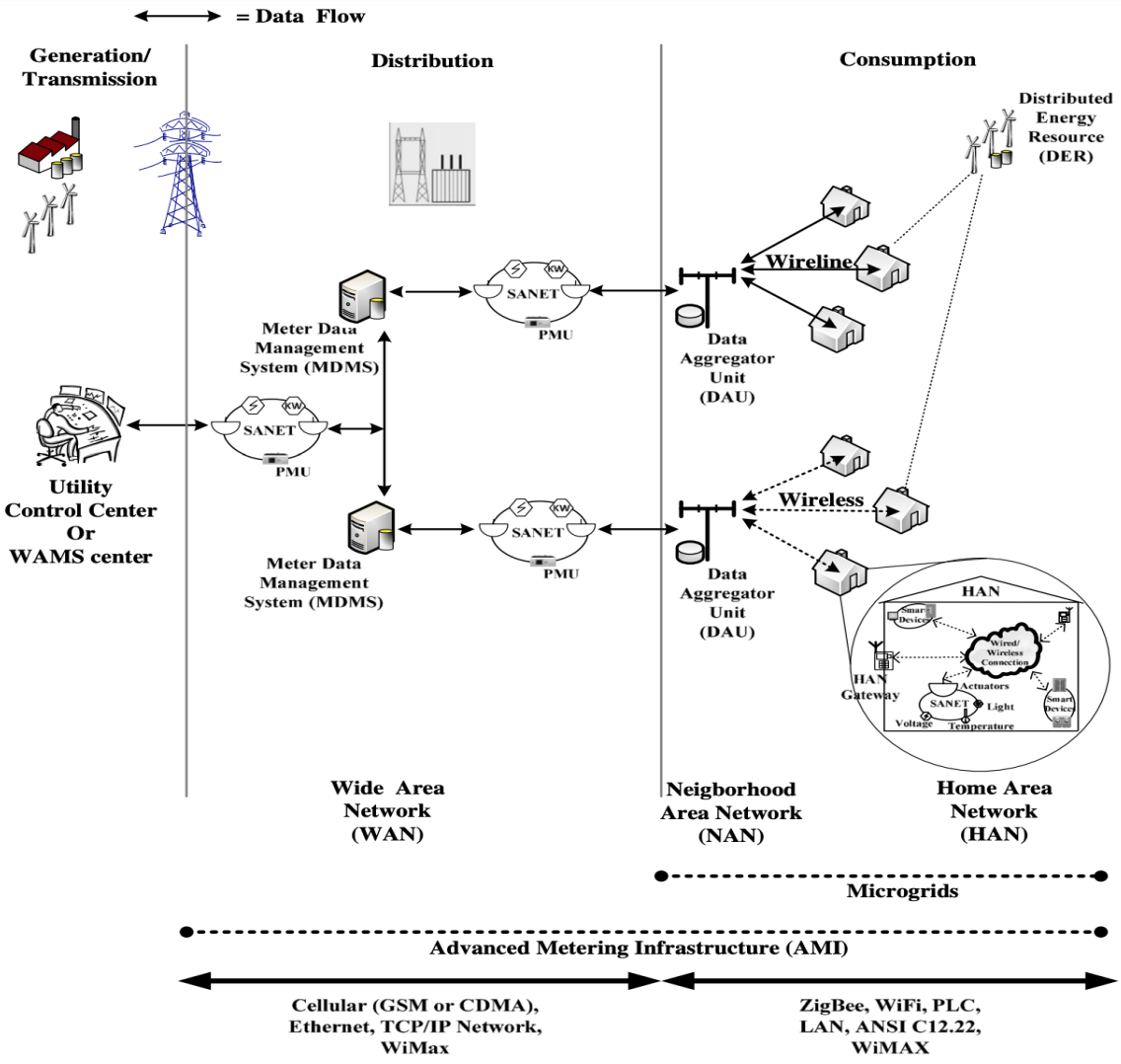

Figure 6: Wide area network WAN and combination of microgrid NAN and HAN [10]

