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Abstract

Electrical systems composed of numerous and usually multifaceted components that are difficult to operate and control by efficient ways having problems such as energy management, cost, air pollution, etc... . Thus, in a recent evolution, Renewable Energy Resources (RERs) have been considered as clean and cost-effective sources for the generation of electrical power. In this context, the awareness of the Smart grids (SGs), booms particularly because of the precise amenities that they can deliver. Therefore, a novel Multi-Agent System (MAS) based model and the optimal management of an SG integrated with RERs are proposed in this work. A controlled architecture of an SG based on the MAS technique is employed for the finest operations of the SG energy management and power delivery and also offers intelligence to the SG at the distributed level. For validation of the proposed model, the power generation within the SG was evaluated by simulation under the capabilities of RERs power production. The simulation results prove that the proposed model for the SG energy management based on the MAS technique offers robustness and high-performance supervision and control

Keywords *Smart Grid, Multi-agent system, Renewable energy resources, Optimization, Energy management*

Résumé

Systèmes électriques est composé de nombreux composants et généralement multiformes qui sont difficiles à exploiter et à contrôler par des moyens efficaces ayant des problèmes tels que la gestion de l'énergie, le coût, la pollution de l'air, etc. Ainsi, dans une évaluation récente, les ressources énergétiques renouvelables (RER) ont considérés comme des sources propres et rentables pour la production d'énergie électrique. Dans ce contexte, la notoriété des Smart grids (SG), est en plein essor notamment en raison des aménagements précis qu'ils peuvent offrir. Par conséquent, un nouveau modèle basé sur un système multi-agents (MAS) et la gestion optimale d'un SG intégré aux RER sont proposés dans cette thèse. Une architecture contrôlée d'une SG basée sur la technique MAS est employée pour les opérations les plus fines de la gestion de l'énergie et de la fourniture de puissance SG et offre également une intelligence au SG au niveau distribué. Pour la validation du modèle proposé, la production d'électricité au sein du SG a été évaluée par simulation sous les capacités de production d'électricité des RER. Les résultats de la simulation prouvent que le modèle proposé pour la gestion de l'énergie SG basé sur la technique MAS offre robustesse et supervision et contrôle performants

Mots clés : *Smart Grid, Système multi-agents, Ressources énergétiques renouvelables, Optimisation, Gestion de l'énergie.*

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General Introduction

In the current society, electricity is one of the most important forms of energy. As electricity is generated from burning fossil fuels, increase in consumption of electricity is one of the leading factors for global warming and tremendous climate changes. These problems can be minimized by decreasing the amount of electricity consumed, and it can be done by optimizing the electricity consumption. Generation, transmission, and distribution are three main sectors of the power industry. Production of electricity is a process that is often used to cater electricity for industrial, commercial, residential and rural customers. Generators such as gas turbine, steam turbine, diesel engine and nuclear power plants all operate on magnets with copper wire, and motion equals to electric current. Electricity produced via different types of generators was known to be the same irrespective of the source of energy. Generation of power is often done at power stations. Typically, power plants contain generators located at the center [1]. Electric power transmission is a process where electrical power is transferred in bulk form from generation to distribution. It normally goes through substations where transform of high voltage to low voltage or the reverse do happen. In such cases, different voltage levels can be observed at different substations. When transmission lines are interconnected, it becomes transmission networks [2]. At the final stage, electricity is delivered to end users. This is done via power distribution system network which carries electricity from high voltage transmission system to end consumers. Such distribution process is all encompassed to ensure electricity are delivered to all consumers [3]. All this structure makes up the electric power grid.

This work is about the interaction between automatic energy management of a smart grid to achieve smart power distribution that brings high efficiency and sustainability to the system. This work sets out to realistic design and development of ICT (Information and Communications Technology)-enabled collaborative technical and commercial architecture for smart grid . Smart grid is a modernized electrical grid that leads to much efficient and reliable distribution of electricity. This would help creating a more productive environment for the use of electricity [4].

Multi-agent system is a computational intelligent technique which shows its potential to implement smart grid [5]. This technique comprises of multiple interactive intelligent agents in an environment. An agent is a software or hardware entity that can respond to changes in an environment.

Implementation of multi-agent system for energy management of smart grid allows consumers to check the amount of energy used through electronic meters or smart meters, and able to solve problems when it occurred. The monitoring and controlling functions are known as SCADA (Supervisory Control and Data Acquisition) with optimizing function referred as “advanced applications” would help to ensure the network is not overloaded due to over usage of electrical appliances.

The remaining work is organized as follows: Section I General introduction . Section II presents information about Smart Grid. Section III explains energy management and proposed method for smart Grid. Section IV describes the proposed MAS architecture for smart Grid energy management. Section V provides simulation results and discussion. Finally, this work is concluded in the section VI.

Chapter 1

Smart grid

1.1 Introduction

The traditional electrical power grid is unidirectional in nature, where the electricity flows from power generation facilities to end-users. This system has served well for the last hundred years. Recently, however, it has been subjected to government deregulation and has suffered from several technical, economic, and environmental issues. Modern society demands this system to be more reliable, scalable, and manageable while also being cost-effective, secure, and interoperable [6]. The next-generation electric power system, known as the "smart grid" [7], is a promising solution to the long-term industry evolution. The smart grid is expected to revolutionize electricity generation, transmission, and distribution by allowing two-way flows for both electrical power and information [8]. Moreover, it can complement the current electric grid system by including renewable energy resources, such as wind, solar, and biomass, which is environmentally cleaner as compared to the fossil fuels used in many bulk electric power generation facilities. Furthermore, each of these new power generating systems can be relatively small and can be distributed around the load centers to increase the reliability and reduce the transmission loss, which adds another degree of flexibility while also increasing the complexity of the current power system.

1.2 Definition of SG

A smart grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control, and communication within the supply chain to help improve efficiency, reduce the energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. The smart grid was introduced with the aim of overcoming the weaknesses of conventional electrical grids by using smart net meters. In this smart grid technology consumers turns to "Prosumers" [9]

Figure 1.1 – Smart grid

1.3 Smart grid component

The components of a smart grid are a combination of intelligent appliances and heavy equipment that play an important role in the production of electricity as mentioned below. These appliances work in a predefined manner, they are smart enough to understand the incoming power supply and how to utilize it.

1.3.1 Smart appliances

These appliances are set to consumer's predefined preference level and they have an idea on when to consume energy on what level. These tech appliances have an important impact on the grid generators since they help in understanding the power position and reduce the peak load factors. [10].

1.3.2 Smart maters

The smart meters are a two-way communicator that helps create a bridge between the power providers and the end consumer. It automates the billing data collection in a very convenient manner, detects system failures and sends repairing teams much faster than before because as soon as a system or a unit fails, the service providers are notified immediately. [10].

Figure 1.2 – smart metter

1.3.3 Smart substations

Substations are located in every region as s sub-branch for their main station. They monitor the performance of the station and control any critical and non-critical data that could be the status of the power, power performance, circuit breakers, security and the operationalization of the transformers. These are also used to transform voltage at several stations and operational regions and to split the path of electricity into several routes. Smart grid's substations require heavy equipment and manpower to be operationalized thoroughly. This equipment may include transformers, switches, capacitor banks, circuit breakers, and a network protected relay. [10].

1.3.4 Synchro Phasors

Recent advancement in synchrophasor technology has played a key role in the supervisory control and data acquisition (SCADA) and energy management systems (EMS). The most common advantages of phasor measurement technology include: Dynamic monitoring of the whole interconnected system, Post-event analysis, Oscillation detection, Island detection Synchro phasors gather data from various locations of the grid to get a coherent picture of the whole network using GPS and transmit for analysis to central locations. [10].

1.4 Smart grid Architecture

1.4.1 Conceptual Model

The conceptual model presented in this white paper supports planning and organization of the diverse, expanding collection of interconnected networks that will compose the Smart Grid. [11] The Smart Grid Conceptual Model is a set of views (diagrams) and descriptions that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements and standards of the Smart Grid. [11].

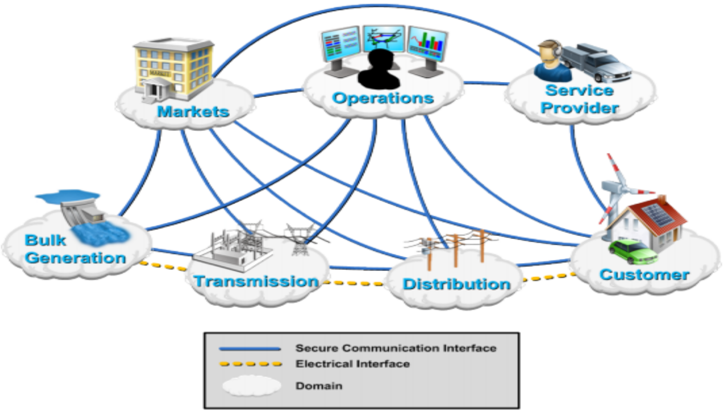
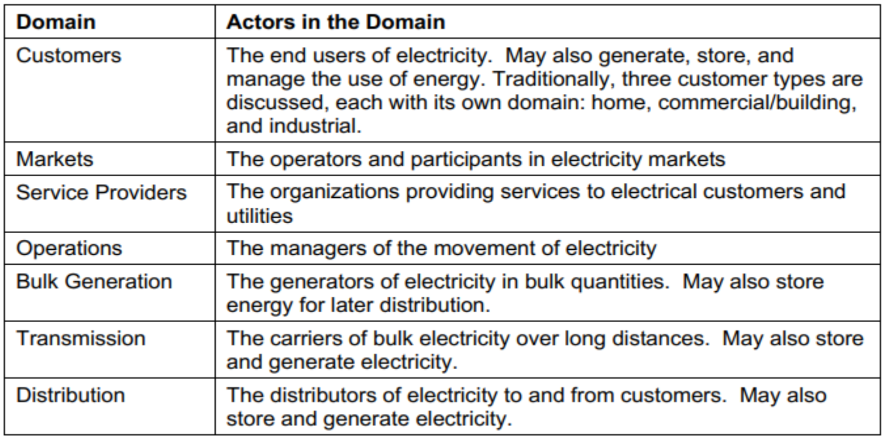