Security is essential to ensure reliability for the smart grid and provide power consistency over WAN, NAN, and HAN. The main function of Advanced metering infrastructure (AMI) is collecting and transmitting smart meter data that is allocated to devices and meter data management system (MDMS) technological evolution, such as internal web and web portals, reporting functions, independent system operators, and suppliers that are responsible for facilitating data collection, management and storing necessary information. This information is mainly related to the grid condition, automated devices, and operators' modulation. At this level, the system dynamically responds in case any variation occurs.

Some features support the grid and make it more efficient by using better failure controls. From one side they provide consumers with better information concerning energy consumption, and from the other side, they can provide utilities with efficient and evolved operational processes.

The managerial process should undergo evolution to be more effectively developed to allow accurate testing of variables and respond rapidly to several kinds of risks.

Organizations are taking into consideration the technical vulnerabilities related to these kinds of technologies and evaluating them on several levels.

- Vulnerability assessments.
- Threat profiling.
- Security management. [16]

2.1 Smart Meter Cyber Attack Surface

Smart meters are vulnerable to a high level of threats and cyber attacks since they are considered a main part of the information infrastructure and communication network. different forms of cyber attacks can be considered such as power and information theft, service disruption.

The attack of the smart meter can have different forms and intentions. Several methods can be used to invade the target according to the size and scope of the attack. Attacks can be on a large scale and cause the shutdown of the grid stopping power delivery.

2.2 DOG (disruption of grid)

Disruption and instability in the smart grid occur due to the compromisation of the high number of smart meters, which leads to connecting and disconnecting rapidly in an inconvenient way, and disorganized sequences, which affects negatively the stability of the SG. These concepts may affect the termination of power transmission, or losses in large-scale areas. Ultimately SG will be unable to absorb this disposal.

2.3 DOP (Denial of power)

This usually occurs when an attacker intends to stop the power transmitted for the consumers. Critical users could be the main target for the attackers, it may be significantly harmful. Smart meter data can also be changed to distort energy consumption with any other smart meter.

2.4 TOP (theft of power)

This usually occurs when the attacker intends to retrieve power from the consumer. Customers that are disconnected from the utility may try secretly reconnecting to obtain power. Even though data presented by SM could be altered to misrepresent the power consumed on any SM.

Architecture**:** Corporates should be able to upgrade a protection system against any widespread threats, and any anonymous hacks that lead to failure in communication. Local systems intervene autonomously to repair and optimize connectivity. Exploiting weaknesses in the infrastructure by any kind of attack leads to gaining access to MDMS and to the corporate network, considering that AMI's metering network is connected with the MDMS core network.

2.5 Interoperability

AMI technology has a high risk at the level of data and information. MDMS receives data that can be manipulated from the AMI. Therefore, it is necessary to gain operational advantages and protect customers' data through the management and cyber security systems.

2.6 Communication protocols

The communication must be highly encrypted between AMI and MDMS devices to compromise it. Attendance of authentication and authorization are essential to be encrypted against tempered devices.

2.7 Interfaces

Smart grid applications are vulnerable to threats and attacks.

2.8 Home area networks (HANs)

The network between smart home appliances and the smart grid should be secure since these appliances are also subject to hacks and manipulations.

2.9 Customer portals

Network utilities and customer demand may be affected when attackers access customer accounts, especially customer settings

2.10 Hardware

Hardware such as the smart meter is vulnerable to external unauthorized manipulation that can be harmful to the consumer and network.