Figure 1.3 – Smart Grid Conceptual Model

The domains of the Smart Grid are listed briefly in Table 1 and discussed in more detail in the sections that follow. In table 1 , domains are shown as clouds



Domain	**Actors in the Domain**
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: home, commercial/building, and industrial.
Markets	The operators and participants in electricity markets
Service Providers	The organizations providing services to electrical customers and utilities
Operations	The managers of the movement of electricity
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

Figure 1.4 – Domains in the Smart Grid Conceptual Model [20]

1.4.2 The Smart Grid Architecture Model SGAM

The Smart Grid Architecture Model (SGAM) has been developed by the Smart Grid Coordination Group/Reference Architecture Working Group (SG-CG/RA) in the context of the European Commission's Standardisation Mandate M/490 [6] as a holistic view of an overall architecture in the Smart Grid domain [12]. The SGAM subsumes different perspectives and methodologies regarding the development and the conceptualisation of the Smart Grid

The work acted as the initial focal point for basic method engineering research on how to model and document Smart Grid architectures using standardized canonical methods. In addition to the IEC 62559 use case template and methodology for documenting meaningful blueprint solutions for Smart Grid systems of systems to be implemented [13], the SGAM has been created for the purpose of identifying gaps in existing and future standardization. The SGAM acts as a reference designation system [14], providing three main axes for the dimensions of (i) value creations chain ("Domains"); (ii) automation pyramid ("Zones"); and (iii) interoperability ("Interoperability Layer"). Within this visual representation , systems and their interfaces can be allocated to some point in the reference model, thus providing a categorization and classification of individual parts, data exchanged and interfaces of the system landscape

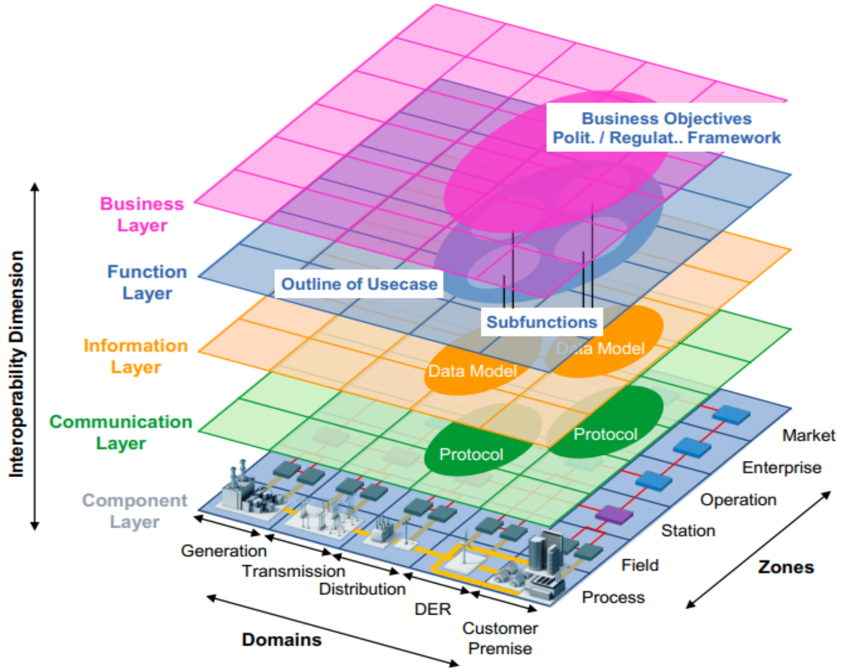


Figure 1.5 – Overview of the Smart Grid Architecture Model (SGAM)

- **Architecture Domains** The Domains basically represent the energy conversion chain as described in the fundamental and well-known NIST Conceptual Model [15]. The individual domains are described as follows [16]

  • Bulk Generation: Represents generation of electricity in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e., Photovoltaic (PV) and Concentrated Solar Power (CSP)), which are typically connected to the transmission system.

  • Transmission: Represents the infrastructure that transports electricity over long distances.

  • Distribution: Represents the infrastructure that distributes electricity to customers.

  • Distributed Energy Resource (DER): Represents distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3–10 MW). These distributed electrical resources may be directly controlled by a Distribution System Operator (DSO).

• Customer Premises: Host both end-users of electricity and producers of electricity. The premises include industrial, commercial and home facilities (e.g., chemical plants, airports, harbors, shopping centers, and homes). In addition, generation in the form of, e.g., PV generation, Electric Vehicles (EV), storage, batteries, micro turbines, etc., are hosted

- **Architecture Zones** The Zones are orthogonal to the domains and basically represent the Information and Communication Technology (ICT) based control systems, controlling the energy conversion chain. Based on the automation pyramid, the individual Zones are described as follows [16]:

  • Market: Reflects the market operations possible along the energy conversion chain, e.g., energy trading, mass market, retail market, etc.

  • Enterprise: Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders, etc.), e.g., asset management, logistics, work force management, staff training, customer relation management, billing, etc.

  • Operation: Hosts power system control operation in the respective domain, e.g., Distribution Management Systems (DMS), Energy Management Systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), and EV fleet charging management systems.

  • Station: Represents the areal aggregation level for field level, e.g., for data concentration, functional aggregation, substation automation, local Supervisory Control and Data Acquisition (SCADA) systems, plant supervision, etc.

  • Field: Includes equipment to protect, control and monitor the process of the power system, e.g., protection relays, bay controller, and any kind of Intelligent Electronic Devices (IED) that acquire and use process data from the power system. • Process: Includes the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind, etc.) and the physical equipment directly involved (e.g., generators, transformers, circuit breakers, overhead lines, cables, electrical loads, any kind of sensors and actuators that are part of or directly connected to the process, etc.).

- **Interoperability Layer** To maintain interoperability between any two components in the Smart Grid, interoperability needs to be considered on five different Interoperability Layers. The first two layers are related to functionality, whereas the lower three layers can be associated with the intended technical implementation. The interoperability layers being used are basically derived by the GridWise Architecture Council (GWAC) interoperability stack [17] and described as follows [12]:
  - Business Layer: Provides a business view on the information exchange related to Smart Grids. Regulatory and economic structures can be mapped on this layer.
  - Function Layer: Describes services including their relationships from an architectural viewpoint.
  - Information Layer: Describes information objects being exchanged and the underlying canonical data models.
  - Communication Layer: Describes protocols and mechanisms for the exchange of information between components.
  - Component Layer: Physical distribution of all participating components including power system and ICT equipment

1.5 Application of smart grid system

Deployment of Digital Technology in smart grids ensures the reliability, efficiency, and accessibility to the consumers regarding all utilities which count towards the economic stability of the nation. Right at the start of transition time, it becomes perilous to execute testing, to improve the technology by up-gradation, developing and maintaining standards on a standard threshold and also application of these efficient grids serve all these problems

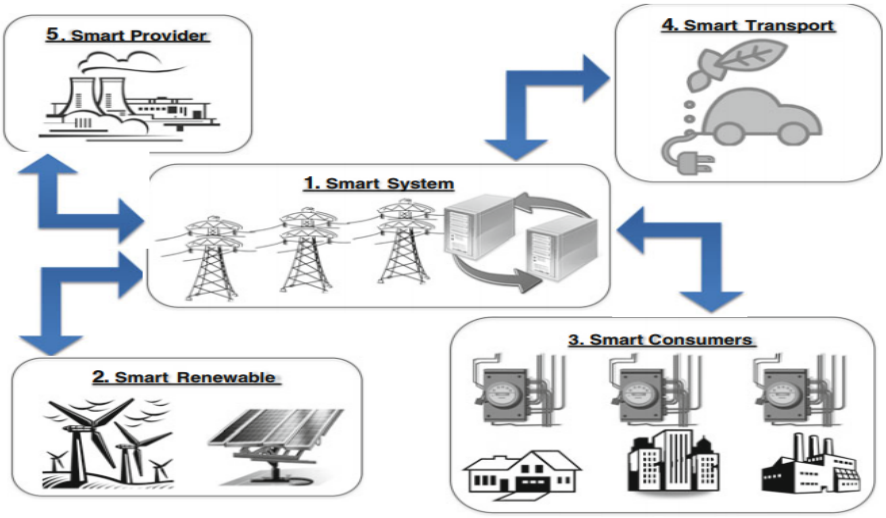


Figure 1.6 – Five major applications of smart grids

1.5.1 Smart systems

SGs can improve resilience to disruptions, attacks, and natural disasters . This can be achieved through advanced sensors and computerbased remote controls. These sophisticated communication technologies and automation can help prevent disruptions rather than simply react to them, and therefore limit outages and network losses. SGs can also identify and fix problems faster [18]

1.5.2 Smart renewables

Smart renewables: Today's grids are mostly designed for centralized supply sources and are therefore less accommodating to renewable resources that are intermittent and widely distributed [18] . SGs can accommodate a variety of generation, including renewable energy resources such as wind and photovoltaic solar, and other forms of distributed generation such as small-scale combined heat and power, and energy storage .[[18], [19]] SGs are regarded as essential to mainstreaming renewables because through state-of-the-art modeling and decision support tools, wind forecasting, and contingency analysis, for example, can be improved and these can enhance the integration of these intermittent sources into the power system [18]

1.5.3 Smart consumers

Smart consumers: In SG systems, consumers are no longer passive purchasers [18] . SGs can inform and empower consumers to proactively manage their consumption [18] . Consumers can be provided with devices and information to manage their energy usage, and to reduce demand in response to peak load [18] . This can be achieved through smart meters and smart appliances that are connected with sensors to collect electricity consumption data, and which is essential to enable dynamic pricing and consumer participation in demand-side management [20]. Power companies can introduce a variety of demand response programmes. Direct load control programmes, for example, are mainly offered to residential and small commercial customers—in which consumers can choose to allow a programme operator to remotely turn off their appliances or equipment at short notice [18]. Consumers in this way can help reduce peak consumption and reduce the costs of generating expensive power to meet peak demand [18].

1.5.4 Smart transport

Smart transport: EV and plug-in hybrid EV can have a major role to play in reducing emissions. SGs can better manage vehicle charging so that rather than increasing peak loads, the charging can be carried out more strategically, when for example electricity demand is low or when the production of renewable electricity is high. In the long run, SGs can use EV as batteries to store renewable and other sources of electricity for later use [19].

1.5.5 smart electricity service providers

Smart electricity service providers: Utility companies will not be the only significant players in SGs. SGs create new markets as these technologies are conducive to new products and energy services, and also new market players. Energy efficiency and intelligent appliances, smart meters, new sensing and communications capabilities, and passenger vehicles are some examples of these new products [18]. SGs, therefore, tend to bring major changes in the market place—they rely on numerous third parties, including energy-service providers and brokers to provide core and additional services [18]. Energy service providers, such as home energy monitoring service and energy-service companies (ESCOs) can analyze customer energy usage and provide customized energy services to meet customer needs. They can also perform direct load control or provide financial incentives for customer-responsive demand in homes and businesses [18] (Fig. 1.5).

1.6 Smart grid standards

To identify the core set of standards for the future smart grid, various approaches have to be taken into consideration. In the following sub-sections, those approaches are introduced, which give clear recommendations for standards.

- **The German Roadmap E-Energy / Smart Grid** The national smart grid standardization roadmap for Germany [21] considers national and international standards exhaustively, focusing on the smart grid's ICT infrastructure
- **B. US NIST IOP Roadmap** In the United States, the Energy Independence and Security Act (EISA) authorized the Department of Commerce (DoC) in 2007 to coordinate the development of an interoperability framework. This framework is coordinated by NIST and aims at interoperability between and among smart grid systems and equipment with special respects to standards in the fields of ICT protocols and data models. [22].
- **IEC SMB SG 3** In February 2010, the SG 3 (Strategy Group ”Smart Grids”) published a draft of a roadmap [23]including their own standards and eleven high-level recommendations. The SG 3 was appointed by the IEC Standardization Management Board (SMB). The main focus of the IEC roadmap is on improved monitoring and control of all components within the network
- **Microsoft SERA** The Microsoft Smart Energy Reference Architecture (SERA) is a comprehensive reference architecture based on NIST work and Microsoft products [24]. It addresses technology integration throughout the scope of the smart energy ecosystem and the surrounding systems. It should help utilities to create an integrated utility by providing a method of testing the alignment of information technology
- **European Union: Mandate CEN/CENELEC M/441** The European Smart Meter Coordination Group (SM-CG) classifies existing standards into six cate-

gories based on different functionalities for smart metering. The SM-CG operates in the context of the mandate M/441, which was given to Comite European de Normalisation (CEN), European Com-mittee for Electrotechnical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI) by the European Union

- **Institute of Electrical and Electronics Engineers (IEEE)** In January 2010, the IEEE launched the IEEE Smart Grid Web Portal to bring together a broad array of sources within it, including education, news, and intelligence. The IEEE Smart Grid Web Portal is the first phase of the IEEE Smart Grid, which is an initiative launched by the IEEE to provide expertise and guidance for those involved in the Smart Grid worldwide. The IEEE has developed numerous standards related to the Smart Grid, including IEEE P2030, IEEE 802 series, IEEE SCC 21 1457, IEEE 1159, IEEE 762, and IEEE SCC 31 [25]

1.7 Smart Grid Communication Infrastructure

The communication infrastructure of the smart grid can be based on three types of networks: Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN). The schematic diagram of the smart grid communication infrastructure based on these networks is shown in Figure 1. [26]

- **HAN** is deployed and operated within a small area (tens of meters), usually a house or a small office. The HAN has relatively low transmission data rate compared to the other two networks, hundreds of bits per second (bps). In a typical implementation, a HAN consists of a broadband Internet connection that is shared between multiple users through a wired or wireless modem. It enables the communication and sharing of resources between computers, mobile and other devices over a network connection. In smart grid implementation, all smart home devices that consume energy and smart meters can be connected to HAN. The devices data is acquired and transmitted through HAN to the smart meters.

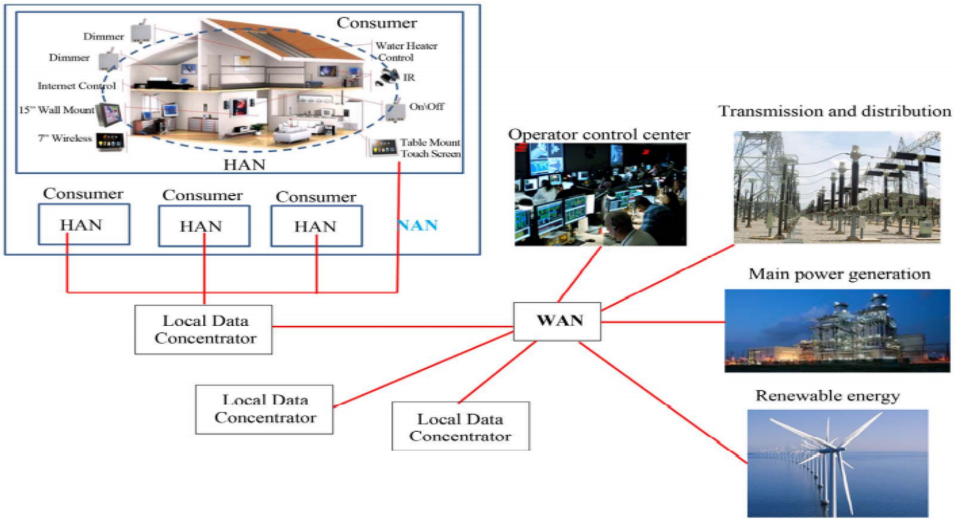


Figure 1.7 – Smart grid communication infrastructure

HAN allows more efficient home energy management. HAN can be implemented by ZigBee or Ethernet technologies. [26]

- **NAN**: is deployed and operated within an area of hundreds of meters which is actually a few urban buildings. Several Hans can be connected to one NAN and they transmit data of energy consumed by each house to the NAN network. The NAN network delivers this data to Local Data Centers for storage. This data storage is important for charging the consumers and data analysis for energy generation-demand pattern recognition. The NAN has up to 2 Kbps transmission data rate. The NAN can be implemented by PLC, Wi-Fi, and cellular technologies.

- **WAN** is deployed and operated within the vast area of tens of kilometers and it consists of several NANs and LDCs. Moreover, the communication of all smart grid components including operator control center, main and renewable energy generation, transmission and distribution, is based on WAN. The WAN has a very high transmission data rate up to a few Gbps. The WAN can be implemented by Ethernet networks, WiMAX, 3G/LTE, and micro-wave transmission. [26]

1.8 Smart Grid Benefits

The benefits obtained from the full implementation of the Smart Grid are enormous [27]. This includes technical, environmental, and electricity marketing benefits:

- Technical benefits	- Energy efficiency improvement - Grid reliability improvement - Operational efficiency improvement - Security and safety improvement - Quality of supply -Improved connection and access of the grid
- Environment benefits	- Reduction in carbon emission - Climate change benefits
- Electricity marketing benefits	- creates healthy electricity market competition - benefits consumers - optimizing the operation of the power system network

Table 1.1 – Smart Grid Benefits

1.9 Challenges for Smart Grids

This section presents the possible challenges on the smart grid :

- Self Healing Actions [1]	- Security - Reliability
-Renewable Energy Integration with the Grid [2]	- Wind forecast - Wind generation dispatch -Power flow optimization- Power system stability
- Energy Storage Systems [3]	- Costs - Complexity - Non-flexibility
- Consumers' Motivation [1]	- Privacy - Security -Consumer education
- Reliability [4]	- Grid automation - Grid reconfiguration
- Power Quality [1]	- Disturbance identification -Harmonics suppression

Table 1.2 – Challenges for Smart Grids

1.10 Conclusion

In this chapter we talked about several points in the smart grid, we started with general about it and then we touched on some special points such as component, architecture, and Application off SG, finally with benefits and challenges in the next chapter, we introduce the energy management in smart grid .

Chapter 2

Optimization methods and energy management in smart grids

2.1 Introduction

with the depleting energy resources, enhancing energy security and energy-access, particularly in emerging economies are one of the major challenges that one has to deal with. In addition to managing the existing energy resources, generating power effectively and intelligently is an equally important agenda. Supplementing the establishment of large power plants from conventional energy sources, there is also a need to focus on distributing small scale generation of power particularly from renewable energy sources. So, to solve these problems. We need several methods. And this is what we will look at in this chapter .

2.2 energy management in smart grid definition and objective

2.2.1 Demand Side Management

In particular, instead than production following electricity demand as is currently the case, the DSM concept states that consumers adjust their consumption to reduce the load of the electricity. Each utility desires to avoid additional expenses by installing extra capacity to meet the daily growing electricity demand. One way to achieve this objective is to utilize existing energy efficiently. Therefore, utilities implement DSM programs to manage the energy consumption of the consumers [28]. Thus the most important aims of DSM implementation are the reduction of the cost of electricity by managing energy consumption, environmental and social development, increasing the reliability and reducing the gird issues.