Common security risks in Smart Grids

2.A Phishing

Phishing is a fraudulent practice in which the attacker sends an email to the victim acting as the email is genuine from a reputable trusted reference, requiring urgent action and asking for

credentials, credit card number, click on a fraudulent link,... Phishing is considered an easy method used by hackers to artifice consumers and use their information. This may affect the user mentally and financially and could lead to hacking the system**.**

2.B Denial-of-Service

The communication network of the smart grid is made in a way to support a high load of data exchange and is vulnerable to cyber-attacks such as Denial-of-Service. In this case, the user's access to the network is interrupted. Taking advantage of the bugs present in the system, attackers can send a very high load of information to the server to be saturated causing it to slow down and in some cases lead to termination. Another way for the Denial-of-service is when attackers send input causing the system to destabilize and crash.[23]

2.C Malware spreading

The communication network is vulnerable to cyber attacks. Attackers of the smart grid invade the network using malware and they try to infect many nodes. According to the infected node, invaders can disconnect elements of the grid as well as they can invade the homes and smart meters so they can manipulate devices and the invoices. The attacker can also have access to sensitive information by infecting servers and devices of organizations. [21]

2.D Eavesdropping and traffic analysis

Eavesdropping is a type of spoofing attack, it permits the hacker to collect sensitive information about users, through monitoring network traffic. Large networks that have been consumed by SG including the network nodes permit data to be stolen since it is hard to maintain the connected devices. Network transmissions may appear operating properly regardless of the difficulty of detecting the hacks on the system.

Strategic Security Considerations

- Supervisory Control and Data Acquisition (SCADA).
- Open network systems.
- Integration of legacy systems.
- Field device authentication.
- Publicly reviewed standards.

Since SG leans on merging technologies such as automation, computer, controller, and other electric equipment, all these components should be highly precise, running efficiently and continuously 24/7. On one side it is necessary to conserve and protect the smart grid from any threat and peril that may occur such as a thunderstorm and weather phenomena that lead to miscarriage of the power lines and terminate the distribution of the electricity to serve final consumers. On the other side attacks and hacks should be taken into consideration, in most cases an email sent to consumers or to employees which are supposed to look like a genuine email, is encoded and programed focuses on collecting all customers personal data, related to the bank confidential data, visa card, bills, consumption.

Proposed security solutions for Smart Grids

The complexity of the smart grid network makes it a place for bugs rendering it highly vulnerable to attacks, therefore it is necessary to protect the system and the user from hacks and frauds. Several security solutions can be implemented procuring several levels of protection.

2.E Encryption

Encryption is the use of mathematical algorithms to scramble some information and make it unreadable. Encryption is used to secure data in a form of a code and usually, VPN connection is encrypted so that network attackers cannot read the data if invaded. “Cypher” is how data is scrambled, and “Decypher” is the way data can be read via a key. VPN providers recommend AES as an Encryption method because it is the highest standard. The size of the “Cypher” used in AES is 256-bit which is high enough to provide a high level of scrambling and therefore a high-level combination leading to a high level of security. 256-bit encryption is considered as a very high

number of combinations that no one in the world can assume and that is why it is usually used by banks and governments to keep their data secure. [22].

2.F Authentication

Authentication is a necessity to keep data secure and inaccessible by anyone other than the concerned person. Therefore, multi-factor authentication (MFA) is suggested in the case of smart grids to provide a high level of security for the user. Multi-factor authentication is applied when the user has to provide several verifications to ensure his identity and have access to the system. A system protected by a multiple factor authentication is much harder to attack compared to a system protected by a single factor authentication. It necessite that the user enters several identity proofs to gain access to the system.