2.2.2 Demand Response

The definition of DR as used by the U. S. Department of Energy in its February 2006 report to Congress and later adopted by the Federal Energy Regulatory Commission is stated as [29]: “Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at time of high wholesale market prices or when system reliability is jeopardized.” DR program is a very important element in SG. For many years, DR was just a peak clipping approach for specific hours of a year. Afterward, definition was modified as change in electricity usage of end-use consumers from their normal consumption pattern in response to changes in the price of electricity over the time [30]. In conventional electrical grid, consumers don’t have the concept of energy efficiency of their loads and they don’t obtain at all any motivation to modify in their consumption manner. In this case, the utility maintain balance between production and demand by the supervision on the production resources

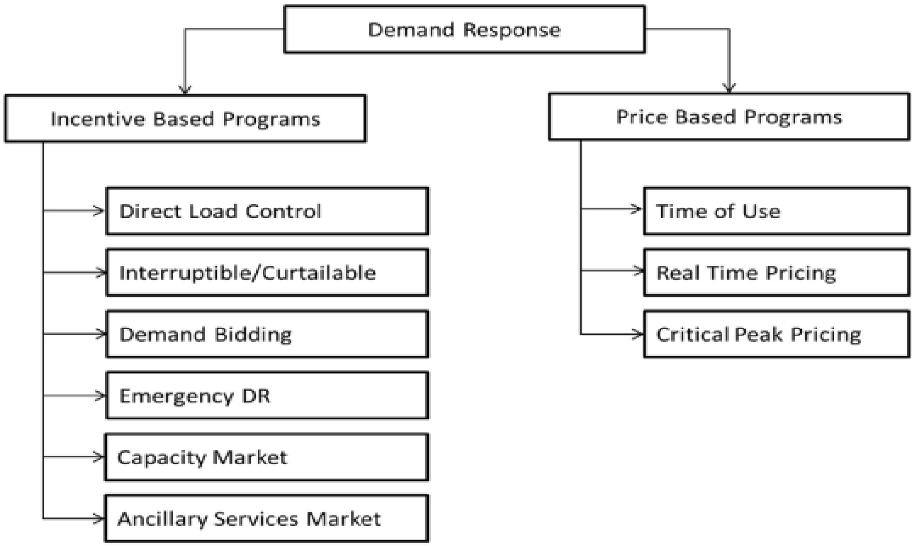


Figure 2.1 – Classification of demand response programs

2.2.3 integrate Renewable Energy Resources in smart grid

The decentralized energy resources (DER), cover all low power systems producing electrical energy at low voltage levels. The term DER is opposed to the term "centralized production" that representing power plants connected to the transmission grid. The primary energy used by DERs is generally renewable and comes from energy sources: solar, wind, hydraulic, biomass, geothermal etc. The essential element of these kinds of energy resources is free and available. For about a decade, the development of wind and solar energy continues at a pace across the word [31] .

- **wind** Wind farms capture the energy of wind flow by using turbines and converting it into electricity. There are several forms of systems used to convert wind energy and each vary. Commercial grade wind-powered generating systems can power many different organizations, while single-wind turbines are used to help supplement pre-existing energy organizations. Another form is utility-scale wind farms, which are purchased by contract or wholesale. Technically, wind energy is a form of solar energy. The phenomenon we call “wind” is caused by the differences in temperature in the atmosphere combined with the rotation of Earth and

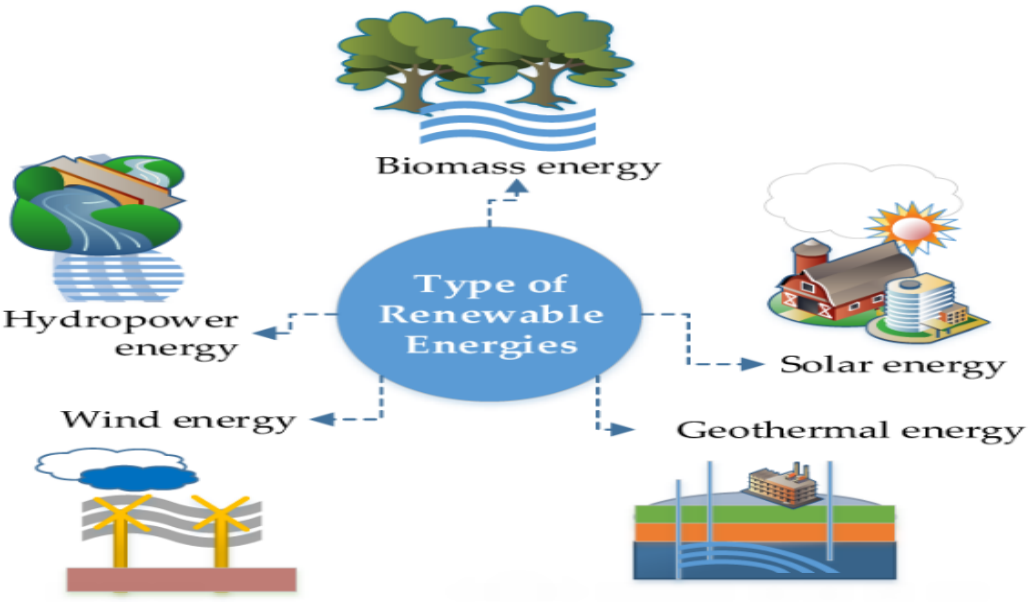


Figure 2.2 – Type of Renewable Energies

the geography of the planet

- **Solar energy** is derived by capturing radiant energy from sunlight and converting it into heat, electricity, or hot water. Photovoltaic (PV) systems can convert direct sunlight into electricity through the use of solar cells.

- **Geothermal energy** is derived from the heat of the earth. This heat can be sourced close to the surface or from heated rock and reservoirs of hot water miles beneath our feet. Geothermal power plants harness these heat sources to generate electricity. On a much smaller scale, a geothermal heat pump system can leverage the constant temperature of the ground found just 10 feet under the surface to help supply heat to a nearby building in the winter or to help cool it in the summer

- **Hydroelectric**Dams are what people most associate when it comes to hydroelectric power. Water flows through the dam's turbines to produce electricity, known as pumped-storage hydropower. Run-of-river hydropower uses a channel to funnel water through rather than powering it through a dam.

- **Ocean**The ocean can produce two types of energy: thermal and mechanical. Ocean thermal energy relies on warm water surface temperatures to generate energy through a variety of different systems. Ocean mechanical energy uses the ebbs and flows of the tides to generate energy, which is created by the earth's rotation and gravity from the moon.

2.2.4 Microgrid

A microgrid is a local electrical network that comprises power generation units, power consumption units, and a means of delivering power from the generation units to the consumption units, may be connected to a larger utility power system, and operates to balance the power supply and demand within the microgrid The microgrids are defined by the European Technology Platform - Smart Grids (ETP-SG) as low and medium voltage networks comprising decentralized production units, storage systems and controllable loads (from a few hundred kW to a few MW installed capacity) .

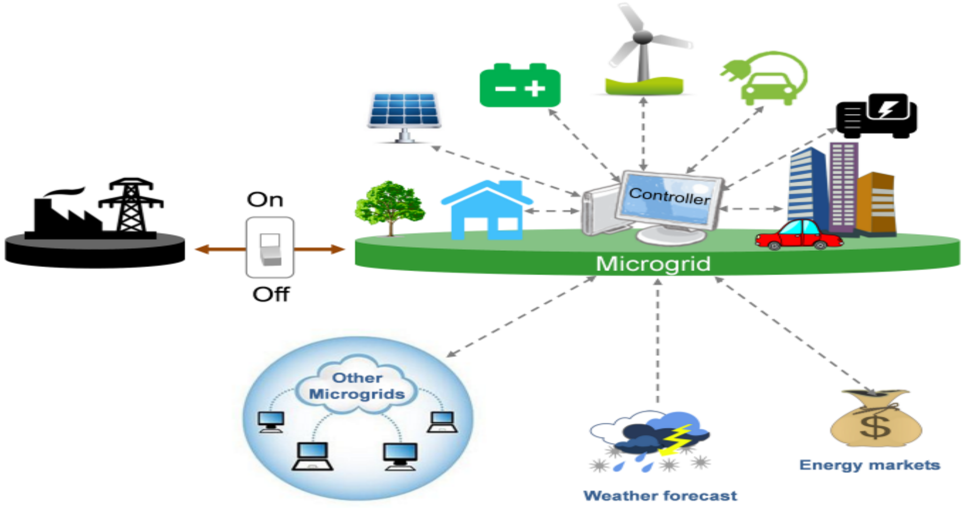


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Figure 2.3 – Microgrid model

2.2.5 definition of energy management in smart grids

energy management is one of the key challenges related to the development of intelligent networks. Here we differentiate between the concepts of demand control (MDE) and energy management through DR programs. Both respond to a notion of energy efficiency, but their application methods and respective impacts are to distinguish. The aim of the MDE is to reduce energy demand at a certain cost. These include, for example, renovating and insulating the home, replacing equipment Energy by less greedy equipment, etc. [32].

2.2.6 Energy management objectives

In order to efficiently integrate renewable energies into the system Electric, energy management offers several savings perspectives on long- and short-term horizons. In addition, the power stations ensuring the energy production are non-renewable production resources, more emitting toxic gases such as CO2. Energy management should therefore help to reduce toxic gas emissions. Short term.

the objectives of energy management are defined as follows

- Reducing the energy bill of consumers: modulation demand should limit hourly variations in marginal cost of production, and therefore of the price of electricity
- Resolve the intermittency problem of renewable energies: energy management should help balance production and consumption on the electric network which integrates the producers intermittent renewable energy.
- Reduce the use of the grid during peak hours: management of energy should help minimize grid access during hours which are predicted as peak hours. This minimization is done using storage systems that aggregate energy renewable in excess and which store the energy of the grid during Periods when the use of the grid is low

2.3 Optimization Techniques in Smart Grids

2.3.1 Techniques 1: Cloud computing for energy management in smart grid

Cloud Computing

Cloud computing - a model that enables convenient, ubiquitous, on-demand access to a pool of computing resources (e.g. servers, networks, applications, storage, and services) that are configurable with minimal management effort, resources can be provisioned and released seamlessly.

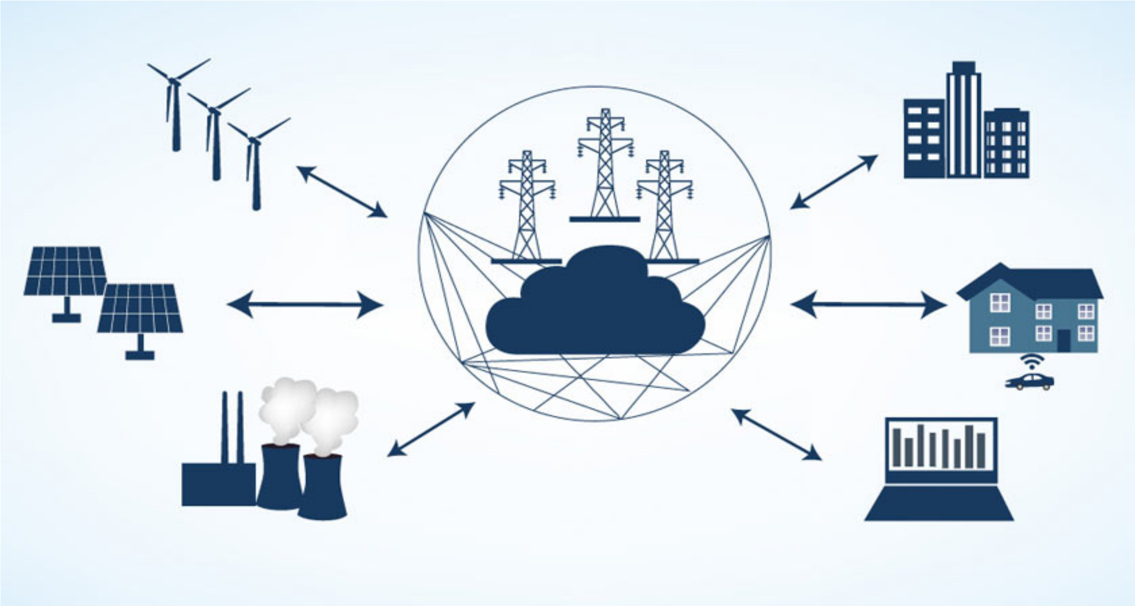


Figure 2.4 – Cloud computing technology

Cloud Applications for Energy Management

Energy management is the process of monitoring, controlling, and conserving energy [33] In a smart grid, energy management is a major concern [34]. It is needed for resource conservation, climate protection and cost-saving without compromising work processes by optimally coordinating several energy sources. BEMS (Building Energy Management System) and HEMS (Home Energy Management System), dynamic pricing, and load shifting are different applications that are implemented by researchers in the past to address energy management.

2.3.2 Techniques 2: Multi-Agent Systems in Smart Grids

Multi-Agent Systems

Multi-agent systems (SMA) represent a form of distributed artificial intelligence [35]. They allow a systemic approach to problems which can be broken down into several interacting entities. An SMA is composed of several entities called agents, who have their own intelligence and autonomy [35]. These agents located in an environment can interact based on their perception (for example, measurements) and by executing actions.

Interest in an energy management system

The use of the concept of SMA in the issue of smart grids is motivated by the 3 reasons [36]. following:

• Due to their distributed structure, SMA is easily adaptable to a spatially distributed system such as an electrical network. This notably makes it possible to reduce the bandwidth and computing power: problems (interruptions, instabilities, etc.) can at least partly be dealt with locally, allowing greater responsiveness. If necessary, they can also cooperate or enter in the competition.

• SMA is flexible, thanks to their distributed architecture, and can, therefore, adapt to changes of the network, whether it faults, adding or removing components, and these events have been included in the system design or not. They are therefore faulted tolerant and allow degraded operation and plug and play

• SMA is proactive, seeking to meet their needs or objectives according to their roles and constraints. A load will, therefore, seek to be supplied, just like a plant manager will seek to minimize its costs while respecting its operational and legal constraints. In the case of agents can also get the information they need to make decisions and plan actions. We, therefore, note adequacy between the characteristics of SMA and those required by smart grids, showing the interest of their use.

Optimization algorithms

1- Algorithm MPSOM (Metropolis Particle Swarm Optimization with Mutation Operator)
2- Algorithm ICA (Imperialist Competitive Algorithm)

2.3.3 Techniques 2: demand Side Management in Smart Grid

To minimize the Peak to Average load Ratio (PAR) per day of end-users so that the smart grids (SG) efficiency is increased. Set of appliances differentiated as elastic and fixed are considered for optimal scheduling at the user end.

DSM algorithm

Demand-side management (DSM) in a smart grid is one that permits customers to reach determinations affecting their energy consumption, and reduces the peak hour demand of the energy providers and reshapes the load profile. A genetic algorithm (GA) is a powerful technique to obtain a near-optimal solution. Hence GA is used for this load rescheduling problem for a sample test system to minimize the cost of end-user.

2.4 Conclution

This chapter presents some necessary point SG energy .The SG concept is presented with their subsets such as the DSM and DR, followed by the renewable energy resources, then the EVs and wind etc ... ,and to finish with the microgrid which is a local electrical network. Subsequently, several optimization and programming techniques are presented that permit the right operation and control of the considered systems in the SG. The next chapter presents an conseption about the best method in the smart gird to optimize the energy production and consumption systems.

Chapter 3

Design of Multi-Agent System in Smart Grids

3.1 introduction

In this chapter, we will discuss how to build a multi-agent system concept in the SG. And we'll see the most important parts of it. The design of MAS at SG allows us to give an illustrative picture to facilitate energy modeling in the smart grid. And facilitate the creation of an application for it.

3.2 Multi-Agent System

Multi-agent systems (SMA) represent a form of distributed artificial intelligence [35]. They allow a systemic approach to problems which can be broken down into several interacting entities. An SMA is composed of several entities called agents, who have their own intelligence and autonomy [35]. These agents located in an environment can interact based on their perception (for example, measurements) and by executing actions.

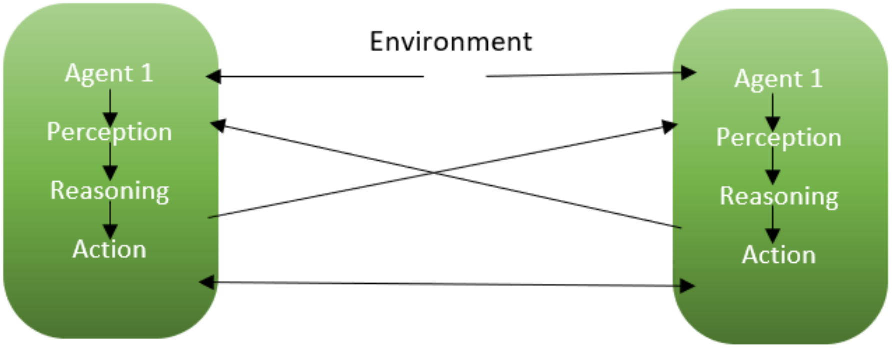


Figure 3.1 – interaction of agnets with their environment

3.2.1 Classification of agents

Classification of agents is very important and the literature includes numerous agent's classification. In [37], three different forms of agents: cognitive, reactive, and hybrid agents were discussed

- Cognitive agents : These have a capability of reminiscence, interaction, and reasoning ability. They perform in a supplementary "imitated" method derived from a selection among a set of conceivable activities. This selection is the outcome of the intellect.
- Reactive agents: Such agents usually have a limited/low communication capability and have insignificant or not any classical model about the environment, other agents, or even for themselves. Their performance arrangement is something like stimulus-response.
- Hybrid agents: Such agents can be categorized according to their degree of autonomy, agent's actions, adaptation, and assistance. As a hybrid agent, they practice both types of actions: reactive and cognitive

3.3 multi-agent system architecture in smart-grid

The idea behind any multi-agent system is to break down a complex problem handled by a single entity a centralized system into smaller simpler problems handled by several entities a distributed system. The architecture of a multi-agent system is presented in Figure 3.2 .

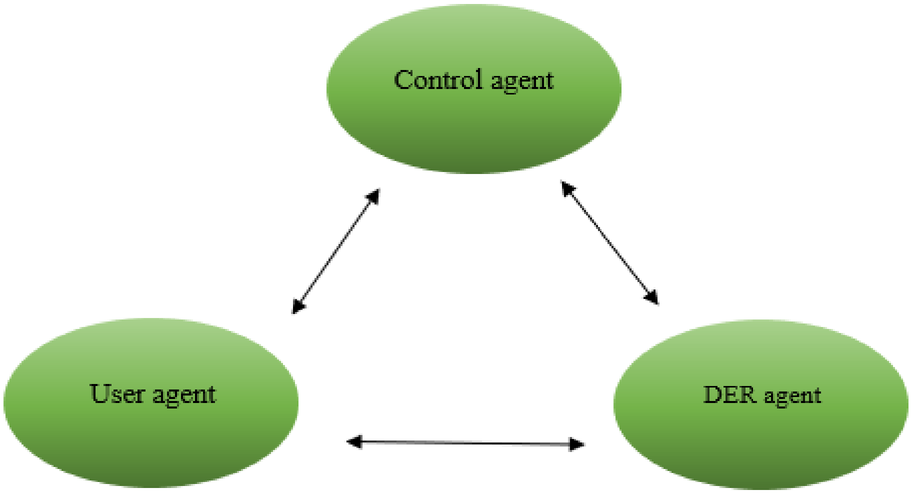


Figure 3.2 – The architecture of multi-agent system

3.3.1 Agent Specification

1 Control agent (CAg): CAg is also known as a switching agent. CAg is mainly responsible for taking quick operation once it receives information from the GAg or any other agent.

2 Generation agent (GAg): GAg consists of WT, solar PV, and FC generation. GAg is primarily responsible for monitoring the generation of electrical power

3 User-agent : It includes the responsibility of providing users with real-time information of entities residing in the system. A user agent also monitors electricity consumption. A user agent also allows users to control the status of loads , in our simulation A user agent is the interface agent .

3.4 Application Analysis

After the agent specification step, the second step involves the formalization of agent roles and responsibilities that simplify understanding and modeling the problem at hand.