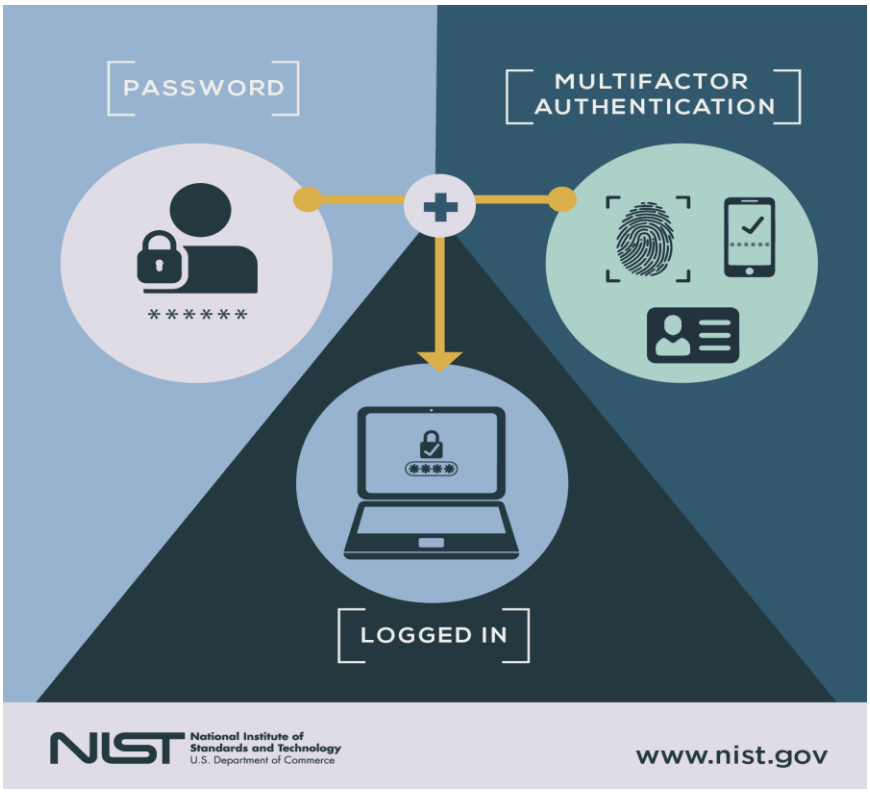

Figure 7: Multi-factor authentication [24]

One of the most common MFA factors is. OTPs are 4-8 digit codes that a user receives via email and/or SMS requiring him to re-type it in the corresponding place so that he can gain access to the

system/application. With OTPs a new code is generated periodically or each time an authentication request is submitted.

2.G Malware Protection

The embedded system and the general interconnected system which are connected to SG needed to be protected and secured from any cyber attack. Any asset of SG such as smart meter, control room, substation, and home gateways are potential targets for a cyber attack.
The embedded system in the SG is highly secured because it is exposed and runs through the manufacturer and to validate the software, a manufacturer key is required.
Using the manufacturer key only to verify the software authenticity and if it is not duplicated software with any kind of authorization.[26]

2.H Network Security

The virtual private network is more secure than the public network since it uses encryption to secure data and protect the information transmitted along the communication pathway.

Security Level	European Grid Stability Scenario Security Level Examples
5 - Highly Critical	▪ Assets whose disruption could lead to a power loss above 10 GW ▪ Pan-European incident
4 - Critical	▪ Assets whose disruption could lead to a power loss from above 1 GW to 10 GW ▪ European/country incident
3 - High	▪ Assets whose disruption could lead to a power loss from above 100 MW to 1 GW ▪ Country/regional incident
2 - Medium	▪ Assets whose disruption could lead to a power loss from 1 MW to 100 MW ▪ Regional/town incident
1 - Low	▪ Assets whose disruption could lead to a power loss under 1 MW ▪ Town/neighborhood incident

Fig 8: Architecture of security level and SG stability[25]

2.I Remote access VPN

The remote VPN is connected to a public network that provides access to the private network for organizations. In this case, users have the ability to connect their electronic devices to the internet after finalizing the authentication process on the VPN gateway. After credentials correctness inspections, authentication validates the access permitting organizations and users to reach resources on the network. This resource includes documents and business applications. Users are permitted to access their work anywhere through a remote VPN gateway. Authentication can gain access to all resources viable on the network.

2.J IDS & IPS

These are two complementary fast and efficient services used to detect and prevent malicious threats and cyberattacks attacking the network system. Network Intrusion detection system (IDS) detects threats and incidents through the network. Network Intrusion prevention systems (IPS) continuously monitor the system to prevent and limit the activity of cyberattacks. Malicious events are reported to the administrator who can act by closing access points to prevent hacks and identified threats in the future. Also provides security policies protection to the organizations by deterring any rules violation that could be activated by employees and guests visiting the network.

Intrusion detection systems (IDS) deal with (IPS) solutions in most popular networking applications for preventing several damages. The divergence between IPS and IDS lies in the operations performed when a potential event is discovered. Intrusion prevention systems regulate access to networks and protect them against abuse and attacks. Systems are intended to monitor intrusive data and react to prevent attacks from occurring and extending.
IDS are responsible for detecting threats instead of blocking attacks, and automatically notifying the administration department.

2.K Site-to-site VPN

Site-to-site VPN and the Remote access VPN are more or less equivalent. However, while they usually connect the entire network in one place, these networks are located in different

locations,which means that large organizations can safely share resources or access them at multiple points in different locations for partners or corporate customers.

2.L Risk and Maturity Assessments

System attacks are usually exerted by thieves whose intention is to withdraw electricity from the system. Theft is performed between the distribution transformer and the smart meter that is located in homes. Electricity theft is detected as energy loss.[22]

System energy loss can be the result of technical losses, such as line resistance or weak isolation of electrical wires, as well as theft losses. Technical energy loss is hard and expensive to be measured, that is why it is difficult to detect if the loss is due to theft or technical losses. The common method adopted by MDMS for loss detection is to estimate the loss by calculating the difference between energy supplied and energy consumed, and considering that there is electricity theft in case the amount calculated exceeds a certain limit. This calculation is more simple to be performed in case of smart meters that measure energy consumption at very small intervals of time. [9]

At the end of this chapter we can say that security problems are different, they vary with the component attacked and its vulnerability. Since smart contains a large variety of components and a complex network, therefore different types of hacks and attacks may occur. Implementing cybersecurity risk assessment and security audits limits the cyberattacks and helps applying security solutions to the vulnerable areas.

Chapter 3- Advantages and economic disadvantages

The term smart grid is synonymous with ingenuity and evolved benefits.

Energy networks that meet the diverse needs of society in terms of sustainability and energy efficiency. Smart grids promise better energy management for energy providers and consumers, provide opportunities for grid integration, support the development of microgrids, and engage citizens in greater responsibility for energy management. However, this can be accompanied by issues like cyber security breaches and privacy threats.That it is essential for the future of energy management and the key issues in the design of energy management systems in modern environments. The network has the background of the power management system. The answer to the question is also analyzed. The advantages and disadvantages of implementing an energy management system with an electrical system are explained.

3.1 Energy savings through reducing consumption

At any time consumers can monitor their energy consumption and have detailed information about real consumption through an energy meter that is connected to the grid. Therefore, the consumer can choose the best time to use electricity and regulate energy consumption according to their needs. this way consumers can reduce electricity bills

3.2 Better customer service and more accurate bills

Telemanagement systems provide accurate bills, and show the real power consumption of each month without estimation, unlike the manual reading of the traditional electric grid system which is costly in some manifestations. Although it promotes easy diagnostic of problems and responds faster for maintenance as well as access information about the remote installation to provide a high level of customer service.

Nowadays consumers don’t have to inform the electric companies about any incident that can occur, the system itself is proactive against any fault, it reports it directly and automatically via the remote management system to the company that in turn works on solving the problem quickly.

3.3 Fraud detection and technical losses

There are some direct and indirect effects if we are asking how fraud being perpetuated by other customers affects us. The Telemanagement system detects fraud accurately, with the support of Power line communication (PLC) technology and sensors that are connected to monitor if the terminal strip cover was opened. In case fraud occurs to the system, it increases the electricity bills toward consumers without affecting the utilities.