To accomplish this task, a Activity Diagram which defines the interaction among agents is shown in (Fig 3.3)

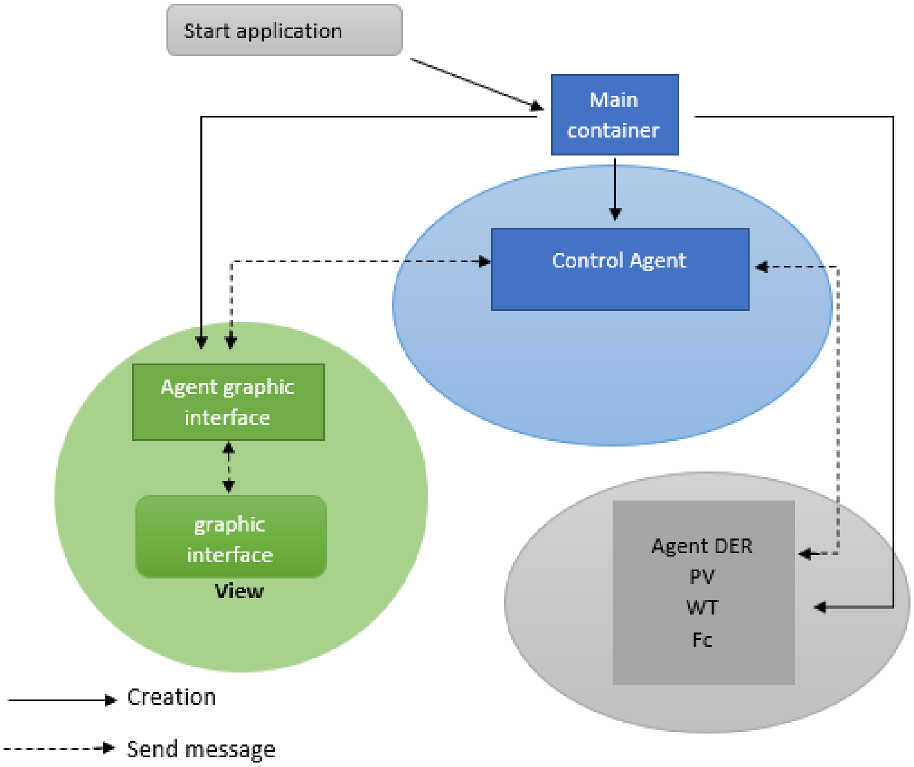


Figure 3.3 – Overview of architecture for MAS in smart grid

3.5 Detail architecture

in this section, we use the UML sequence diagram to make batter clearly view how the architect of MAS work

3.5.1 user

the user plays the role a customer .so he needs to log in system by login agent figure 3.4
after receiving the information the main page shows up to the user. this last has communication with agent controller figure 3.5

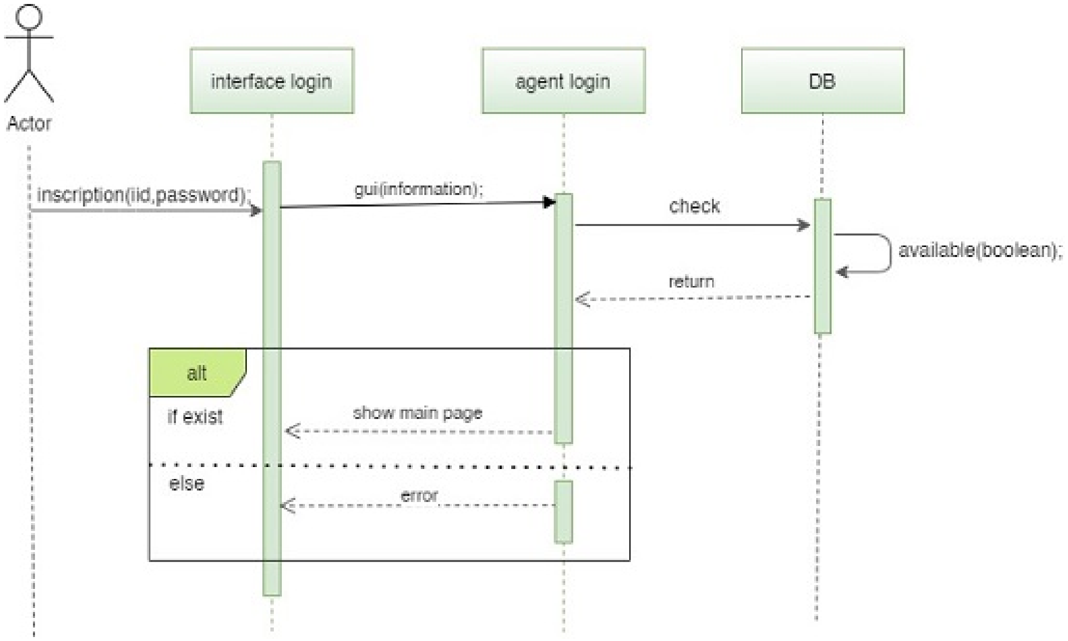


Figure 3.4 – diagram sequence of user

Figure 3.5 – Cominication between interfaces and agents

3.5.2 Agent Controller

The Controller agent is one of the key elements in the management system. It interacts with all agents, based on external data (information about weather conditions), as well as based on the electrical load data of the Generator. The Agent controller determines the amount of energy and the energy needed to cover it and manages it accordingly. Based on this information,the Controlle agent manages local agents to distribute the available power to the appliance. figure 3.6

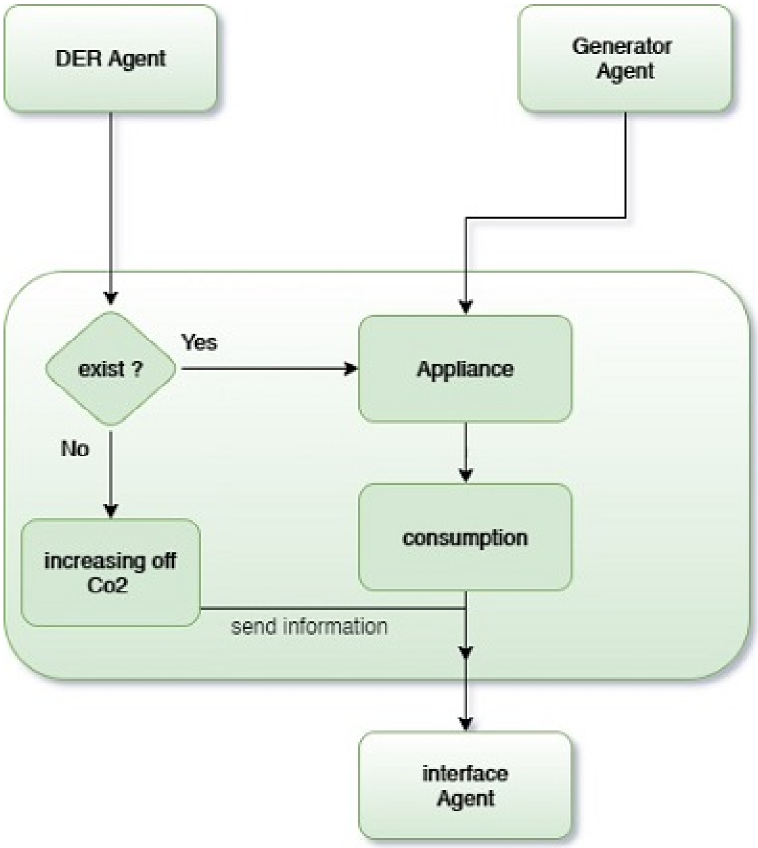


Figure 3.6 – Structure of controller agents.

To clarify more how agent controller work, we make a sequence diagram shown in figure 3.7

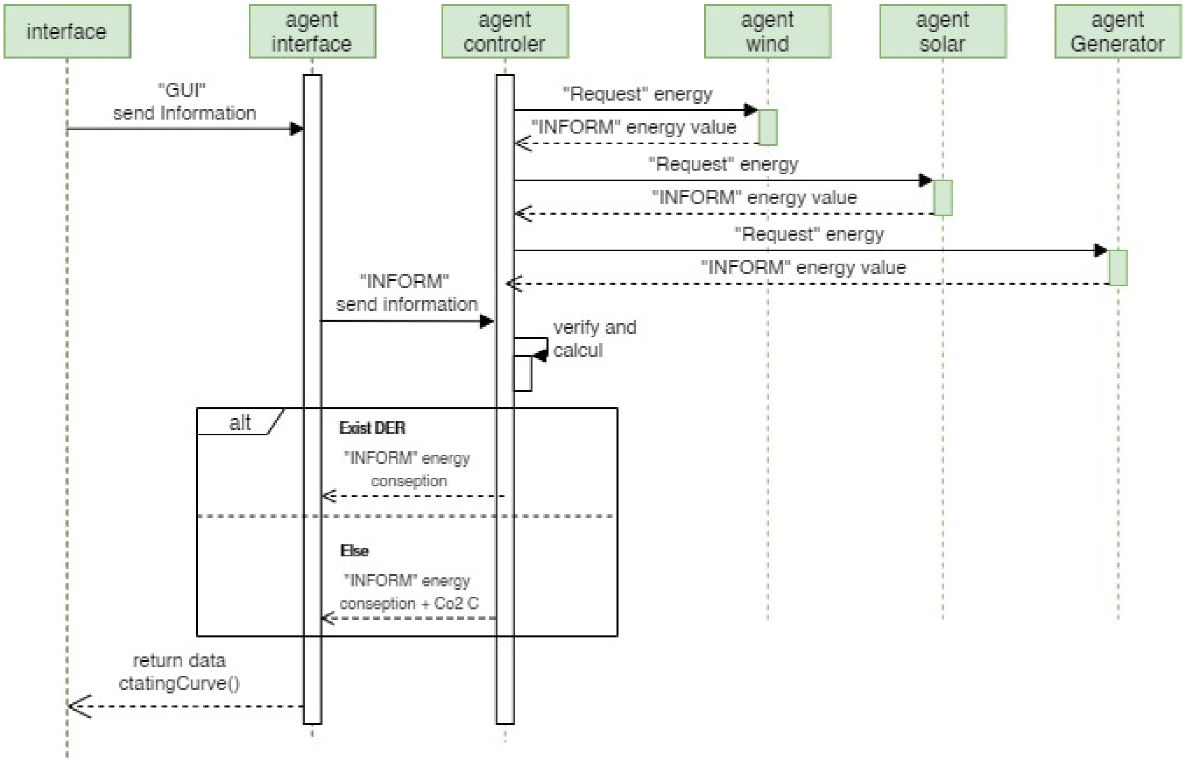


Figure 3.7 – diagram sequence of Agent controller

3.6 Conclution

In this chapter, we make a conception for MAS in smart grid energy management. Started with a definition and some details of MAS, followed by the global architecture of MAS in SG, and specification of any agent role in this system which presented in sequence diagram , next chapter, we make a simulation of EMSG

Chapter 4

Implementation

4.1 Introduction

In this chapter we will present the tools and platforms used to develop our approach. Then, we present the different developed interfaces of our solution. Finally, the results obtained will be discussed.

4.2 Programming language

4.2.1 Java

Java is a general-purpose programming language that is class-based, object-oriented, and designed to have as few implementation dependencies as possible

Jade-software framework

Java Agent Development Framework, or JADE, is a software framework for the development of intelligent agents, implemented in Java. JADE system supports coordination between several agents FIPA and provides a standard implementation of the communication language FIPA-ACL, which facilitates the communication between agents and allows the services detection of the system.