Moreover, PLC technology prevents fraud by warning the managers. The control center sends signals and alerts automatically to managers so they can take action against any attack.

Energy balances can be performed by the units with PLC technology. Therefore, the whole energy consumption revealed by the smart meters installed should be calculated by additivity. Total calculated consumption is then compared to the sum shown by the totaliser {9*} that is installed on the top of the line. In this stage, technicians can check whether it is prodigal or theft at any point on the system that the control unit is not aware of.

Totaliser{9*}: A totalizer is **a measurement feature included with some types of meters that stores or maintains a record of the accumulated quantity of some substance over time**.

3.4 Reduced balancing cost

A huge amount of data is collected by the smart grid as opposed to the energy meter system. From this perspective, sophisticated algorithms are implemented to perform data analysis taking into consideration many more variables to facilitate the forecast of realistic energy consumption.

Prosumers can have an indirectly impact trade on electricity consumption, in some cases they play role of being producers by contributing to sell their energy surplus back to the utilities. While the whole sale trading are the main influencers in the electrical industry consumption. Estimation model such as (MPC) Model Predictive Control analysis energy consumed hourly, daily, and seasonally are the optimal times and essential to forecast the amount of energy needed to be purchased by the end-users in the upcoming period. That is how production meets the exact electricity users and maintains the electricity market balance.

Markets are incentivized to contribute by balancing supply and demand on the grid by generating the power domestically, reducing transportation costs of SG. Losing energy on the network transmission lines occurs by increasing electricity transportation. Mitigating transportation losses can be compensated when supply and demand are connected locally. [35]

As mentioned in previous chapter using Wi-Fi connected to SM's that provides data to HAN this lowers the communication cost.

Cost-benefit analysis (CBA) shows a systematic process from society's perspective comparing the advantages and disadvantages of SG. It shows the analysis of literature on social costs and solutions for SG's by identifying gaps.

Effect Category	**Examples: smart metering systems[4]**
Investment and reinvestment in production, transmission and distribution	Avoided investment in conventional meters, but sunk costs from removal of existing meters.
Security of supply	
Congestion costs	Reduced costs related to limitations in transmission capacity.
Costs for reserve capacity	Reduced costs for reserve capacity.
Restoration costs	Reduced costs for restoration.
Management costs	Costs for training staff and consumers.
Monitoring costs	Reduced costs for meter reading.
Customer service costs	Reduced costs for call center/customer care, higher costs for consumer engagement programmes.
Costs of theft/fraud	Reduced costs of electricity theft.
Security – reduced usage of oil	Reduced dependency on fossil fuels.
Security – wide scale blackouts	

Figure 10: Costs and benefits from investments in Smart Grid. [36].

3.5 Increased competition

Awareness about consumed energy data plays a good role for the companies to adjust their prices concerning the energy demand. Although, when companies have more data they can make wider offers through promotion and marketing on the final goods, increasing competitiveness by launching a variety of offers such as energy packages and hourly tariffs.

Consumers can leverage competitive pricing as competition increases in the market. Commercial and industrial consumers, given that they consume more electricity and demand is higher than the regular household levels, may have the opportunity to reduce their cost of energy bills by connecting to the SG. Customers can interact through HAN and SM's to the electricity market which gives them the ability to be more efficient in their consumption, and being more motivated to reduce their consumption by reducing transportation costs with the presence of EV. While each customer is contributing even limitedly it results radically by exploiting the presence of SG to reduce their bills, and for being a future prosumer. [37]

3.6 Demand curve Leveling (Peak reduction)

Optimization of the electrical network usage could be achieved by lowering the demand curve on the global SG. Managing the utility can be done when customers intentionally increase load at off-peak times when the kWh is less expensive. When the customers substitute their consumption habits they increase loyalty to save money from an economic side, leading to avoiding overloads on the line in the peak time, and encouraging the utility to balance consumption. In transition, the power plant reduces the turning on and off of its equipment to produce power many times. They can, at off-peak times, sell the surplus already available and that is feasible due to the consistent consumption. This leads to reduced energy generated and lowering the generation costs, which has a positive effect on the consumer by reducing electricity bills.

3.7 Auto management intelligent system

Smart Grid is considered as an Intelligent system since sensors are located in several sites in the pathway, making it capable of sensing and detecting any shortage. the system is capable of

rerouting the power therefore the area of the shortage will be minimized. in addition to many other features such as running autonomously with the least technicians intervention.

3.8 Carbon emissions reduction

SG switched from traditional production based on fuel to sustainable and renewable power resources. These renewable resources will be used exponentially in the future. They do not only serve by reducing consumption but through reduction of CO2 emissions. Renewable energy resources are such as solar photovoltaic panels PV, wind turbines, hydropower, and eco wave energy lately in some countries. These are essential constituents of smart grid systems. They positively affect the environment by reducing carbon emissions as well as the economic sector as they are renewable. The implementation of renewable resources not only reduces the electricity cost on the consumer side but also contributes to making a profit by selling the excess energy stored to the control unit.

Additional necessity advantages in power compensation

3.A Efficient

The smart grid allows an efficient transmission of electricity capable of meeting higher consumer demand due to its sophisticated infrastructure, so it can easily adapt to increased power demands without any change in the infrastructure

3.B Accommodating

Using any fuel source including natural gas, wind, transparently wind and solar, any and capable for the integration of technologies. All these resources are viable and energy storage technologies are market-proven.

3.C Motivating

Consumers are implicated in the management of their own electricity needs and this is feasible through the smart meter that can help the user decide the time preferences that suit him best to use

power. Consumers will apply time management to decrease their electricity bills. Moreover, they have the opportunity to sell electricity surplus back to the power grid and in transition get paid for this service, switching from being a natural consumer to proactive prosumer.

3.D Opportunistic

The smart grid's opportunistic side is revealed in creating new opportunities for employment and new markets. Billions are paid for the investment in the smart grids which boosts productivity and the economy. In addition, smart grids will increase the opportunity to put into the market new products and services that use its infrastructure to function such as plug-in hybrid electric vehicles. Furthermore, it is a new way to make money such that any person can now sell electricity back to the main grid.

3.E Quality-focused

Smart Grid delivers high-quality power to consumers and utilities. It optimizes the voltage for each consumer, which also will be free of interruptions, sags, and spikes. Connected renewable resources are necessary in power compensation in case of any interruption. Power quality management in smart grids ensures several parameters are running well such as voltage, current, and frequency.

3.F Resilient

Cybersecurity is a crucial integrated element in the smart grid as it becomes strongly resistant to cyber-attacks. Moreover, the structure and distribution of substations make the smart grid a decentralized system, that can reroute electricity to other places in case of any malfunction or natural disaster, so that disrupted areas can be minimized. In addition, the system has a high threat detection ability so it can proact to any inconvenience.

3.G Renewable resources for minimizing total cost

The current task is to define optimization algorithms to reduce the total cost of electricity for many generations, taking into account renewable energy sources such as wind, solar (PV), and heat and electricity. Such as hydropower, gas, and heating power generation to MG. The planned repair problem is solved in a controlled manner. In addition, a BESS operating system proposal was

developed and the proper management problem was solved with the concept of Dynamic Programming (DP). This method is very simple, and at a low cost can be best for working on islands or remote areas using BESS, standard products, and microgrid-related EnR tools. Systems designed for different BESS metrics were evaluated and cost savings. It has been shown that some methods lead to greater savings over time [29]. The smart grids concept ensures the integration of renewable energy sources such as solar systems, wind turbines, and hydro stations. These sources have a positive effect on the environment as they slow the advance of global climate change by reducing carbon emissions [20].