4.2.2 MySQL

MySQL is an open-source relational database management system, Its name is a combination of "My", the name of co-founder Michael Widenius's daughter, and "SQL", the abbreviation for Structured Query Language.

4.3 programming tools

4.3.1 NetBeans

is an integrated development environment (IDE) for Java. NetBeans allows applications to be developed from a set of modular software components called modules

4.3.2 XAMPP

is a free and open-source cross-platform web server solution stack package developed by Apache Friends,consisting mainly of the Apache HTTP Server, MariaDB database

4.4 System interfaces overview

4.4.1 Login interface

in this interface, the agent login plays his role. he gets the information and checks in the databases if the user is available or not

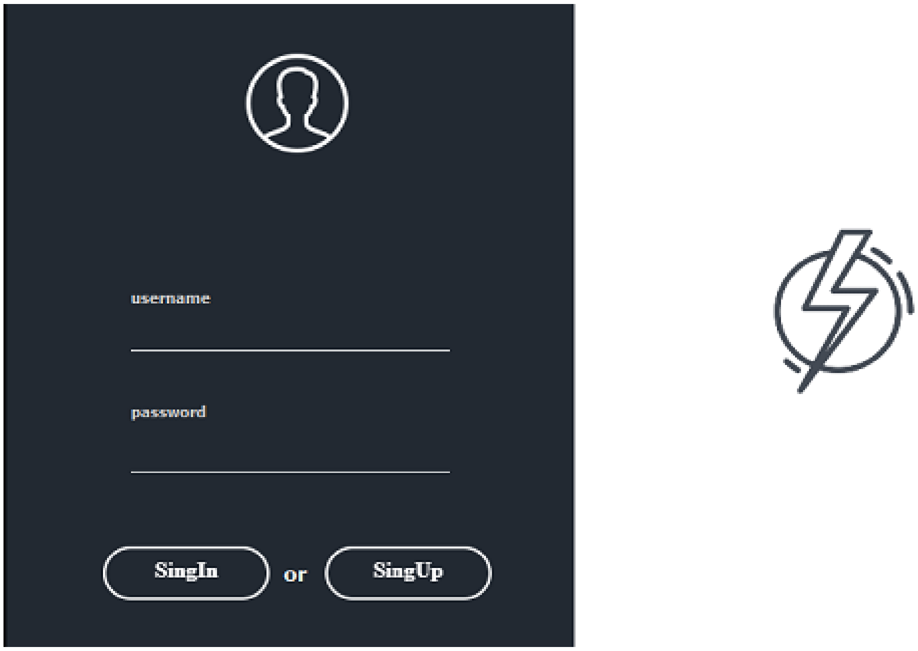


Figure 4.1 – Logine interface

4.4.2 Registration interface

in this interface, the user full his own information .and their control if they're an empty space and send the data with query information by SQL into the DB by Xamp server

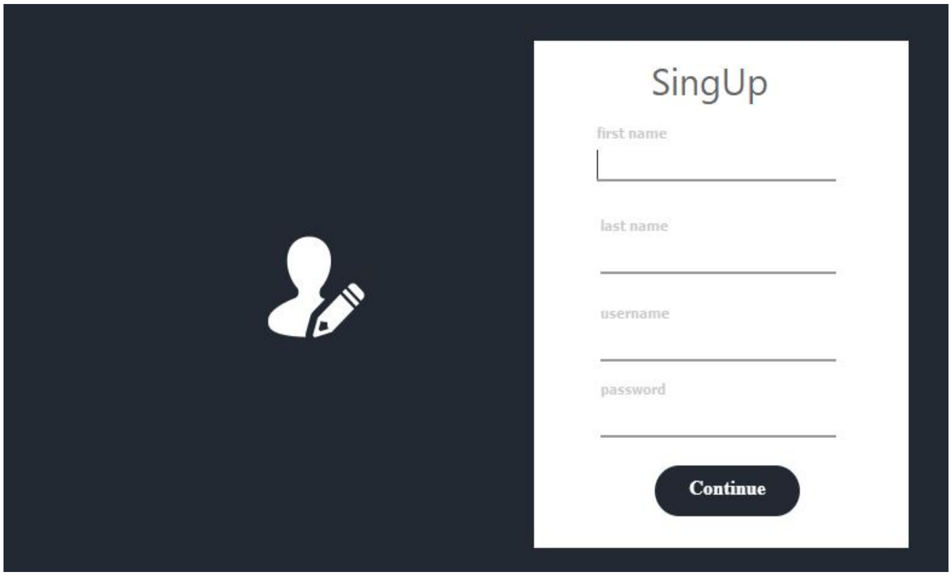


Figure 4.2 – Registration interface

4.4.3 Main interface

in this interface (Figure 4.3) allow to User to Simulate and enter the different situation . in this case we have :

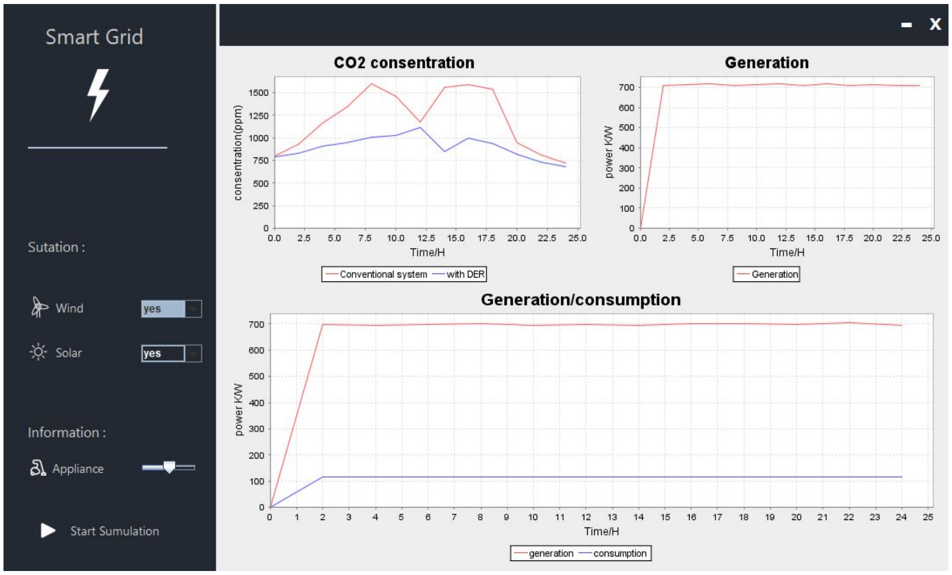

Sutation :
Wind yes
Solar yes

Figure 4.3 – Main interface

the wind: it means there is a wind power in this simulation or not
the solar:the same as the wind , allow to user check there is solar power or not
the information: the information here is about a percent of appliance in ou simulation chosen by the User
and we have 3 curves: Generation, Co2 concentration, and Consumption they are we will discuss in the next point.

4.5 The Result

first of all, we show the communication between our Agent .show in Figure 4.4

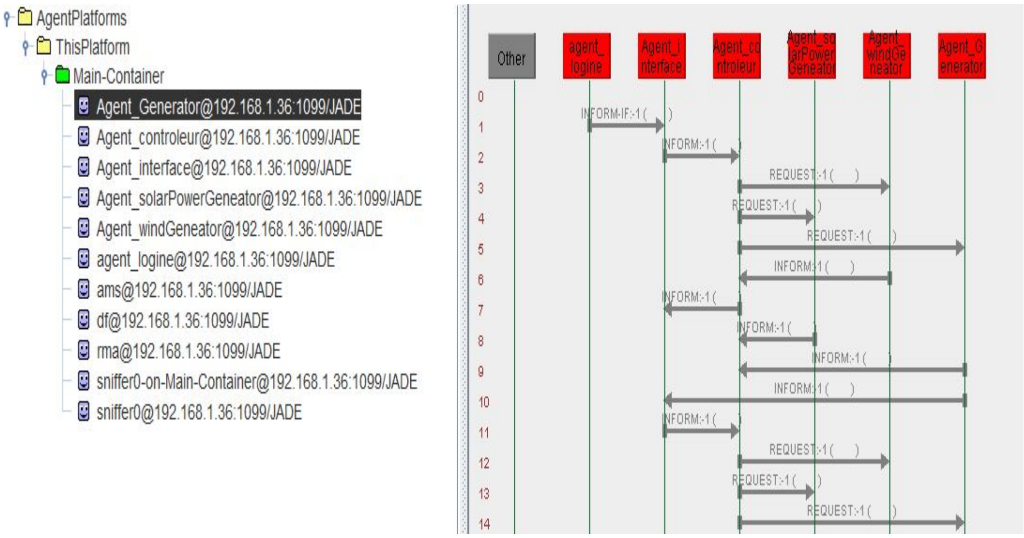


Figure 4.4 – Overview of Sniffer Agent

4.5.1 Result of Co2 Concentration

In this situation, we have two cases, n 1 with Distributed energy resources and number two without them. Figure 4.5
case 1 : When there is a source of renewable energies there is less carbon dioxide emission because not many factories operate. This reduces the concentration of carbon dioxide in the atmosphere
case 2 : We find one curve. Because of the lack of renewable energies, we find a high

concentration of carbon dioxide in the atmosphere due to the large number of gaseous emissions from energy-producing factories.

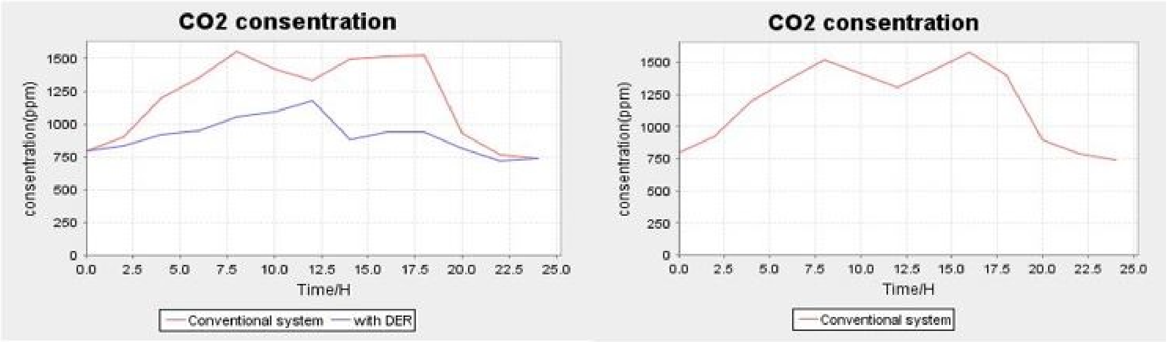


Figure 4.5 – Air quality set points comparison.