Chapter 4- Disadvantages and uncertainties in smart grids behavior

4.1 Issues and challenges of SG

An electrical grid is a collection of components that connect power supplies, such as power plants, to users or customers to provide what they need. The goal of delivering the necessary supplies with high reliability requires a large number of tightly coupled production machines integrated into areas that are difficult to communicate and deliver to customers. In this way, generation errors are replicated to other parts of the system. To explain the size of the system, it is enough to look at the network, as in the United States, which has around 10,000 power plants that transmit electricity along more than a dozen transmission lines: 300,000 km. [30]

4.2 Transmission levels

The electrical network installed to SG's has a multi-layered hierarchical structure, which includes several generation levels, the high-voltage transmission level, the medium partial transmission voltage, and the medium and low-voltage distribution level. Creating a multi-state system that can react to disruptions with concrete operational and control measures and reactions. Conventional methods and techniques include, such as cost-effective transmission, load frequency control, and prediction; Disturbances include collapses, instability, and heaving; Recovery methods and procedures include load recovery programming, resynchronization, and reprogramming.

4.3 Operational efficiency

Power grids are multi-scaled by operation, ranging from nanoseconds of rabid wave dynamic phenomena to expansions decades with the establishment of the power plants.

4.4 Technological issue

What strongly affects the problem of production and supply of electricity is the complicated process for storing electricity, which requires a continuous combination of production and consumption. There are primary load generators, which work continuously to meet the minimum demand, supplemented by peak load generators, which intervene only to meet the demand for maximum load power, and medium generators, which take care of all other situations. Sophisticated controls deploy generators as needed, taking into account different customer requirements daily and seasonally.

4.5 Economic pressure

lack of investment due to mounting economic pressures, public opposition has been seen in many countries and regions, resulting in inadequate systems monitoring TSOs control and automation, network expansion and maintenance, including logging programs (Great Lakes, Switzerland / Italy), and in this way contribute significantly to previous eclipses.
Northern Italy and the unloading (for a total of 10 GV), voltage, and frequency drops in the Italian network could not be remedied and production facilities began to be shut down. [30]

4.6 Uncertainties in the future development and operation

Projects and ventures related to SG's require intensive capital investments. In some cases, projects may delay, or expenses may be unpredictable before gaining profits. Technological development may be uncertain over time. Investors and policymakers' decisions in such projects may face open issues and barriers to entry.

Supply and demand are the main drivers to ensure the development of the operation of the smart grid properly. In the short run hourly/daily power demand is predictable and the forecast for the future period electricity demand levels. While on the long-run expectation of power demand is significantly increasing globally. Forecasting future energy consumption leads to additional resources to be satisfied. This is essential to capacity installation and accounting for capacity management.

In the future development and operation of electric power grids, demand and supply uncertainty will play a crucial role, the latter depending on the former, which is the true driver of the system.

The design of the Electrical smart grid must be protected against these events so that demand does not exceed available capacity and therefore the required electricity is not supplied efficiently.

4.7 Uncertainty of energy development

Uncertainties surrounding the development and operation of the "smart" electricity grids of the future are technological, social, economic, political, and environmental. They are usually large, dynamic including current phenomena, and difficult to characterize. This uncertainty is reflected in the modeling of the system, which in itself is a very complex task as it involves multiple layers with different properties, multiple space-time scales, complex, dynamic, and often unknown relationships.

Uncertainty in energy and environmental policy is currently quite high. Long-term climate goals have been set to some extent, but the impact on future energy policy and the inclusion of related environmental costs in electricity prices are unknown. Therefore, the development of renewable technology projects depends on variable short-term funding from national funding programs.

We can thus say that the Smart grid's advantages outweigh the disadvantages. Advantages are related to the environment as well as to the economy and consumer. Otherwise, disadvantages that are related to the economy can be considered as a challenge to be resolved in the future by relying on cost-effective strategies, as well as engineering and technology to optimize the flow of electricity and information.

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