4.5.2 Generation

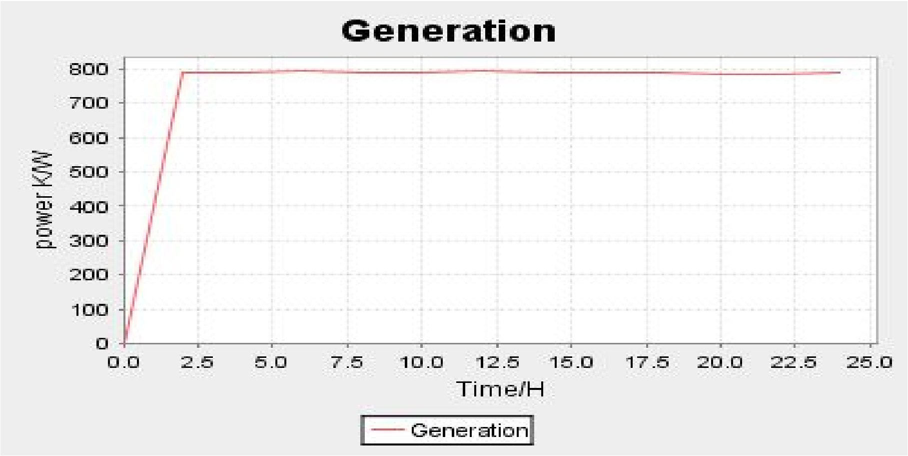
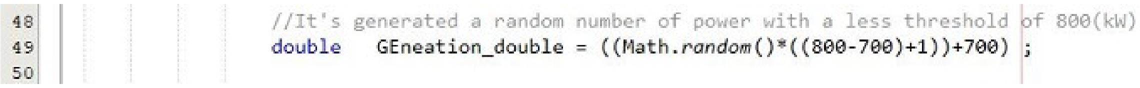


Figure 4.6 – overview of power Generation

the responsible for the generation in our simulation is Agent generator . is create a random number of (Kw) and send it to the Agent controller



```
//It's generated a random number of power with a less threshold of 800(kW)
double   GEneation_double = ((Math.random()*((800-700)+1))+700) ;
```

Figure 4.7 – source code for generation .

4.5.3 Consumption

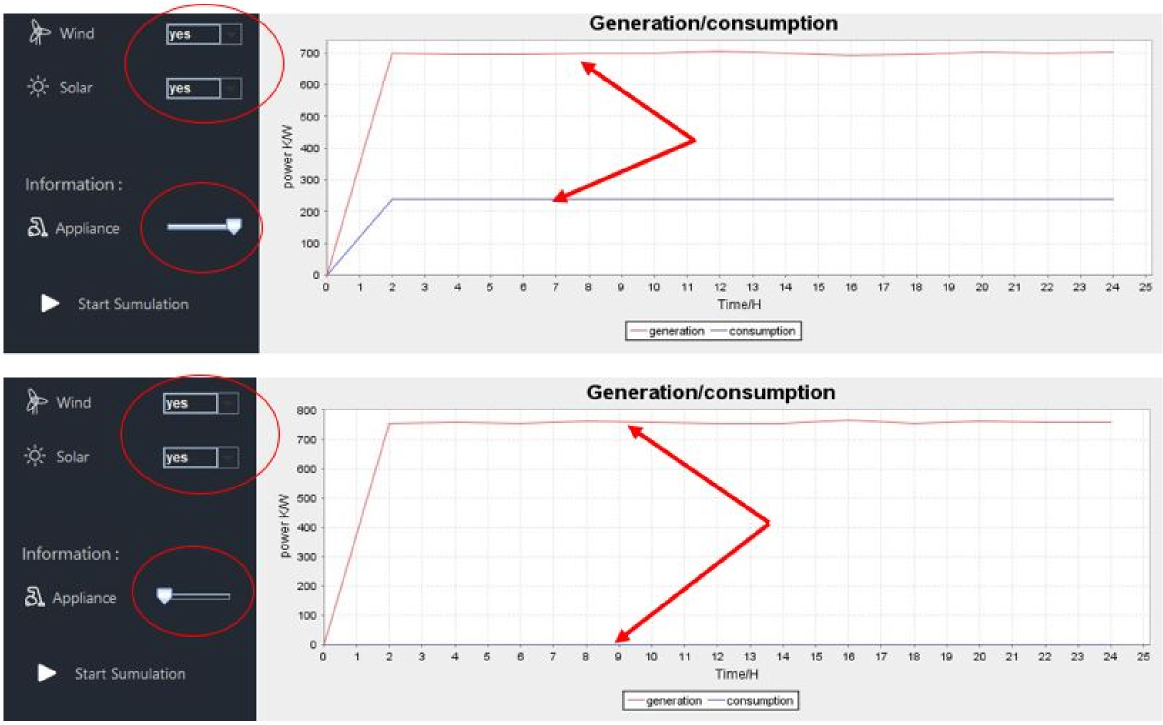
the most important thing in smart grid energy is consumption. because when you get less consumption it means less cost. and we will discuss the next multiple curves :

With Distributed Energy Resources

- **case 1 :** we notice that there is an increase in the number of appliances. Energy consumption is large, but it does not reach a peak because there are renewable energy resources.
- **case 2 :** As for the bottom curve, it shows the non-use of appliances, and in this case the consumption rate is very low, show in figure 4.8

Without Distributed Energy Resources

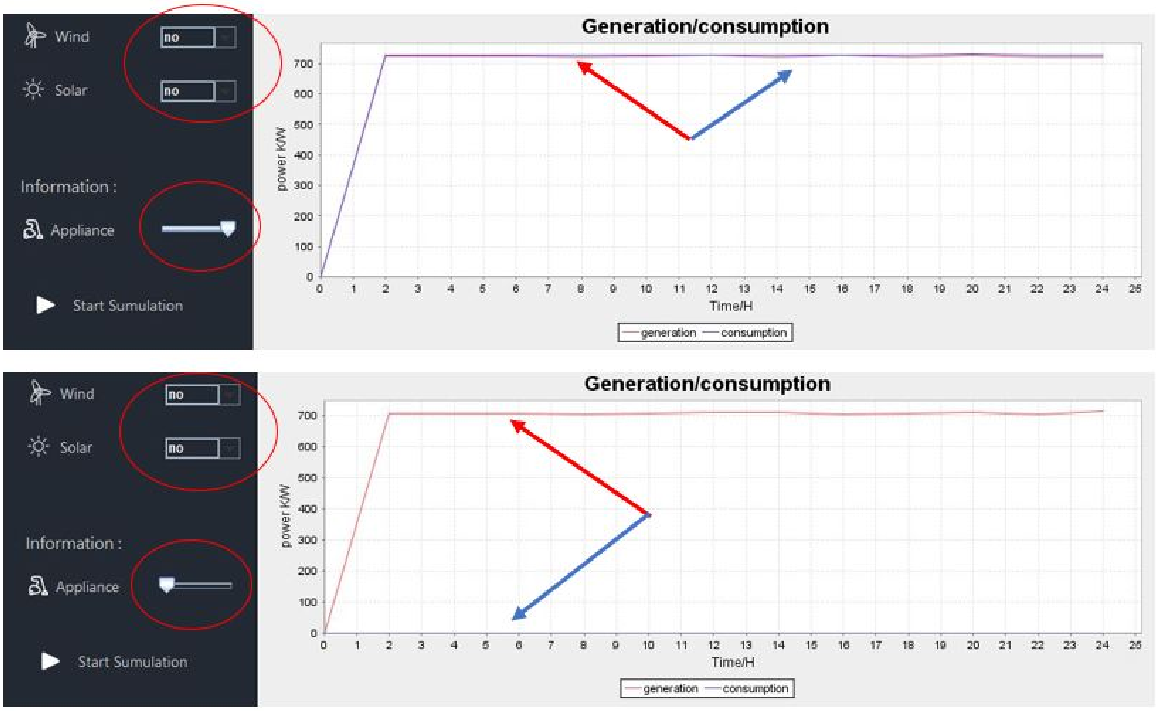
- **case 1 :** As for the absence of renewable energies, we notice in the first case the increasing number of appliances, so the energy consumption is large and reaches its peak because there are no renewable energy resources and this also increases the price.
- **case 2 :** As for the bottom curve, it shows the non-use of appliances, and in this case the consumption rate is very low, show in figure 4.9



Wind: yes
Solar: yes

Wind: yes
Solar: yes

Figure 4.8 – Overall power consumption comparison with DER



Wind: no
Solar: no

Wind: no
Solar: no

Figure 4.9 – Overall power consumption comparison without DER.

4.6 Conclusion

in this chapter, we discussed the simulation of MAS in the smart grid energy management and we take the result obtained .and the agent responsible for each curve .

General conclusion

In this work, the development of a Smart Grid model was designed and developed using a multi-agent system to have high comfort level, power efficiency, and energy cost of saving of a household. A general concept of smart Grid energy management was developed using a multi-agent system which enables smart Grids to communicate, interact and negotiate with energy sources and devices in the smart home that achieves maximum overall energy efficiency and minimum electricity bill.

In this work, we have several difficulties passed. because the smart grid is not implemented in our country . and this research about SGEM is one of the first in the department of computer science here. but This work brings us closer to understanding how to control and management system for the electrical power system. The SGEMS software would help to build a smart grid for the smart nations by providing optimization tools and a two-way communication channel for the smart grid entities. Further enhancement of the smart grid technique would benefit the entire power grid due to the capabilities of increasing the reliability of supplies for the grid and software advancement. It would also decrease the overloading of the thermal generators in the grid with the help of renewable energy. Decentralized intelligent agents would help to increase the efficiency of communication, local and decentralized decision makings thus further enhancing the grid efficiency. Ultimately, it provides fault tolerance and reliable control and management system.

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